Determinacion of Draft Power Requirements for Tillage Implements under Central Gezira Clay Soil Conditions

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Dedication

To my Family,
Father
Mother
Brothers
Sister
My wife
My daughter.
My colleagues
And my friends
Acknowledgments

Praise to be Allah, the almighty, who give me health, strength and patience to conduct this work. It is true that words are not enough to express the feeling towards help that was received from those who give so easily even at times of difficulties. My sincere thanks and great appreciation are due to my main adviser Prof. Mohamed Ahmed Ali Omer, Department of Agricultural Engineering (Machinery Engineering) for his help, guidance and patience. Thanks are also extended to my Co-adviser Dr. Osama Abbas Muhierdeen for his help, and I am also grateful to all teaching staff, Department of Agricultural, Engineering Faculty of Agricultural Sciences, University of Gezira for their help and useful comments during the course of study. Great thanks are due to Dr. Bakhiet Dousa, Ustaz Mubark Hasballa, Ustaz Khider Suliman, Dr. Ahmed Babiker, Ustaz ELwleed Mohammed and Ustaz Hishsm Mousa. Last but not least thanks are due to my family and colleagues for their encouragement, help and support.
Determination of Draft Power Requirements for Tillage Implements under Central Gezira Clay Soil Conditions

Abstract

The availability of draft power data for tillage implements is considered an important factor in selecting suitable tillage implements for particular farming conditions, and are also used to determine the appropriate size of tractor to be used. The draft power for a tillage implement is affected by many factors, particularly the soil type and soil conditions. This study was conducted to determine the draft power required for different tillage implements under central Gezira clay soil conditions. The experimental work involved five implements (chisel plow, moldboard plow, disk plow, disk harrow and ridger) which were tested at three speeds (3.5, 4.0 and 4.5 km/h) under two levels of soil moisture content (14.8% - pre-watered soil, and 4.2% - dry soil). A split-split plot experimental design with three replicates was used. The draft power required, and the fuel consumed, for the operation of individual implements for primary tillage were measured. Moreover, the draft power, and the fuel consumed, for the operation of a secondary tillage implement (disk harrow) after primary tillage were measured. Results showed that the required draft power and fuel consumption for primary and secondary tillage operations were significantly increased with increased speed and decreased with increased soil moisture content. For primary tillage, the draft power required to operate the chisel plow was significantly higher than for the other tested implements, regardless of the operating speed and the soil moisture content; while the ridger requirements were significantly the lowest. In addition, the fuel consumed during the operation of the chisel plow was significantly higher compared to the other tested implements, while the fuel requirements for the disk harrow were significantly the lowest. For secondary tillage, the draft power required and the fuel consumed, in operating the disk harrow after the chisel plow were significantly the highest. However, no significant differences were observed when using the disk harrow after the other tested implements. The results indicated that pre-watering of the field two weeks before primary tillage, and operating the implement at a medium speed of 4.0 km/h, will significantly decrease the draft power and fuel required for both primary and secondary tillage operations. However, the chisel plow requires a very dry soil for optimum operation, thus pre-watering is not recommended for this implement.
تحديد متطلبات قدرة الجر لآلات الحراثة تحت ظروف التربة الطينية لوسط الجزيرة

ملخص الدراسة

توفر البيانات لقوة الجر لآلات الحراثة تعتبر من العوامل المهمة لاختيار آلات الحراثة المناسبة للظروف الحقلية المعينة، وتعتبر أيضا لتحديد حجم الجر المستخدم للإستخدام. وقوة الجر لآلات الحراثة تتأثر بالعديد من العوامل وبصفة خاصة نوع وظروف التربة. أجريت هذه الدراسة لتحديد قوة الجر المطلوبة لآلات حراثة مختلفة تحت ظروف تربة وسط الجزيرة. التجربة شملت خمسة آلات (المحراث الحفار والمحراث المطرحي و المحرات القرصي و المشط القرصي والطراد) والتي تم اختبارها على ثلاث سرعات (3.5 و 4.0 و 4.5 كم/ساعة) تحت مستويين من رطوبة التربة (14.8% للترية المروية مسبقا و 4.2% للترية الجافة ) نفتذت هذه التجربة بتصميم نظام القطع المنشقة بثلاث مكروتات، تم قياس قوة الجر المطلوبة والوقود المستهلك لتشغيل آلات الحراثة الأولية والمطرية، بالإضافة لذلك تم قياس قوة الجر والوقود المستهلك لتشغيل آلة حراثة ثانية (المشط القرصي) بعد الحراثة الأولية. أظهر التحليل الإحصائي أن احتياجات قوة الجر واستهلاك الوقود للحراثة الأولية، والثانية ازدادت معنوية بزيادة السرعة وانخفاضة مع زيادة محتوى رطوبة التربة. للحرية الأولية، كانت قوة الجر المطلوبة لتشغيل المحارات الحفار هي الأعلى معنوية من بين الآلات المختبرة الأخرى، بغض النظر عن سرعة التشغيل ومحفو رطوبة التربة، في حين كانت احتياجات الطراد هي الأقل معنوية. بالإضافة لذلك كان الوقود المستهلك أثناء تشغيل المحارات الحفار أعلى معنوية من الآلات المختبرة الأخرى، في حين كانت احتياجات المشط القرصي الأقل معنوية، وللحرية الثانية وكانت احتياجات قوة الجر والوقود المستهلك لتشغيل المشط القرصي بعد المحارات الحفار الأعلى معنوية، ولكن لم تكن هناك فروقات معنوية واضحة عند استخدام المشط القرصي بعد الآلات المختبرة الأخرى. تشير النتائج بوضوح إلى أن الري المسبق للحقل قبل أسبوعين من الحراثة الأولية وتشغيل الآلة على سرعة متوسطة 4 كم/ساعة سوف تقلل معنوية من احتياجات قوة الجر والوقود للحرية الأولية والثانية معا، لكن المحارات الحفار يحتاج إلى تربة جافة للتشغيل الأهم وبالتالي لا يوصى بالري المسبق للترية لهذه الآلة.
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CHAPTER ONE
INTRODUCTION

1.1 Food Security:

The United Nations defines food security as "all people at all times having both physical and economic access to the basic food they need." For approximately two billion people throughout the world, this security is anything but guaranteed. In fact, food security is a complicated issue that is susceptible to many forces (http://pulitzercenter.org food insecurity, 2009).

Currently there is a need to keep pace of food production with ever increasing world population; however, the grain yields are on the decline because of poor soil fertility in the farmers fields (Violic et al, 1991).

Mean global temperatures have been increasing since about 1850, mainly owing to the accumulation of greenhouse gases in the atmosphere. The main causes are the burning fossil fuels (coal, oil and gas) to meet increasing energy demand, and the spread of intensive agriculture to meet increasing food demand, which is often accompanied by deforestation. The process of global warming shows no signs of abating and is expected to bring about long term changes in weather conditions (FAO, 2004).

Climate change will affect all four dimensions of food security: food availability, food accessibility, food utilization and food systems stability (FAO, 2008). It will have an impact on human health, livelihood assets, food production and distribution channels, as well as changing purchasing power and market flows. Its impacts will be both short term, resulting from more frequent and more intense extreme weather events, and long term, caused by changing temperatures and precipitation patterns. People who are already vulnerable and food insecure are likely to be the first affected. Agriculture-based livelihood systems that are already vulnerable to food insecurity face immediate risk of increased crop failure, new patterns of pests and diseases, lack of appropriate seeds and planting material, and loss of livestock. People living on the coasts and floodplains and in mountains, dry lands and the Arctic are most at risk. As an indirect effect, low-income people everywhere, particularly in urban areas, will be at risk of food insecurity owing to
loss of assets and lack of adequate insurance coverage. This may also lead to shifting vulnerabilities in both developing and developed countries.

1.2 Agricultural Mechanization:

Agricultural mechanization is the application of mechanical technology and power to agriculture, largely as a means to enhance the productivity of human labor and often achieves results well beyond the capacity of human labor (FAO, 2008).

Mechanization includes the use of tractors of various types as well as animal-powered and human-powered implements and tools, and internal combustion engines, electric motors, solar power and other methods of energy conversion. It also includes irrigation systems, food processing and related technologies and equipment. Mechanization is not an “all or nothing” process. Levels and types of improved mechanical technologies need to be appropriate and compatible with local, agronomic, socio-economic, environmental and industrial conditions (FAO, 2008).

Whatever the objective of soil tillage, mechanization makes it easier to accomplish (Culpin, 1976). Adequate tractor power and suitable implements make it possible to undertake operations that would be out of the question without them. For example, heavy land can be burst up when it is dry, and need seldom be worked when too wet, with the result that soil structure becomes greatly improved; spring cultivations may be done so rapidly that moisture losses are negligible; and seed-beds may be made just as fine or firm as necessary, with a minimum expenditure and trouble. Unfortunately, mechanized methods can also result in some adverse effects on soil structure. High-power tractors need a considerable weight to be carried by the wheels in order to make full use of their power; and when soils are wet tractor wheels can cause puddling of the soil either by sheer compression or by smearing. These adverse effects are particularly marked in wet late seasons when crops have to be carted off waterlogged land.

The aim of mechanization must be to equip in such a way that work does not have to be carried out in the worst soil conditions. This is, of course, a counsel of perfection which cannot always be followed (Culpin, 1976).
1.3 Soil Tillage:

For thousands of years of recorded history, human kind has been tilling the soil in order to increase the production of food (McKyes, 1985). Tillage is performed for optimizing productivity by alleviating physical, chemical and biological constraints of the soil (Gajri et al, 2002).

1.3.1 Definition of tillage

Tillage may be defined as any mechanical manipulation of the soil which is used to maintain, modify or promote changes in the soil structure in an effort to produce a more desirable soil environment for crop plant development (Ademosun, 1986).

Krause, et al (1984) defined soil tillage as a sequence of mechanical manipulation of the top soil, in which all the operations are dovetailed and adapted to the overall production technology.

Culpin (1981) defined tillage as the practices of modifying the state of the soil to provide favorable conditions to crop growth. Smith and Wilkes (1984) defined tillage as the preparation of the soil to keep it loose and free from weeds during the growth of crops.

Soil tillage, in general, is one of the fundamental agrotechnical operations in agriculture because of its influence on soil properties, environment, and crop production. To assure normal plant growth, the soil must be prepared in such conditions that roots can have enough air, water, and nutrients. Structure of the A-horizon is largely influenced by soil tillage systems and the implements used for tillage (Lal, 1997; Husnjak et al., 2002).

Tillage induced changes in soil properties are difficult to predict, yet can influence infiltration, redistribution of water within the profile, subsequent evaporation rates, and water availability to crops. The influence of tillage on soil hydraulic properties and infiltration are not always consistent across locations and soils. Initially, tillage may have a positive influence on infiltration (Messing and Jarvis, 1993) but this effect is usually transitory and usually leads to a decline in infiltration rates on tilled surfaces as a result of reconsolidation and aggregate disintegration after repeated rainstorms (Moret and Arru, 2007)
1.3.2 Primary tillage:

Primary tillage implements displace and shatter soil to reduce soil strength and to bury or mix plant materials, pesticides, and fertilizers in the tilled layer. Primary tillage is more aggressive, deeper, and leaves a rougher soil surface relative to secondary tillage (ASAE Standards, 2004). Examples of primary tillage implements include disk plows, moldboard plows, chisel plows, wide-sweep plows, subsoilers, heavy disk harrows, and rotary tillers.

1.3.3 Secondary tillage:

Secondary tillage implements till the soil to a shallower depth than primary tillage implements, provide additional pulverization, mix pesticides and fertilizers into the soil, level and firm the soil, close air pockets, and eradicate weeds. Seedbed preparation is the final secondary tillage operation (ASAE Standards, 2004). Examples of secondary tillage implements include disk harrows; spring, spike, coil, or tine tooth harrows; packers; ridgers; levelers; field cultivators; and rod weeders.

1.4 Power Requirement:

The draft of a plow is affected by many factors, such as the type and shape of bottom, the sharpness of the share, the overall adjustment of the plow, the depth and width of furrow, soil type and soil characteristics. The speed at which the plow is operated is an important factor affecting draft of plows. When all these factors are considered, there will be a wide range in the draft of any type or shape of bottom from field to field depending on the type and condition of the soil (Smith and Wilkes, 1976).

The availability of draft requirement data for tillage implements is an important factor in selecting suitable tillage implements for a particular farming situation. Farm managers and consultants use draft and power requirement of tillage implements in specific soil types to determine the proper size of tractor required. Also, ownership and operating costs of both tractors and implements can only be minimized by using accurate draft data. Farmers mostly depend upon past experience for selecting tractors and implements for various farming operations. The previous experience may have little effect in selecting newly introduced implements. Therefore, prediction of implement draft
requirement is important for tractor selection and implements matching (Al-Janobi and Al-Suhaibani, 1998).

Draft measurements are required for many studies including energy input for field equipment, matching tractor to an implement size, and tractive performance of a tractor. Vertical force affects weight transfer from implement to the tractor, and consequently, affects the tractive performance and dynamic stability of the tractor (Chen et al., 2007).

Mathematical models have been developed to predict draft of some tillage tools, but the heterogeneity of the soil, coupled with the complex manner in which soil fails, make the understanding of the complex interactions between a specific tillage tool and the soil medium difficult (Grisso et al., 1994).

1.5 Problem Identification and Justification:

The necessity for global food security demands accelerated food production from limited land and energy resources. And in view of the scarcity of hand labor, the large areas to be farmed and the limited growing seasons of most field crops, the world is paying more attention to farm mechanization as the only solution for the food security problem of the ever increasing human and animal populations.

Currently, a wide selection of different types and sizes of tractors and machinery, for farm mechanization, are available on the markets all over the world. However, the selection of the proper tractor –implement combination for soil manipulation is greatly dependent on the soil type and conditions under which they operate in order to achieve best results regarding the efficiency and economy of the field operation undertaken.

Accordingly, to calculate the cost and power requirements of different tillage implements, it is paramount to know beforehand the tractor available power and the draft power required to operate those implements under the specific soil conditions dealt with for proper tractor-implement matching.

Thus, this research endeavor is carried out to determine specific data about draft power requirements of different soil tillage implements under central Gezira clay soil conditions.
CHAPTER TWO

OBJECTIVES

2.1 Main Objective:

The main objective of this research is to determine the draft power required for soil manipulation using a combination of different tillage implements under central Gezira clay soil conditions.

2.2 Specific Objectives:

The specific objectives, through which the main objective is to be achieved, include the following aspects:

(1) Determining draft requirements for operating a disk plow, moldboard plow, chisel plow, offset disk harrow and ridger under different soil moisture contents and operating speeds.

(2) Determining fuel consumption of the selected implements under the stated conditions.

(3) Determining draft requirements, as well as fuel consumption, for secondary tillage using disk harrow after the above selected primary tillage implements.
3.1 Sources of Farm Power:

The availability of power is a pre-requisite for any agricultural activity whether the source is human, animal or motorized. In developed country agriculture, the general availability of virtually unlimited amounts of farm power in its different forms is almost taken for granted and comes almost exclusively from internal combustion engines or electric motors. The human is just the “brain” and control of the system. However, in most developing countries, the human is a major source of farm power. Just how significant is this and to what extent is human power used? How will this change in the future, and can the required farm surpluses required to feed burgeoning urban populations be produced from an agricultural situation in those countries which rely to a large extent on human labor? (Clarke and Bishop, 2002).

In developing countries there is a great variation in the proportional use of the three primary sources of farm power. In some countries there is a dynamic situation in which human and animal power is being replaced by mechanical power, but in others, farmers are having to give up mechanical and animal power and revert back to human power. In some others which are tragically hit by HIV/AIDS and other diseases, even the human power base is shrinking (Clarke and Bishop, 2002).

Moving into the third millennium, it is important to take a look at the most fundamental requirement for progress in the expansion and adoption of mechanized technologies: the present and future availability of farm power in developing countries. FAO is carrying out work that believed to be of vital importance if planers are to understand and attempt to influence the progress of agricultural engineering development into this millennium (Clarke, and. Bishop, 2002). FAO, over the past few years, has been gathering information on the different sources of farm power in developing countries, and in the process of generating a global picture and making projections as to how this might change over the next 20 to 30 years and identifying which factors will influence these
changes. However, at this stage of the work FAO is only looking at farm power used for field cultivations and not at a total farm picture as the latter is extremely complicated and data is not readily available, and that in manually based systems field work is probably the most arduous. In order to examine the contribution of the different power sources to agricultural production, two approaches were considered. The first was to base the discussion of the relative contributions of the different power sources to the total power input to agriculture, and the second was to take an area-based approach, focusing on the proportion of the total harvested area cultivated either by humans, draft animals or tractors at a country level.

The first method starts with estimating the number of people, draft animals and tractors working in agriculture; converting each of the three power sources into a kW equivalent; aggregating the total power input to agriculture; and then expressing the contribution of each power source as a percentage of the total. There are, however, four principal concerns with this approach; namely:

(a) The lack of availability and reliability of the base data.

(b) The conversion into kW equivalents which relies on estimates of the power equivalents of human beings, draft animals and engine powered machines.

(c) The expression of the data as a percentage of total power equivalents (due to the fact that the power produced by humans is so insignificant when compared to tractors).

(d) The difficulties in projecting over time, particularly the occurrence of substitution between power sources.

As a result of these problems in using a kW equivalent an area-based approach was adopted, initially focusing on the proportion of the total harvested area cultivated by humans, draft animals or tractors at a country level, and then aggregating it at both sub-regional and regional levels. There are two premises under-pinning this methodology:

(a) The power source used for primary tillage, because land preparation represents one of, if not, the most significant users of power and it is usually one of the first tasks to benefit from additional power inputs.
(b) The area cultivated by each power source as a percentage of the total harvested area.

On the basis of information collected, as well as expert opinion, attempts were made to characterize different countries into different groupings according to their use of farm power. Moreover, efforts were made to determine whether there are any similarities in economic and social indicators between countries with a similar mix of types of farm power. Using these indicators and data, predictions were made of how the farm power situation will change from country to country and from region to region over the next two to three decades.

As a basis for the FAO work countries were categorized into six farm power typologies as follows (Clark and Bishop, 2002):

1. Humans are the predominant source of power for land cultivation, with modest contributions from draft animals and tractors.
2. Significant use is made of draft animals, although humans are still the most important power source.
3. Draft animals are the principal power source.
4. Significant use is made of motorized power.
5. Tractors are the dominant power source.
6. Land cultivation is fully motorized.

As an overview, the World map (Fig. 1.1) shows individual countries assessed according to the farm power typology in use (developing countries excluding China). All three sources of power (human, draft animal power (DAP), tractor) are widely used and widely dispersed; however, the use of the different sources and the extent to which they contribute to agricultural production varies from region to region, within a region and even within a country.

In Sub-Saharan Africa, in overall terms, humans are the principal power source, cultivating two thirds of the area under cultivation, but there are regional differences with manual power being dominant in the Central region, draft animals being used to a greater extent in Western and Eastern Africa, and in Southern Africa there is an increasing use of tractors Fig. (1.2).
In Asia, one third of the land is prepared by draft animals whilst tractors are a significant source of farm power in much of Central and South America and the Caribbean. The use of tractors is also well established in the Near East and in North Africa. The extent of these differences is shown in Fig. (1.1).

Power sources for tillage and transport in the smallholder-farming sector are tractors, oxen, donkeys, horses, mules and hand labor. In the past, farming in the rural communities was highly developed using animal traction as an indigenous technology in South Africa (Starkey, 1995). However, with the introduction of the policies of subsidized tractor hiring services, animal traction development was discouraged. Most of these government tractor-hiring schemes, which were established in different rural regions, are not operational and facing serious management and financial problems. Many of them are out-of operations which have left farmers with no source of power for their farming operations (Fischer, 2000; Simalenga and Joubert, 1997; Nedavhe et al, 2002).

3.2 Agricultural Tractors:

The main power source for on-farm tillage and transport work in the large-scale commercial sector is the tractor. Globally, it has been estimated that there is, on average, between 3 and 14 tractors on a given commercial farm, depending on the size of the farm, the farming system and the location of the farm (Simalenga et al. 2002).

The proper matching of an implement to a tractor is one of the methods of increasing operational efficiency. For a specified implement working on a given soil, the magnitude of its draft is a function of travel speed, operating tillage depth and width. The operating cost for any given implement could be minimized either by optimizing the travel speed or the operating width.
Fig. (1.1): Farm power typology (Clarke and Bishop 2002).
(Note: South Africa not classified as a developing country)

Fig. (1.2): Africa – Developing Countries by Farm Power Typology (Clarke and Bishop 2002).
Furthermore, the choice of an efficient implement, such as a chisel plow instead of a moldboard plow, can reduce the tillage energy requirement by up to 40% (Michel et al., 1985). The matching and performance prediction of a tractor implement system involves many decision-making processes that depend on a host of factors. Some factors, like tractor, tire and implement specifications; soil conditions, are inherent to the tractor- implement system and cannot be altered or controlled. Others like hitching characteristics (mounted, semi-mounted and trailed), operating conditions (depth and speed of operation), and types of field operation (primary or secondary); can be adjusted for the purpose of achieving maximum performance. This is what is known as matching of the tractor- implement system. A correct matching of tractor-implement system would result in decreased power losses, improved efficiency of operation, reduced operating costs and optimum utilization of capital or fixed costs (Taylor et al., 1991).

3.3 Agricultural Machinery:

Farm machinery and equipment are increasing in complexity, price, and, in many cases, size. Expenditures on farm machinery make up to 13 percent of the total production expenditures, and farm machinery assets are 9 percent of the total farm assets (Marcel and Charies, 1996). Trends toward conservation tillage and no-till have prompted inventions such as the air drill and the coulter chisel plow. Precision farming is the impetus for new inventions, including continuous yield monitoring equipment and variable-input gaging devices, and will likely inspire more inventions in the near future.

3.3.1 The use of mechanical power in farming:

The farmer uses mechanical power and machinery either to increase food production or to maintain a given volume of production at a smaller cost. The problem is essentially the economics of how to organize the use of labor and equipment in the most profitable way. Power and equipment costs today represent an important and increasing proportion of the total farm costs, and vary widely. Robinson (1977) indicated that farm knowledge of power and machinery will enable the farmers to:

(1) chose and buy equipment well suited to the need of the farm.
(2) understand the working principles of the machines so that they may be kept in good running order.

(3) understand the applications of the equipment in order that it may be operated efficiently.

3.3.2 The objectives and principles of tillage:

Tillage is the practice of working the soil with implements in order to provide conditions favorable to the growth of crops. It is based partly on knowledge of soil science, and to a larger extent on an acquired skill which comes by practice and experience. It has been truly said that the cultivation of the soil remains today more an art than a science. Not only different soils vary greatly in their reactions to implements, but an individual soil varies from day to day according to such factors as its moisture content (which is easily recorded) and the exact sequence of moisture changes in individual clods. In general, light or sandy soils are easy to work and can be tilled at almost any time of the year, while heavy or clay soils are more difficult to manipulate and can be satisfactorily tilled only at certain seasons when the moisture content and weather are suitable. The effects of natural agencies on soils are a matter of great importance to the farmer, since it is only by working with these natural agencies that the most economic methods of working can be achieved (Robinson, 1977).

Tillage is important to provide the correct conditions for crop establishment and growth and, in general, requires mechanical manipulation of the soil by equipment that either cuts, shatters, inverts or mixes the soil (Cannell, 1985; Gajri et al., 2002). It is performed for optimizing productivity by alleviating physical, chemical and biological constraints of the soil (Gajri et al., 2002). An important aim of soil tillage is to ensure that the seedbed created is optimally structured for the germination and establishment of the following crop.

The optimum seedbed also depends on soil texture (Kritz, 1983). The required soil tilth can be defined in terms of the distribution of aggregate sizes in the seedbed layer or planting row, surface micro relief or bulk density. Scientists disagree as to which aggregate size range provides the ideal seedbed, but most suggest small amounts of dust (<0.5mm) and clods (>20mm) are necessary (Adem et al., 1984).
3.3.3 Tillage methods:

Tillage is the preparation of the soil for planting and keeping it lose and free from weeds during the growth of crops. It is generally intended to prepare suitable seed bed, destroy competitive weeds, and improve the physical condition of soil. The equipment used by farmers to brake and loosen the soil for depths of 6 to 36in (15.2 to 91cm) are called primary tillage equipment, which include the moldboard, disk plow, rotary tiller, chisel and subsoil plows, (Smith and Wilkes, 1976).

Tillage operations for seedbed preparation are often classified as primary or secondary, although the distinction is not always clear cut. A primary tillage operation constitutes the initial, major soil-working operation, and is normally designed to reduce soil strength, cover plant materials and rearrange aggregates, while secondary tillage operation are intended to create refined soil conditions following primary tillage (Kepner et al,1975).

3.3. 3.1. Primary tillage:

The first tillage after the last harvest, and usually the most aggressive one, is called primary tillage (McKyes, 1985).

Primary tillage operations were mainly introduced for cutting and loosening the soil to depths ranging from 15 to 90 cm ( Kepner et al, 1978).

3.3.3.2 Secondary tillage:

Secondary tillage operations are generally required to prepare the seedbed on the top ten centimeters of the soil. This ensures better seeds to soil contact, provides water for germination and early growth, and prevents seedling roots from being obstructed by large soil clods. The main objectives of secondary tillage operations are (McKyes, 1985) as follows:

(1) Working the soil to shallower depths than primary tillage.
(2) Providing additional soil pulverization.
(3) Leveling and firming the soil to minimize air pockets.
(4) Control weeds.
(5) Help to conserve soil moisture.
3.3.4 Tillage Systems:

3.3.4.1 Intensive tillage:

Intensive tillage systems leave less than 15% of crop residue cover or less than 500 pounds per acre (560 kg/ha) of small grain residue on the soil surface. These types of tillage systems are often referred to as conventional tillage systems, and some times as reduced and conservation tillage systems; and it is often not appropriate to refer to them as conventional. These systems often involve multiple operations with implements such as a moldboard plow, disk plow, and/or chisel plow. Then, a finishing operation with a harrow, rolling packer and cutter, beside many other variations, can be used to prepare the seed bed (Milton and Triplett. 1986).

3.3.4.2 Reduced tillage:

Reduced tillage systems leave between 15 and 30% residue cover on the soil or 500 to 1000 pounds per acre (560 to 1100 kg/ha) of small grain residue during the critical erosion period. This may involve the use of a chisel plow, field cultivators, or other implements. (Troeh et al., 1991).

3.3.4.3 Conservation tillage:

Conservation tillage systems with the purpose of saving soil and water resources have, recently, replaced traditional tillage practices. In conservation tillage systems fewer soil engaging implements are used which result in lower production costs, lower soil moisture loss and lower soil erosion. Furthermore, retaining crop residue on the soil surface provides a source of plant nutrients, improves organic matter level in the soil, and increases soil water content by reducing evaporation and increasing infiltration rate (Chastin et al, 1995).

Conservation tillage is defined to be any tillage/planting system which leaves at least 30% of the field covered with crop residue after planting has been completed. In such soils, erosion is reduced by at least 50% as compared to bare, fallow soils (McCarthy et al, 1999).
One important impediment to the wide use of conservation tillage is the difficulty of planting in such soils. Klocke (1979) reported unsatisfactory performance of planters under conservation tillage, mainly due to residue accumulation between the furrow openers of the planting machines. Jasa and Dickey (1982) concluded that coulter attachments improve uniformity in seed spacing. Moreover, previous crop residue is claimed to cause variation in seed placement indices such as placement depth (Mock and Erbach, 1977; Nafziger et al., 1991; Ford and Hicks, 1992; Swan et al., 1994).

3.3.5 Tillage Implements:

The moldboard plough, cultivator and disc harrow are generally used to prepare the soil for growing crops in the least possible time by accomplishing maximum field capacity of tillage implements. Such practice is usually followed by larger equipment at low speeds or smaller equipment at higher speeds to prepare the final seed bed. Thus a combination that enables the task to be completed in the shortest time with minimum operating cost and energy requirement is usually selected (Onwualu and Watts, 1998).

3.3.5.1 Moldboard plows:

The moldboard plow is still the standard implement for primary tillage in mechanized agriculture and it is associated with high tillage erosive action (Gerontidis et al., 2001; Van Muysen et al., 2002).

The moldboard plow is one of the oldest of all agricultural implements and is generally considered to be the most important tillage implement. Plowing accounts for more traction energy than any other field operation. Although yield studies have indicated that under certain conditions with field crops there is no apparent advantage in plowing, the moldboard plow is still by far the most used implement for primary tillage in seedbed preparation (Kepner et al., 1975).

The moldboard plow is the most common primary tillage tool in the world and has the capacity to break up many types of soil. It has the ability to turn over and cover sods, crop residues, and weeds (Bernacki et al., 1972; McKyes, 1985; Hakansson et al., 1998).

Although moldboard and chisel tillage make the major part of annual sequence of tillage operations, they do not generally result in a surface that is smooth enough for...
seeding or planting, and most often a sequence of moldboard and chisel tillage is followed by harrowing to reduce clod size and surface smoothening before seeding is carried out (Govers et al., 1999).

For special applications, there are different types of moldboard plows including the stubble, general purpose, clay soil, stiff-sod, backland, chilled general purpose, and slatted plows (McKyes, 1985).

Mounted moldboard plows for small and medium-size tractors have been popular ever since the advent of hydraulically controlled integral hitches. As tractor sizes were increased, sizes of mounted plows increased to some extent, but their size is limited because the rearward overhang of large plows causes tractor instability in the transport position. Semi mounted large plows were developed to overcome the instability problem while retaining most of the advantages of mounted implements (Kepner et al, 1975).

The draft of the moldboard plow is affected by many factors, such as the type and shape of bottom, especially the moldboard unit; the sharpness of the share; the overall adjustment of the plow; the depth and width of furrow; and the type and characteristics of the soil. The speed at which the plow is operated is also an important factor affecting the draft of the plow. When all these factors are considered, there will be a wide range in the draft of any type or shape of bottom from field to field, depending on the type and condition of the soil (Smith and Wilkes, 1976).

The specific draft of plows varies widely under different conditions, being affected by such factors as the soil type and condition, plowing speed, plow–bottom shape, friction characteristic of the soil-engaging surface, share sharpness and shape, depth of plowing, width of furrow slice, type of attachments and adjustment of the plow attachment. A great deal of work has been done in evaluating the various factors and investigating possible means for reducing draft (Kepner et al., 1975).

3.3.5.2 Standard disk plows:

The standard disk plow has one or more disk blades, each with its own bearings and each slanted at an angle to the vertical. In some designs the disk plow can be adjusted to suit different soil conditions. Slow speed is necessary for the cutting action of the plow (Archie and Gulvin, 1967).
The standard disk plow is slightly higher in draft requirement than the moldboard when plowing under similar conditions and turning the same volume of soil. The type of soil is the greatest external factor to consider in the draft of any disk plow (Smith and Wilkes, 1976).

### 3.3.5.3 Chisel plows:

The chisel plow is an implement with long straight shanks and double ended chisel points which are usually about four to six cm in width (McKyes, 1985). Chisel shanks are usually mounted on rectangular frames in gangs of five to ten or more shanks at spacing of 30 to 50 cm. The chisel tools can cut, loosen and stir the soil but cause very little turning over. Chisel plows are well adapted to loosening hard dry soils, shattering hard pans and maintaining crop residue cover. The soil is broken by the chisel plow by stirring; it is not inverted and pulverized to the extent that moldboard and disk plows crush the soil. Therefore, the chisel plow is often used to loosen hard, dry soils before the regular plow is used. The chiseling and stirring operation does not throw enough soil to cover trash completely. Hence, the chisel-type plow is used for stubble-mulch or subsurface tillage practices (Smith and Wilkes, 1976). The chisel plowing is considered a potential conservation tillage method (Carter M. R, 1996).

Grisso et al. (1996) and Chandon and Kushwaha (2002) reported that the draft force and tillage energy required during tillage using a chisel plow is a linear function with operation speed, directly proportional to plowing depth and width, tool characteristics, and soil properties. Kirisci, V.A. (1994) found that the relationship between force and depth is linear for a chisel plow, and Awady (2001) indicated that the draft varies according to a second degree polynomial with speed.

Backingham (1984) stated that typical power or draft required for a chisel plow is 270-1100 N/m/cm of width or 50-160N/m/cm of depth at 5.5-10.5km/h typical speed, and typical range of field efficiency from 74 to 90%. The ASAE Standards (1985) indicated that the maximum draft force for a chisel plow in 3625 N per shank at a depth of 20 cm and a speed of 2 km/h. Khalilian et al. (1988) studied the draft energy for a chisel plow compared with other plow types on a loamy sand soil at two different depths.
of 25 and 35 cm. They concluded that the draft per shank for the chisel plow was 2.25 kN at 25 cm depth.

Iqbal et al. (1994) determined the draft requirement of selected primary and secondary tillage implements in a silty loam soil using a field speed of 2.5 km/h. He found that the draft consumed by the chisel plow increased linearly with the increase in depth of cultivation, whereby increasing the depth from 7 to 47 cm increased the total drawbar power from 1.35 to 14.11 kW.

Zein Al-Din (1985) and Younis et al. (1991) found that the energy required (kW-h/fed.) for seedbed preparation, generally, increased with increasing plowing depth. They also found that the minimum energy required was obtained with a chisel plow due to its high actual field capacity and low slip during the plowing. Al-Janobi and Wahby (1998) found that the chisel plow had the smallest value of specific energy for a forward speed from 6.3 to 9.3 km/h compared to moldboard and disc harrow tillage treatments.

**3.3.5.4 Disk harrows:**

A harrow is an implement used to level the ground and crush the clods, to stir the soil, and to destroy weeds. Under some conditions, harrows can be used to cover seeds (Smith and Wilkes, 1976).

There are two main types of disk harrows, the regular and the offset. The regular harrow may consist of a single section (single action) or of a double section (tandem). The single-action disk harrow usually consists of two gangs. On the other hand the regular disk harrow of the two-section type has one section of gangs trailing behind another. It is also called a double-action, or tandem harrow, because the rear section turns back the furrows created by the front section (Stone and Gulvin, 1967).

The offset disk harrow has two gangs of disks. One gang is located behind the other. It is like one-half of a tandem harrow, but the gangs are connected in an offset position to the centerline of pull. The offset harrow leaves the soil level, and the furrow left by the last disk blade on the rear section is usually filled the next time around. This type of harrows works well close to shrubs and trees with low-hanging branches (Stone and Gulvin, 1967).
Many factors affect disk harrow draft including gang angle, mass per blade, blade type and spacing, operating depth and forward speed (Summers et al., 1986). Draft data for disk harrows were reported by ASAE (1985) with draft expressed as a function of implement mass and type of soil. More recent studies by Harrigan and Rotz (1994) updated the ASAE data report by including disk harrow draft as a function of speed, working width, working depth and soil conditions. They indicated that tillage draft of disk harrows is further influenced by site-specific conditions including soil type, moisture, density and residue cover.

3.3.5.5 Ridger:

The ridger is an implement which cuts and turns the soil in two opposite directions simultaneously for forming ridges. It is also known as the furrower. The ridger is used to form ridges for sowing row crop seeds and plants in well tilted soil, and is also used for forming field channels or furrows, earthing up and similar other operations. A ridger consists of a beam, clevis, frog, handle, mould boards, braces, share, and a sliding shoe. The ridger generally has V-shaped or wedge shaped share, fitted to the frog. The nose or the tip of the share penetrates into the soil and breaks the earth. The mould boards lift, invert and cast aside the soil, forming deep channels and ridges of the required size (Nakra, 1986).

The ridger is used for building ridges or for bordering plots. It is also used for controlling weeds and covering fertilizes and herbicides. Moreover, ridgers facilitate water movement and help water management for surface irrigation systems (McKyes, 1985).

3.3.6 Tillage implements power requirement:

3.3.6.1 Draft requirements:

Abd El-Wahab (1994) reported that more than 50% of the power required for agricultural production is consumed in soil tillage. El-Sayed and Ismail (1994) found that the energy required for traditional, minimum and improved tillage treatment was 48.64, 25.13 and 67.38 kw.h/fed., respectively.
Generally the overall field energy efficiency is the ratio of the specific energy transferred from the tractor for operating the implement to the energy equivalent of the fuel consumption required to perform the operation (Smith, 1993). The availability of data on the draft requirements of tillage implements is an important factor in selecting tillage implements for a particular farm situation. Farm managers and consultants use draft and power requirement data of tillage implements in specific soil types to determine the size of tractor required and to calculate the cost and energy requirement of different tillage implements. The draft requirement of any tillage implement was found to be a function of soil properties, tool geometry, working depth, travel speed, and width of the implement (Glancey et al., 1996).

The draft or drawbar pull is the force required to propel an implement in the direction of travel (ASABE, 2006). However, draft requirement should also be related to the results of the tillage operation (e.g. the aggregate size distribution). Both these factors are greatly influenced by the soil water content (Watts and Dexter, 1994). Despite this, there are relatively few tillage experiments reported with soil water content as an experimental factor.

The tractor is still the basic power unit in crop production. Beside tractors, additional driven machines need to be included in a tillage process. The composition of tractor–machinery systems depends on many parameters: the seeding structure, soil conditions, farm area, fuel consumption etc. Among others, the importance of optimal choice of applied tractor–machinery tillage systems is concerned with fuel economy. Additionally, intensive agricultural development in the last decades has produced new economic, energy and ecological demands on the applied production technology and agricultural mechanization (Nikolić, 2006).

A standard testing procedure for agricultural implements draft determination and other practical alternatives, such as the techniques demonstrated by Nicholson and Bashford (1984) and Upadhyaya (1984), need to be developed if substantial improvements in available management data are to be obtained. Glancey (1990) has developed a methodology to predict the draft and energy requirement of an implement using measurements obtained from a standard reference tillage tool.
The draft of tillage implements plays a vital role in developing more efficient tillage systems by selecting suitable tractor-implement combinations. The availability of data on draft requirement of tillage implements is an important factor in selecting suitable tillage implements for a particular farm situation. However, collecting draft data under a wide range of field conditions is a tedious and time consuming job. Therefore, draft prediction models are required to predict the draft of tillage implements under different soil and operating conditions. The magnitude of draft is affected by soil type and its condition, tool characteristics, working speed and depth (Reed, 1937; Gill and Vanden Berg, 1967; Kydd et al., 1984; Grisso et al., 1996; Al-Janobi and Al-Suhaibani, 1998; ASAE Standards, 2003).

Equations of draft versus speed were obtained by regression analysis of the measured data (Dransfield et al., 1964; Summers et al., 1986; Owen, 1989; ASAE, 1992). This method describes the observed relations well but provides no theoretical reasons why a certain tillage tool needs a certain draft. A second approach uses an analytical method comprising the development of models to predict the draft under various conditions, and the results of the models were compared with experimental results (Payne, 1956; Rowe and Barnes, 1961; Wismer and Luth, 1972; Upadhyaya, 1984). All these results showed that the draft of moldboard and disk plows increased as the square of speed while the increase of draft of many other tillage implements was linear. These relations were apparently intended only for typical field speeds, which are generally under 4 ms⁻¹, above which the relations were different (Hendrik and Gill 1973).

There are many factors which determine the power required to move an implement in the soil which in turn determine the fuel and energy required for a specific operation. These factors include (McKyes, 1985):

1. Total soil density.
2. Total working depth below the soil surface.
3. Soil cohesion, or strength.
4. The vertical pressure acting on the soil surface.
5. Total width.
6. Total rake angle.
(7) The possible curvature of the tool shape.
(8) The soil angle of internal friction.
(9) Critical working depth of the tools.

In studying the energy requirement of different tillage implements Khalilian et al. (1988) found that draft of drawbar increased with the increase in the number of cultivating bodies, and tillage type. Shiners et al (1990) studied the effect of combining active and passive tillage elements on the draft requirement and concluded that the overall draft requirement of the total implement was considerably decreased, since the active elements were forward-rotating thus resulting in a negative draft that reduced the total draft. Moreover, they found that both draft and energy requirement increased with the increase of the working depth regardless of the tillage element.

Since inertial forces increase as the square of the speed, draft increases as the square of the speed (Terpstra, 1977; Owen, 1989). For clay soils, the effect of shear rate on shear and adhesive strength is more significant (Rowe and Barnes, 1961; Wismer and Luth, 1972). For such soils, draft increases exponentially with speed (Stafford, 1979). The usefulness of these relationships is in the development of models which can be used in estimating draft and, hence, power requirement. The simplest of such approaches is the use of regression equations. Such equations are given by ASAE Standards D230.4 for a limited range of soil and tool conditions (Hahn and Rosentreter, 1989).

Many changes in tillage practices have been found during the last 30 years. Conservation tillage practices are replacing moldboard plowing and other major seedbed preparation practices on a large portion of the total area under cropping in the developed countries (Harrigan and Rotz, 1995). Information on the draft requirements of combination tillage implements is limited. The lack of information about the implement compels the farmers to rely mostly on past experience for selection of implements and tractors. The farmers’ experience may be of little value in selecting the efficient tillage system as the size and speed of operation of new agricultural implements are increasing. Therefore, prediction of draft requirements of combination tillage implements is necessary for the design and selection of machinery and the matching of tractors with implements for efficient operation. Many researchers have developed various regression equations for draft prediction of
individual tillage implement under different soils and operating conditions (Collins et al., 1978; Kepner et al., 1982; Kydd et al., 1984; Nicholson et al., 1984; Upadhyaya et al., 1984; Glancey and Upadhyaya, 1995; Glancey et al., 1996; Grisso et al., 1996; Desbiolles et al., 1997; ASAE, 2000; and Sahu and Raheman, 2004).

3.3.6.2 Effect of speed upon draft:

Tillage operations are usually carried out at low speeds, largely because of the fact that to disturb large masses of soil demands high draft forces from tractors. High-speed tillage operations allow the farmer to increase machine work rates and get the field operations done in a timely manner (ASAE 2000). However, at speeds of 1.25-1.50 and 1.75 m/s tillage implements had a significant effect on the soil moisture content at $P < 0.05$, but the effect of operating at lower speeds on the moisture content was not significant (Mustafa, 2007).

Saunders et al. (2000) studied the effect of furrow depth, width and forward speed on the measured total draft forces and work rates of moldboard ploughs. They found that depth has the greatest effect by increasing the draft force by 76% when the depth is increased from 125 to 225 mm. Increasing the furrow width from 400 to 500 mm, on average, increased the total draft force by 32% and increasing the speed from 4.5 to 10 km/h increased the force by 11 and 21% at depths of 225 and 125 mm, respectively. They showed that the draft force of the tines takes 9% less draft force to pull at 500 mm wide, 125 mm deep furrow and 10 km/h than it does at 400 mm wide, 225 mm deep furrow and 4.5 km/h.

Mathematical models have been developed to predict the magnitude of the soil forces acting upon implements of different geometry (Godwin and Spoor, 1977; Godwin et al., 1984; Godwin and Wheeler, 1996). These models are based upon the general soil mechanics equation developed by Hettiaratchi et al (1966) and enable the calculation of draft and vertical forces from knowledge of the tool geometry, working depth, soil physical properties and the type of the soil disturbance pattern produced by the tool. They have been integrated into a unified model described by Godwin and O’Dogherty (2006) and formulated into a number of spreadsheets for the use of those who wish to estimate the effects of different implement geometry on the soil forces in a given soil and the
effect of different soils on a given implement shape. The spreadsheets consider a range of implements, namely: single and multiple tines, land anchors, disks, and moldboard plows.

Increased forward speed increases the draft with most tillage implements, mainly because of the more rapid acceleration of any soil that is moved appreciably. Soil acceleration increase draft for at least two reasons: first because acceleration forces increase the normal loads on the soil-engaging surface, thereby increasing the frictional resistance, and second because of the kinetic energy imparted to the soil (Kepner et al., 1975).

3.3.6.3 Effect of soil moisture content on draft power:

Soil moisture is the most restrictive factor to crop yields in many areas. The tillage systems conserving the soil moisture content are important in increasing crop yields, and reducing the devastating consequences of drought (Hughes and Baker, 1977).

Soil water content during tillage is a decisive factor for the outcome and may be more important than the tillage implement used. Despite this, more experiments have been carried out to investigate the effect of different implements on soil physical properties than to investigate the effect of soil water content (Tisdall and Adem, 1986; Braunack and McPhee, 1991; Watts and Dexter, 1994; Riley and Ekeberg, 1998; and Mueller et al., 2003). The optimum workability or optimum water content for tillage can be defined as ‘the water content where tillage produces the largest proportion of small aggregates’ (Dexter, 1988).

In general, tillage at very low water contents or high soil strengths requires high draft and gives little soil fragmentation. On the other hand, tillage at high water contents induces plastic deformation and shearing, which is considered unfavorable for soil structure. Therefore, the optimum water content for tillage can be found at an intermediate water content, which is often stated in relation to the plastic limit. However, Dexter and Bird (2001) suggested that the optimum water content should, instead, be derived as the inflection point of the water retention curve. Mueller et al. (2003), when comparing different methods, found that it is most relevant to relate the optimum water content to the plastic limit, and they found that 0.9 PL(Plastic Limit) to be the upper limit for optimum tillage.
3.3.7 Power requirement of a tractor:

The study of energy requirements of agricultural implements continues to be an important consideration for engineers and researchers. Recent studies conducted by Bowers (1989), Girma (1989), Cullum et al. (1989), Gregory and M'Hedhbi (1988), Brassington (1987) and Summers et al. (1986), among others, have measured draft requirements for various implements in their respective areas and countries. Alternate approaches to the testing procedures employed for agricultural equipment have been proposed by Nicholson and Bashford (1984), Upadhyaya (1984) and Glancey and Upadhyaya (1995). These investigations proposed the use of a standard tillage tool to provide the information necessary to predict the performance of an implement in a given soil type and condition.

The power requirement of a tractor for different field operations can be calculated after obtaining the preliminary details regarding land holding, total available working time, soil conditions and type of operations (Jain and Philip, 2003). The size of land holding is very important for the determination of power requirement of a tractor. Sometimes it happens that a very high power tractor is purchased which remains underutilized causing financial loss in terms of depreciation and interest. Whereas, on the other hand, a low power tractor may not be able to complete the work in time. Since the tractor is used for various field operations, it is recommended that the field operation which is the most time sensitive or that requires the highest power should be taken into consideration for determining the power of a tractor.

3.3.8 Tractor-machine compatibility:

3.3.8.1 Power requirement for selected implements:

The drawbar power required to pull a tillage implement is a function of travel speed and draft of implement (i.e. the power that the tractor should be able to provide at the drawbar). The engine power will be quite a bit higher. The improvement of the operational efficiency of tractors has been a subject of considerable research. Operation efficiency can be improved by maximizing the work output or reducing fuel consumption potential. Savings of up to 20% in fuel consumption could be achieved with the gear-up
throttle-down technique (Chancellor and Thai, 1984; Schrock et al., 1986; Grogan et al., 1987; Smith, 1993).

The proper matching of an implement to a tractor is another method of increasing operational efficiency. The operating cost for any given implement could be minimized either by optimizing the travel speed or the operating width. Furthermore, the choice of an efficient implement, such as a chisel plow instead of a moldboard plow, can reduce the tillage energy requirement by up to 40% (Michel et al., 1985).

Both controllable and uncontrollable factors for the tractor- implement system options cover a wide variety of alternatives on which decisions have to be based, such as which implement and of what size is to be attached to the tractor. This is what is known as matching of the tractor- implement system.

A correct matching of the tractor- implement system would result in decreased power losses, improved efficiency of operation, reduced operating costs and optimum utilization of capital or fixed costs (Taylor et al., 1991). Several interactive computer models, templates, and software programs have been developed to predict the draft requirement of implement tractive performance parameters (slip, net traction, gross traction, and motion resistance), fuel consumption, turning time and field capacity of a tractor implement system during operation in different soil and operating conditions across the world. These studies are soil and site specific and their validity needs to be checked in other soils and locations. A few other researchers mentioned the general procedures for matching of tractor and implement on the basis of power availability and power required by considering the soil factor, unit draft, field efficiency, tractive efficiency and transmission efficiency (Downs et al., 1990; Downs and Hansen, 1998; Gould et al., 1999; Powell, 2001).

3.3.8.2 Size of implement:

The starting point in any matching exercise is to determine the most critical field operation. This will vary from region to region and often between farms within any one region. It is often determined by the time available to cover the area between rainfall events and can be estimated based on local knowledge or local rainfall records. The
required width of machine/ implement can be calculated by knowing the available time and operating speed for completing those operations (Singh and Selvan, 2009).

3.3.9 Measurement of power:

3.3.9.1 Dynamometers:

Dynamometers are devices for measuring power. Traction dynamometers are used for measuring the power expended in haulage operations when any implement or vehicle is being pulled by an independent source of power. Though the dynamometer may measure all quantities required for the calculation of the power exerted (i.e. force, distance, and time) the term dynamometer is generally applied to devices which may give only a record or an indication of the force exerted. The power at any given moment may be calculated from simultaneous values of the force or drawbar pull and the speed. In practice, it is usual to employ average drawbar pulls and speeds in calculating the power. The average speed is obtained by noting, by means of a stop-watch, the time taken for the outfit to travel a known distance, and the average drawbar pull is obtained by the use of a dynamometer (Culpin, 1976).

3.3.9.2 Type of dynamometer:

A dynamometer is a load device which is generally used for measuring the power output of an engine. Several kinds of dynamometers are in common use, and they include dry friction break dynamometers, hydraulic or water break dynamometers and eddy current dynamometers.

(1) The dry friction dynamometers:

Dry friction dynamometers (Fig.3.1) are the oldest kinds, and consist of some sort of mechanical breaking device, often a belt or frictional "shoe" which rubs a rotating hub or shaft. The hub or shaft is spun by the engine. Increasing tension in the belt, or force of the shoe against the hub increases the load on the engine.

(2) Hydraulic dynamometers:

Hydraulic dynamometers (Fig.3.2) are basically hydraulic pumps where the impeller is spun by the engine. Load on the engine is varied by opening or closing a valve, which changes the back pressure on the hydraulic pump.
(3) **Eddy current dynamometers:**

Eddy current dynamometers (Fig.3.3) are electromagnetic load devices. The engine being tested spins a disk in the dynamometer. Electrical current passes through coils surrounding the disk, and induce a magnetic resistance to the motion of the disk. Varying the current varies the load on the engine.

(4) **Draft dynamometers:**

The draft dynamometer (Fig.3.4) is generally used for accurate measurement of tension force, and specifically for measuring implement draft requirements when installed between the power unit (tractor) and the implement.
Fig. (3.1): Dry friction dynamometer.
Fig.(3.2): Hydraulic dynamometer.
Fig. (3.3): Eddy current dynamometer.
Fig. (3.4): Draft dynamometer.
3.3.9 Force action upon a tillage tool or implement:

Tillage tool draft depends on soil condition, tool geometry, tool width, operating depth and speed (Upadhyaya et al., 1984). Accurate prediction of the forces of tillage implements is of great value to both implement designers and farmers (Desbiolles et al., 1997). There are many available soil cutting models that can be used to predict the forces acting on a tillage tool (Zhang and Kushwaha, 1995). Analytical and numerical modeling methods are differently used approaches to achieve this goal. In the analytical methods, soil–tool forces are considered as functions of three categories of variables, namely soil engineering properties, tool design parameters and operational conditions. Soil engineering properties are conventionally considered to be constant, reflecting a homogeneous soil profile, and tillage forces are calculated for assigned tool design parameters and operational conditions (Godwin, 2007; Godwin and O’Dogherty, 2006; Godwin et al., 2007).
CHAPTER FOUR

MATERIALS AND METHODS

4.1 Experimental Site:

The experimental work to determine the draft requirement of different tillage implements under central Gezira clay soil conditions was conducted in the Demonstration Farm of the Faculty of Agriculture and Natural Resources, University of Gezira.

The experimental site is located at latitude 14° 25' N and longitude 33° 31' E within Greater Wad Medani Municipality. The climate, which is typical for central Sudan, is tropical semi-arid characterized by a summer rainy season (Walsh, 1991) with an annual precipitation of 200 to 300mm falling between June and October and reaching its peak during July and August. The soil of the site is typical central Gezira soil which is classified as vertisol; and is characterized by its deep dark color, low organic matter content, low permeability, and deep cracks when dry. Its clay content is around 58%; and its reaction is moderately alkaline (pH-8.1), non-saline (EC< 0.3ds/m) and slightly sodic (ESP =18%) (Agricultural Research and Technology Corporation, 2005).

4.2 Machinery and Equipment:

4.2.1 Tractors:

Two tractors were used in the experimental tests of this research work. A Massey Ferguson (FM 185) tractor was used as the main test tractor, while a Farmtrac (80) tractor was used as an auxiliary tractor (Plate 4.1). The specifications of the two tractors are shown in Table (4.1).

4.2.2 Implements:

The implements used in this experimental work are those commonly used for soil tillage in Sudan, and they included the following:
Plate (4.1): The Massy-Ferguson and Farmtrac Tractors

(1) **Moldboard plow:**

A Gherardi moldboard plow, made in Italy, was used (Plate 4.2). It is fully mounted, and consists of three moldboard bottoms. It has a 1.2 m width of cut.

(2) **Standard disk plow:**

A Balddan, Brazilian made, fully mounted disk plow was used (Plate 4.3). It has three disk bottoms and a 1.2 m width of cut.

(3) **Chisel plow:**

A RAU chisel plow, made in West Germany, was used (Plate 4.4). It is fully mounted, and consists of nine shanks arranged in three rows, each having three shanks. Reversible shovel are attached to the shanks. The width of cut of the plow is 2.0 m.
Table (4.1): Specifications of the tractors used in the experimental work.

<table>
<thead>
<tr>
<th>ITEM</th>
<th>TRACTOR TYPE</th>
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<td></td>
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<td>_</td>
<td></td>
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<td>4</td>
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<td>Water</td>
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</tr>
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<td>7.50 – 16</td>
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</tr>
<tr>
<td>Condition</td>
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<td>Moderate</td>
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</tbody>
</table>

(4) Disk harrow:

A PIETRO offset disk harrow, made in Brazil, was used (Plate 4.5). This harrow is fully mounted and has two disk gangs. Each disk gang consists of seven disks. The disks of the front gang are notched, while those of the rear gang are plain. The harrow has a 2.00 m width of cut.
Plate (4.3): Standard disk plow

Plate (4.4): Chisel plow
(5) **Ridger:**

A Nardi ridger, of Italian origin, was used (Plate 4.6). It is fully mounted, and has four ridger bodies, each of which is made up of a shank, a frog, a shovel and two wings. The ridger units were adjusted to give a 3.2 m working width.
4.2.3 Equipment:

Different equipment were used for conducting the different aspects of this research work. They included the following:

(1) **Dynamometer:**

The dynamometer used for measuring the draft (in kN) for the different tillage implements was a spring, pull-type PIAB dynamometer of Swedish origin (Plate 4.7).

(2) **Balance:**

An FWE sensitive balance model MACS, made in China was used to weigh the soil samples taken from the field for the purpose of determining moisture content (Plate 4.8). The balance has an electronic scale for a maximum weight of 7.5 kg, and a minimum weight of 0.5 kg.

Plate (4.7): PIAB dynamometer
(3) **Oven:**

A Gallen–Kamp electric oven, made in England, was used for drying the soil samples taken from the experimental site for the purpose of the determination of soil moisture content. The range of oven temperature is from 0 to 110°C, with thermostatic control.

(4) **Auger:**

A standard soil auger was used to take soil samples from the experimental site. It is graded in cm for marking sample depth.

(5) **Measuring tape:**

A Chinese measuring tape, 50 m long with cm grading, was used to measure all required distances for the experimental work.
(6) **Stopwatch:**
A Nokia mobile, model 1650, stopwatch was used to measure all aspects of time during the execution of the experimental work.

(7) **Measuring cylinder:**
A measuring cylinder (1000 ml) was used to refill the tractor tank with fuel in order to determine the fuel consumption of operating the tillage implement.

### 4.3 Experimental Methods:

The experimental work was carried out to determine the power required to operate individual soil tillage implement and various implements combination under central Gezira soil conditions. The experimental work involved five implements, which were chisel plow, moldboard plow, disk plow, disk harrow, and ridger. These were tested at three operational speeds, which were $S_1 = 3.5\text{km/h}$, $S_2 = 4.0\text{km/h}$, and $S_3 = 4.5\text{km/h}$ and under two levels of soil moisture content, which were $M_1 = 14.8\%$ and $M_2 = 4.2\%$.

#### 4.3.1 Experimental Design:

The experimental design was split- split plot design, with three replications. The main plots were the soil moisture contents, the sub-plots were the operational speeds, while the implements types assigned to the sub-sub plots. There were 2 moisture level $\times$ 3 speeds $\times$ 5 implements combination, sub−sub plots, each the size of 3$\times$40 m. The total experimental area $2.5\text{ feddans} + 300\text{ m}^2$ (Fig. 4.1).

#### 4.3.2 Experimental Procedures:

##### 4.3.2.1 Soil moisture content:

The irrigated main plots were left to dry for two weeks to represent the first level ($M_1$) of the soil moisture content, and the other main plots were left dry as it were to represent the second level ($M_2$). The two soil moisture levels were determined at the depth of 10-20 cm after the elapse of the two weeks period. The soil samples were taken using the standard soil auger, weighed, oven-dried at $105^\circ\text{C}$ for 24 hours, and then
The soil samples moisture content (%) was determined using the following equation (Blake and Hartge, 1986):

\[
M.C \% = \frac{W_w - W_d}{W_d} \times 100 \quad \text{........................ (4.1)}
\]

where:

- \( M.C \% \) = Percent soil moisture content on dry basis.
- \( W_w \) = Wet weight of soil sample (g).
- \( W_d \) = Dry weight of soil sample (g).
Fig. (4.1) Field Layout for the experimental work

Key. P = Disk plow  M = Moldboard plow  H = Disk harrow  Ch = Chisel plow  Rid = Ridger

S₁ = First speed  S₂ = Second speed  S₃ = Third speed.
4.3.2.2 Draft measurement:

The draft of implement or implements combination was measured using the pull-type dynamo meter through the following procedure (Hassanin, 2003):

(1) Two tractors, which were a test tractor (MF-185) and an auxiliary one (Farmtrac), were used to determine the draft requirement for soil tillage.

(2) The dynamometer was placed and connected between the auxiliary tractor and the test tractor on which the tillage implement was attached (Fig.4.2).

(3) Two draft measurements were taken using the above arrangement as follows:

(a) The first measurement (D1) was taken while the auxiliary tractor was pulling the test tractor, which was in the neutral gear position and the implement was not in work with the soil.

(b) The second measurement (D2) was taken while the auxiliary tractor was pulling the test tractor, which was also in the neutral gear position, and the implement was in work with the soil.

(4) The dynamometer readings were recorded along a 40 m distance.

(5) The required draft for operating the tillage implement was, then, calculated as follows:

\[ D = D2 - D1 \]  

(4.2)

where:

D = Draft (kN).

D1 = The first reading of the dynamometer when the implement is not working with the soil (kN).

D2 = The second reading of the dynamometer when the implement is working with the soil (kN).
Fig.(4.2): Operating arrangement for draft measurement (Hassanin, 2003).
(6) To determine the power required to operate the tillage implement, the draft (kN) was converted to horse power (HP) as follows (Dahab - in Arabic 2001):

\[ DHP = \frac{D \times S}{C} \]

where:

- \( DHP \) = Draft horse power.
- \( D \) = Draft (kN).
- \( S \) = Operational speed (km/h).
- \( C \) = Constant (3.6).

(7) The operation depth for the different tillage implements was 22cm for the chisel plow, 18cm for the moldboard plow, 18cm for the disk plow, 10cm for the disk harrow, and 15cm for the ridger.

### 4.3.2.3 Fuel consumption:

The method used for determination of the fuel consumption for each tillage implement, and implements combination, was as follows:

1. The auxiliary tractor fuel tank was filled to a specified level.
2. At the end of completion of the run test on the experimental plot (3×40m) the measuring cylinder was used to refill the fuel tank to the pre-specified level.
3. The amount of fuel required to refill the tank to the starting level was the amount of fuel consumed in the experimental plot.
4. The fuel consumption (gal/fed) for the test run was determined by the follows equation:

\[
\text{Fuel consumption (gal/fed)} = \frac{V(L) \times 4200 \left(\frac{m^2}{fed}\right) \times 0.26 g/L}{A(m^2)} \]

(4.3)

where:

- \( V \) = Volume of consumed fuel (L).
- \( A \) = Test plot area (m²).
CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Prelude:

All parameters collected data to determine the draft power of different tillage implements, and implement combinations, were statically analysed and tabulated.

5.2 Draft Power and Fuel Consumption with the use of each Primary Tillage Implement:

The analysis of variance of the obtained results indicated that there were significant differences (P< 0.05) between for the disk plow (Table 5.1 and Fig.5.1), moldboard plow (table 5.1 and fig. 5.2), chisel plow (Table 5.1 and Fig. 5.3), offset disk harrow (Table 5.1 and Fig. 5.4) and ridger (Table 5.1 and Fig 5.5). For all implements, the results indicated that the draft power significantly increased with the increased speed under both soil moisture content. On the other hand, fuel consumption also significantly increased with increased speed; however, there was no significant difference in fuel consumption between the two lower speeds (S1 and S2) under the first moisture content (M1), and between the two higher speeds (S2 and S3) under the second soil moisture content (M2). Moreover, draft power and fuel consumption, at all speeds levels, decreased with the increase in the soil moisture content.

Generally, form all the above results, it is obvious that draft power and fuel consumption increase with the increase in operating speed, regardless of the tillage implement used, which agree with the studies carried out by Kydd et al (1984), Mckeys (1985), Grisso et al(1996), Al Janobi and El-Suhaibani (1998), and Saunders et al (2000). Moreover, draft power and fuel consumption decrease with increase in soil moisture content, up to a certain limit, regardless of the tillage implement used, which agrees with the findings of Dexter and Bird (2001) and Mueller et al (2003).
For each implement, means followed by the same letter (s) within the same row for the soil moisture content are not significantly (P<0.05) different according to Duncan's Multiple Range Test.

S₁ = First speed (3.5 km/h).
S₂ = Second speed (4.0 km/h).
S₃ = Third speed (4.5 km/h).
M₁ = First level of moisture content (14.81%).
M₂ = Second level of moisture content (4.17%).

<table>
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<th>C.V (%)</th>
<th>M₂</th>
<th>SE±</th>
<th>C.V (%)</th>
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<td>S₂</td>
<td>S₃</td>
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<td>S₂</td>
<td>S₃</td>
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<th>M₂</th>
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<th>SE±</th>
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<th>M₂</th>
<th>SE±</th>
<th>C.V (%)</th>
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<td>15.94b</td>
<td>18.16a</td>
<td>0.31</td>
<td>0.76</td>
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<td>0.76a</td>
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<td>0.76c</td>
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For each implement, means followed by the same letter (s) within the same row for the soil moisture content are not significantly (P<0.05) different according to Duncan's Multiple Range Test.

S₁ = First speed (3.5 km/h).
S₂ = Second speed (4.0 km/h).
S₃ = Third speed (4.5 km/h).
M₁ = First level of moisture content (14.81%).
M₂ = Second level of moisture content (4.17%).

Table (5.1): Draft power and fuel consumption for the individual tillage implement.
Fig.(5.1): Draft power and fuel consumption for disk plow at two moisture content levels and three speeds.

Fig.(5.2): Draft power and fuel consumption for moldboard plow at two moisture content levels and three speeds.
Fig. (5.3): Draft power and fuel consumption for chisel plow at two moisture content levels and three speeds.

Fig. (5.4): Draft power and fuel consumption for disk harrow at two moisture content levels and three speeds.
Fig. (5.5): Draft power and fuel consumption for ridger at two moisture content levels and three speeds.

5.3 Draft Power and Fuel Consumption with the use of Secondary Tillage Implement (Disk harrow) after Primary Tillage Operation:

The analysis of variance of the obtained results showed that there were significant difference ($P < 0.05$) between treatments for the disk plow (Table 5.2 and Fig. 5.6), moldboard plow (Table 5.2 and Fig 5.7), chisel (Table 5.2 and Fig.5.8) and disk harrow (Table 5.2 and Fig 5.9). For all implements, the results showed that the draft power significantly increased with the increased speed under both soil moisture content. And fuel consumption, at all speed levels, deceased with the increase in the soil moisture content. The results indicated that draft power significantly increased with increased speed under both soil moisture contents. On the other hand, fuel consumption, also, significantly increased with increased speed; however, there was no significant difference in fuel consumption between the two lower speeds ($S_1$ and $S_2$) under the first moisture content ($M_1$), and between the higher speeds ($S_2$ and $S_3$) under the second soil moisture content ($M_2$). Moreover, draft power and fuel consumption, at all speed levels, deceased with the increase in the soil moisture content.
5.4 Draft Power and Fuel Consumption Comparisons Between the Different Primary Tillage Implements at Specified Plowing Depth

5.4.1 Draft power:

Table (5.3) and Fig.(5.10) present the results of draft power for the primary tillage implements tested. The analysis of variance showed that there were significant differences ($P < 0.05$) between the treatments.

At the first and second moisture levels (M1 and M2) the results indicated that the chisel plow had the highest draft power, while the ridger had the lowest draft power at all speed levels. However, there was no significant different in draft power between the disk plow and the moldboard plow at the first speed ($S_1$) under the first moisture content level ($M_1$) and at the first and second speeds ($S_1$ and $S_2$) under the second moisture level ($M_2$). Moreover, the results indicated that there was no significance difference in draft power beween the disk harrow and the ridger at the first and second speeds ($S_1$ and $S_2$) under the first moisture level ($M_1$) and at all seepds under the second moisture level ($M_2$).

It is clear that the chisel plow requires more draft power than both the moldboard and the disk plows. This agrees with the findings of Bauder et al.(1981) who reported that penetration resistance was lower under the moldboard plow than under the chisl plow. Similarly, according to the studies of Mielke et al. (1984) and Erbach et al.(1992), the lowest penetration resistance was obtined from the moldboard plow, and that the chisel plow requires more force than the moldboard plow and other tillage implements. On the other hand, both the disk harrow and the ridger, although wider in operating width, required the least draft power, because they have better penetration and are lighter in weight.
Table (5.2): Draft power and fuel consumption for the disk harrow after primary tillage.

<table>
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<th>C.V (%)</th>
<th>M_2</th>
<th>SE±</th>
<th>C.V (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed km/h</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Draft (HP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_1</td>
<td>13.34&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.56&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_2</td>
<td>14.80&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.57&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_3</td>
<td>16.65&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.67&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel (gal/fed)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Draft (HP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_1</td>
<td>12.65&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.57&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_2</td>
<td>14.40&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.58&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_3</td>
<td>12.39&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.68&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel (gal/fed)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Draft (HP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_1</td>
<td>13.47&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.61&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_2</td>
<td>15.54&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.63&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_3</td>
<td>17.65&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.70&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel (gal/fed)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Draft (HP)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_1</td>
<td>12.47&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.55&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_2</td>
<td>14.65&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.56&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S_3</td>
<td>16.31&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.58&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same letter (s) with in the same row for soil moisture content at p = 0.05 are not significantly different according to Duncan's Multiple Range Test.

S_1 = First speed (3.5 km/h).
S_2 = Second speed (4.0 km/h).
S_3 = Third speed (4.5 km/h).
M_1 = First level of moisture content (14.81%).
M_2 = Second level of moisture content (4.17%).
Fig. (5.6): Draft power and fuel consumption for disk harrow after disk plow at two moisture content levels and three speeds.

Fig.(5.7): Draft power and fuel consumption for disk harrow after moldboard plow at two moisture content levels and three speeds.
Fig. (5.8): Draft power and fuel consumption for disk harrow after chisel plow at two moisture content levels and three speeds.

Fig. (5.9): Draft power and fuel consumption for disk harrow after disk harrow at two moisture content levels and three speeds.
Table (5.3): Comparisons of draft power for primary tillage implements.

<table>
<thead>
<tr>
<th>Implement</th>
<th>Draft power (HP)</th>
<th>Moisture level (M₁)</th>
<th>Moisture level (M₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>S₁</td>
<td>S₂</td>
</tr>
<tr>
<td>Disk Plow</td>
<td>17.33ᵇ</td>
<td>19.87ᵇ</td>
<td>22.85ᵇ</td>
</tr>
<tr>
<td>Moldboard Plow</td>
<td>19.95ᵇ</td>
<td>22.25ᵃ</td>
<td>24.42ᵇ</td>
</tr>
<tr>
<td>Chisel Plow</td>
<td>20.24ᵃ</td>
<td>24.64ᵃ</td>
<td>27.07ᵃ</td>
</tr>
<tr>
<td>Disk Harrow</td>
<td>14.82ᶜ</td>
<td>15.94ᶜ</td>
<td>18.16ᶜ</td>
</tr>
<tr>
<td>Ridger</td>
<td>14.86ᶜ</td>
<td>17.73ᶜ</td>
<td>20.29ᵈ</td>
</tr>
<tr>
<td>Cv%</td>
<td>2.05</td>
<td>2.11</td>
<td>1.41</td>
</tr>
<tr>
<td>SE±</td>
<td>0.92</td>
<td>0.94</td>
<td>0.63</td>
</tr>
</tbody>
</table>

Means followed by the same letter(s) within the same column are not significantly different at P = 0.05 according to Duncan’s Multiple Range Test.

S₁ = speed (3.5 km/h)
S₂ = speed (4.0 km/h)
S₃ = speed (4.5 km/h)
HP = Horse power
Fig. (5.10): Comparison of draft power (HP) for primary tillage implements at two levels of soil moisture and three speeds.
5.4.2. Fuel consumption:

Table (5.4) and Fig. (5.11) display the results of fuel consumption for the primary tillage implements tested. The analysis of variance showed that there were significant differences (P< 0.05) between the treatments.

At the first and second moisture levels (M₁ and M₂) the results indicated that the chisel plow had the highest fuel consumption, while the disk harrow had the lowest fuel consumption at almost all speed levels. However, there was no significant difference in fuel consumption between the disk plow and the moldboard plow at the first speed (S₁) under the first moisture content (M₁), and at the first and third speeds (S₁ and S₃) under the second moisture level (M₂). Moreover, the results indicated that there was no significant difference in fuel consumption between the disk harrow and the ridger at the first and third speeds (S₁ and S₃) under the second moisture level (M₂).

It is clear that fuel consumption followed closely the trend of draft power, in such a way that it increased with increased speed and decreased with the increase in soil moisture content.

5.5. Draft Power and Fuel Consumption Comparisons for Secondary Tillage Implement (Disk Harrow):

5.5.1. Draft power:

Table (5.5) and Fig.(5.12) present the results for draft power for the secondary tillage implement (disk harrow) that used after primary tillage operations. The analysis of variance showed that there were significant differences (P< 0.05) between treatments.

At the first and second moisture levels (M₁ and M₂) the results indicated that the disk harrow after the chisel plow had the highest draft power, exceeded only by the disk harrow after the moldboard plow at the second speed (S₂) under the second moisture level (M₂). On the other hand the disk harrow after the disk harrow had the lowest draft at all speeds and under both moisture content levels.

Moreover the results indicated that there was no significant difference in draft power between the disk harrow after the disk plow and after the moldboard plow at all speeds also there were no significant difference between disk harrow after disk plow and disk harrow after chisel plow at first speed under the first moisture level (M₁), and
at the third speed ($S_3$) under the second moisture level for all primary tillage operations. Also, there was no significant difference in draft power between the disk harrow after the disk plow, after the moldboard plow and after the disk harrow at the second and third speeds ($S_2$ and $S_3$) under the first moisture level ($M_1$), and between the disk harrow after disk plow and after disk harrow at the first speed ($S_1$) under the second moisture level ($M_2$) for all primary tillage operation.

Generally, the draft power for secondary tillage using disk harrow was much higher after the chisel plow compared to the other primary tillage implements tested.

**5.5.2 Fuel consumption:**

Table (5.6) and Fig.(5.13) show the consumption (gal/fed) for the secondary tillage implement (disk harrow) used after primary tillage operations. The analysis of variance showed that there were significant differences ($P< 0.05$) between treatments.

The results indicated that the disk harrow after the chisel plow had the highest significant fuel consumption at all speeds and under both moisture levels except disk harrow after moldboard there were no significant differences between them at speed three under ($M_1$) and also at speed three under ($M_2$). On the other hand, no appreciable differences in fuel consumption were observed for the disk harrow after the disk plow, after the moldboard plow and after the disk harrow at all speeds and under both moisture levels.
Table (5.4): Comparisons of Fuel consumption for primary tillage implements.

<table>
<thead>
<tr>
<th>Implement</th>
<th>Fuel consumption (gal/fed)</th>
<th>Moisture level(M₁)</th>
<th>Moisture level(M₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>S1</td>
<td>S2</td>
</tr>
<tr>
<td>Disk Plow</td>
<td>1.12⁹⁴</td>
<td>1.12¹⁵₂</td>
<td>1.30¹³⁰</td>
</tr>
<tr>
<td>Moldboard Plow</td>
<td>1.14¹¹⁴</td>
<td>1.32¹³⁶</td>
<td>1.35¹³⁵</td>
</tr>
<tr>
<td>Chisel Plow</td>
<td>1.32¹³²</td>
<td>1.32¹³²</td>
<td>1.50¹¹⁵</td>
</tr>
<tr>
<td>Disk Harrow</td>
<td>0.56¹⁰⁶</td>
<td>0.57¹⁰⁷</td>
<td>0.76¹⁰⁷</td>
</tr>
<tr>
<td>Ridger</td>
<td>0.75¹³⁷</td>
<td>0.76¹³⁷</td>
<td>0.92¹³⁷</td>
</tr>
<tr>
<td>Cv%</td>
<td>0.03</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>SE</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Means followed by the same letter (s) within the same column are not significantly different at P = 0.05 according to Duncan’s Multiple Range Test.

S1 = speed (3.5 km/h)
S2 = speed (4.0 km/h)
S3 = speed (4.5 km/h)
gal/fed= gallon/fedan
Fig. (5.11): Comparisons of fuel consumption (gal/fed) for primary tillage implements at two levels of soil moisture and three speeds.
Table (5.5): Comparisons of draft power for secondary tillage implement after primary tillage.

<table>
<thead>
<tr>
<th>Implements</th>
<th>Horse power (HP)</th>
<th>Moisture level (M₁)</th>
<th>Moisture level (M₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>S1</td>
<td>S2</td>
</tr>
<tr>
<td>Disk harrow after Disk Plow</td>
<td>13.34&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>14.80&lt;sup&gt;b&lt;/sup&gt;</td>
<td>16.65&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Disk harrow after Moldboard Plow</td>
<td>12.65&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>14.40&lt;sup&gt;b&lt;/sup&gt;</td>
<td>16.40&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Disk harrow after Chisel Plow</td>
<td>13.47&lt;sup&gt;a&lt;/sup&gt;</td>
<td>15.54&lt;sup&gt;a&lt;/sup&gt;</td>
<td>17.65&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Disk Harrow after Disk Harrow</td>
<td>12.47&lt;sup&gt;c&lt;/sup&gt;</td>
<td>14.65&lt;sup&gt;b&lt;/sup&gt;</td>
<td>16.32&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Cv%</td>
<td>0.75</td>
<td>0.42</td>
<td>0.59</td>
</tr>
<tr>
<td>SE±</td>
<td>0.33</td>
<td>0.18</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Means followed by the same letter (s) with in the same column are not significantly different at \( P = 0.05 \) according to Duncan’s Multiple Range Test.

S1 = speed (3.5 km/h)
S2 = speed (4.0 km/h)
S3 = speed (4.5 km/h)
Fig.(5.12): Comparisons of draft power (HP) for secondary tillage implement (Disk Harrow) at two levels of soil moisture and three speeds.
Table (5.6): Comparisons of fuel consumption for secondary tillage implement after primary tillage:

<table>
<thead>
<tr>
<th>Implements</th>
<th>Fuel consumption (gal/fed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Moisture level (M₁)</td>
</tr>
<tr>
<td></td>
<td>S₁</td>
</tr>
<tr>
<td>Disk harrow after Disk Plow</td>
<td>0.56ᵇ</td>
</tr>
<tr>
<td>Disk harrow after Moldboard Plow</td>
<td>0.57ᵇ</td>
</tr>
<tr>
<td>Disk harrow after Chisel Plow</td>
<td>0.61ᵃ</td>
</tr>
<tr>
<td>Disk Harrow after Disk Harrow</td>
<td>0.55ᵇ</td>
</tr>
<tr>
<td>CV%</td>
<td>0.02</td>
</tr>
<tr>
<td>SE±</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Means followed by the same letter (s) within the same column are not significantly different at P = 0.05 according to Duncan’s Multiple Range Test.

- S₁ = speed (3.5 km/h)
- S₂ = speed (4.0 km/h)
- S₃ = speed (4.5 km/h)

gal\fed = gallon\fedan

---

66
Fig. (5.13): Comparisons of fuel consumption (gal/fed) for secondary tillage implement (Disk harrow) at two levels of soil moisture and three speeds.
CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions:

From the findings of this research study the following conclusions could be drawn:

(1) For primary tillage operations, the draft power and fuel consumption of each tested implement significantly increased with increased operating speed and decreased with increased soil moisture content level.

(2) For secondary tillage operations using a disk harrow over previously tilled soil, the draft power and fuel consumption significantly increased with increased operating speed and decreased with increased soil moisture content level, regardless of the primary tillage operation performed.

(3) The draft power required to operate the chisel plow was significantly higher than the other tested implements, regardless of the operating speed or the soil moisture content level, ranging between 20.24 and 31.07 HP; while the ridger requirements were significantly the lowest, ranging between 14.86 and 20.51 HP.

(4) The fuel consumed during the operation of the chisel plow was significantly higher than the other tested implements, regardless of the operating speed or the soil moisture content level, ranging from 1.32 to 1.69 gal/fed; while the disk harrow fuel requirements were significantly the lowest, ranging from 0.56 to 0.93 gal/fed.

(5) The draft power required to operate the disk harrow after the chisel plow, for the purpose of secondary tillage operation, was significantly higher than after the other tested implements regardless of the operating speed or the soil moisture content level, ranging between 13.47 and 18.10 HP; however, no clear significant differences were observed when using the disk harrow after all primary tillage operations at the third speed (S₃) under the second moisture level (M₂), ranging between 17.16 and 18.16 HP. Moreover, there were no significant differences in draft power for the disk harrow after the disk plow
the moldboard plow and the disk harrow at all speeds under the first moisture level ($M_1$).

(6) The fuel consumed during the operation of the disk harrow after the chisel plow, for secondary tillage, was significantly higher than after the other tested implements, regardless of the operating speed or the soil moisture content level, ranging from 0.61 to 0.73 gal/fed. However, there was no significant difference in fuel consumption for secondary tillage after the chisel plow and the moldboard plow at the third speed ($S_3$) under the first soil moisture level ($M_1$) (0.68 to 0.70 gal/fed) and at the second and the third speeds ($S_2$ and $S_3$) under the second soil moisture level ($M_2$) (0.70 to 0.73 gal/fed). Moreover, there were no significant differences in fuel consumption for secondary tillage after the disk plow and the disk harrow at all speeds and under all soil moisture levels (0.55 to 0.66 gal/fed).

6.2 Recommendations:

(1) Pre-watering of the soil should be applied two weeks, at least, before any primary tillage operation using disk or moldboard plows or heavy disk harrows.

(2) Pre-watering of the soil must be avoided when a chisel plow is used, since it is designed to work in very dry soils for best tillage results, due to its mode of action which involves breakage of the soil.

(3) For the type of soil under study, the working speed must not exceed 4.0 km/h for primary tillage operations, while for secondary tillage operations the highest speed of 4.5 km/h must be used. In order to increase the effective field capacity.

(4) Further studies are required to determine the optimum soil moisture content after pre-watering for primary tillage operations under different soil types with the use different tillage implements.
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