MATHEMATICAL MODELLING OF DRAUGHT CHARACTERISTICS OF SELECTED ANIMAL-DRAWN IMPLEMENTS ON THE UPLAND SOILS OF SAMARU, NIGERIA

BY

KAWUYO, UMARU ADAMU

(PhD/ENG/43426/2004-2005)

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, AHMADU BELLO UNIVERSITY, ZARIA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN AGRICULTURAL ENGINEERING

DEPARTMENT OF AGRICULTURAL ENGINEERING

FACULTY OF ENGINEERING,

AHMADU BELLO UNIVERSITY,

ZARIA.

JUNE, 2011

DECLARATION

I hereby declare that this thesis has been written by me and that it is a record of my own research work. It has not been presented in any previous application for a higher degree. The information derived from literature has been duly acknowledged in the text and a list of references provided.

Kawuyo, Umaru Adamu
Name of student

Date

CERTIFICATION

This thesis titled "**MATHEMATICAL MODELLING OF DRAUGHT CHARACTERISTICS OF SELECTED ANIMAL-DRAWN IMPLEMENTS ON THE UPLAND SOILS OF SAMARU, NIGERIA"** meets the regulations governing the award of the degree Doctor of Philosophy (Agricultural Engineering) of Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Chairman (Supervisory Committee) Professor M.L. Suleiman	(Date)
Member (Supervisory Committee) Professor D.D. Yusuf	(Date)
Member (Supervisory Committee) Dr. U.S. Mohammed	(Date)
Head of Department Professor D.D. Yusuf	(Date)
Dean, School of Postgraduate Studies Professor A.A. Joshua	(Date)

DEDICATION

This work is dedicated to my dear father, mother, beloved family and my late friend Mallam U.A. Maulud.

AKNOWLEDGEMENT

My deepest gratitude and Allah's blessings to Professors M.L. Suleiman and D.D. Yusuf and Dr. U.S. Mohammed for their thorough scrutiny, criticisms, understanding and encouragement which enabled me carry out this work from beginning to its full pattern. My sincere acknowledgement with thanks to Prof. O.J. Mudiare, Dr. A. El-Okene, Dr. H.E. Igbadun and late Prof. Y.D. Yiljep for their valuable suggestions and contributions. I am also grateful to all the staff of the Department of Agricultural Engineering (A.B.U. Zaria) for their moral support and encouragement. I happily acknowledge the sponsorship of my study to the management of University of Maiduguri.

My sincere appreciation goes to my beloved wife and children, my brothers and sisters for their endurance during the whole period of this study. Also the contributions of my colleagues and friends (many to mention here), who have made my stay in Zaria a happy one and assisted in non measurable way to the success of this research work is highly appreciated.

May Allah *(S.W.T)* bless us ALL, Amen.

ABSTRACT

A study on the mathematical development of draft model for two animal-drawn tillage implements was conducted on the upland soils of Samaru, Zaria for three years (2008 – 2010). The draft characteristics considered include soil moisture content, bulk density, speed of operation, tillage depth and mass of the implement. Two white Fulani bulls were used to pull Emcot ridger and mould board implements and a spring type dynamometer was used to measure the pull exerted by the animals on the implements. A 2 x 3 x 3 factorial experimental design was arranged in a Randomized Complete Block Design. The experimental design comprised of eighteen treatments replicated three times. Results show that draft increased with increase in tillage depth and all the other parameters considered in the study. The highest draft value of 432.1 N was obtained in treatment T_{18} [the combination of Mould board plough (I_2), speed of 1.25 m/s (S_3) and tillage depth of 16 – 20 cm (d_3)] and the lowest value of 243.4 N was obtained in treatment T_1 [the combination of Emcot ridger (I_1), speed of 0.69 m/s (S_1) and tillage depth of 5 – 10 cm (d_1)]. In terms of grain yield, treatments T_8 ($I_1S_3d_2$) and T_{15} ($I_2S_2d_3$) resulted in the highest grain yield (4.71 t/ha and 4.89 t/ha) for the Emcot ridger and mould board plough respectively. Analysis of variance showed that, the speed of operation and tillage depth significantly affected the draft of the implements considered in this study. Also, the interactions of implement x speed of operation x tillage depth significantly affected the draft. The combined analysis of variance showed that tillage depth significantly affected the maize grain yield. The interactions of implement x speed of operation x tillage depth x year also showed significant effect on the maize grain yield. Mathematical models for predicting the draft of the animal – drawn Emcot ridger and mould board plough with regards to the effects of speed of operation, tillage depth, implement mass, soil moisture content and soil bulk density were developed. The developed models predicted experimental data reasonably well with close agreement between the predicted values and the measured results ($r^2 = 0.967$ for Emcot ridger and 0.924 for the mould board plough). The slopes of the regression equation were 0.904 and 0.945 for the Emcot ridger and the mould board plough respectively. The paired t – test revealed that the calculated t – values 0.982 and 1.015 for the Emcot ridger and mould board plough respectively are less than the table value (2.898) at 0.01 significant levels. This showed that there is no significance different between the predicted and the measured values for the two implements considered in this study. This study showed that, the models can be used by animal – draught farmers in selecting the appropriate animal implement combination for any farm operations.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABBREVIATIONS

AMA	Agricultural Mechanization in Asia, Africa and Latin America
ANOVA	Analysis of Variance
ASABE	American Society of Agricultural and Biological Engineers
ASAE	American Society of Agricultural Engineers (Renamed ASABE)
ATNESA	Animal Traction Network for Eastern and Southern Africa
CTA	Technical Centre for Agricultural and Rural Co – Operation
CTVM	Centre for Tropical Veterinary Medicine
DAN	Draft Animal News
FAO	Food and Agricultural Organization of the United Nation
IAR	Institute for Agricultural Research, Zaria
ILCA	International livestock Centre for Africa
JAER	Journal of Agricultural Engineering Research
JAET	Journal of Agricultural Engineering and Technology
LAI	Leaf Area Index
NAMA	National Agricultural Mechanization Authority
WAATN	West African Animal Traction Network
WAP	Weeks After Planting

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND INFORMATION

Agriculture is the dominant economic activity in terms of employment and linkages with the rest of the economy. Roughly 75 % of Nigeria's land is arable, of which about 40 % is cultivated (NEEDS, 2004). Agriculture in most developing countries including Nigeria is predominantly at subsistence level dominated by smallholder farmers (Umar, 1994). Due to their land size, and increasing population about 38 million in 1963 to 135 million in 2007 (Encarta Yearbook, 1997) these farmers cannot meet their food and fibre requirements.

The first operation the farmer has to undertake in growing a crop is to use a soil-engaging implement to prepare the soil (Anonymous, 1992). Agricultural production and rural transportation require power. An agricultural power source is of great importance in determining the level of mechanization and agricultural development in any country. A study conducted by Sutton (1989) shows that farmers with access to their own farm power and machinery achieves better timeliness and intensity of farming operations such as tilling and planting on time. Nowadays in any agricultural crop production system, humans, draught animals and engine or motors provide the motive power in various proportions for crop production, harvesting, transportation and processing (Rijk, 1989; Pearson, 2005). The most appropriate machinery and power source for any farm operation depend on the work to be done and the relative desirability, affordability, availability and technical efficiency of the options. Farmers depend greatly on animal traction for energy supply to meet their agricultural production objectives. The use of animal traction is reported by Jaeger (1984) as an important step in creating more production opportunities and increasing returns through better land preparation and improved timeliness of field operations. According to FAO (2001), in sub-Saharan Africa, human power use accounts for 75 to 85 % of harvested area. Itodo (2007) reported that animal power is still widely used in sub-Saharan Africa for many agricultural activities. Usage of tractors by the peasant farmers is not economical because of the following reasons:

i. Lack of capital;
ii. Low level of capability of local industry;
iii. Lack of training and extension personnel;
iv. Small farm size;
v. Slow industrial development; and
vi. Crop varieties not amendable to tractorization.

Due to rising global fuel cost and the past failures of tractor mechanization projects in many developing countries, Bobobee (2007) reported that, there is renewed interest in research and extension activities on efficient use of animal traction especially, for ploughing and carting. The use of animal traction for agricultural practices is potentially useful and an appropriate means of improving the efficiency of traditional farming system in many developing countries (Phillip *et al.,* 1990).

For all agricultural operations, animal power has been the major source of energy, especially in Asian countries (Al-Janobi and Al-Suhaibaini, 1998). For many years, the general perception of farm mechanization in Nigeria has been synonymous to the use of tractors and perhaps other engine powered technology. Mechanization can take the form of harnessing animal power, an approach much better suited to the need of African smallholders. There is broad agreement that the availability and the use of powerful and appropriate mechanical equipment can make a substantial contribution to the task most developing countries are faced with, that is stabilization and increase of agricultural production, protection of natural resources and attempts to increase farm income (Krause and Poesse, 1997).

During the 20th century, the use of animals for work dwindled in the developed countries as the use of mechanical power based on machines increased (Kaushik, 1998). In the developing countries, however, livestock continue to contribute enormously to the energy requirements of agriculture into the 21st century. Wilson (2003) reported that more than half of the world's population depends on animal power as its main energy source. With the exception of Ethiopia, where animal traction has been in use for centuries, the major introductions of draught power into Africa occurred between 1906 and 1935 (Musa, 1989). Stroud (1993) reported that the introduction of the animal traction was primarily related to increased markets and prices for export crops, as well as rising demand for food crops by wage laborers employed in mining or on estates. Okai (1975) reported that animal traction was introduced in Uganda, by migrant African farmers in the early 1900s. During this decade, animal traction has been introduced in many countries of Africa, including Mali and other Sahelian countries (Jolly and Gadbois, 1996) and in South Africa (Starkey *et al.,*1995), late 1920s and early 1930s in Senegal, Guinea and Mali (Fall and Faye, 2010). Policy-makers have stated that animal traction will be the driving force for agricultural development in many countries (Henriksson and Lindholm, 2000).

Animal traction in Nigeria dates as far back as 1920's in Daura Katsina State, used in accomplishing variety of farm operations mainly on the upland soils and in particular for ridging and transportation of farm produce (Suleiman, 2000). The first animal-drawn implement introduced in Nigeria was a wooden plough (Gwani, 1990), but from 1934, these implements were replaced by the popular Ransome EMCOT ridgers (Chaundhury and Musa, 1984). Musa (1989) reported that the EMCOT ridger was developed, perfected and recommended for local manufacture by the Institute of Agricultural Research, Zaria in 1960. A number of researchers (Kaul, 1989; Musa, 1989; Starkey, 1992; Hassan, 1998) have reported on the introduction and adoption level of animal draught technology in Nigeria in particular, and Africa in general. They all agreed that it is an appropriate, affordable and sustainable technology.

There are approximately 400 million draught and pack animals in the world, some 250 million of which are cattle (Kaul, 1989). The majority of these animals are used in China (92 million) and India (72 - 110 million), Africa has only 15 million (ILCA, 1981; Starkey, 1985; Mrema and Mrema, 1993 and Gupta and Ahmed, 2003). Overall, approximately 10 % of African farmers use draught animals, but this can vary from 1 – 80 % between regions. According to Saror (1995) the 1990 National Livestock Survey showed that Nigeria possesses about 14 million cattle, 936,000 donkeys, 208,000 horses and 88,000 camels. The most common work animals used are cattle and they are generally worked in pairs with wither yokes, used for tilling and harrowing upland soils. In West Africa, the use of draught animals varies from country to country, depending on the climate, environment and the jobs undertaken in the areas.

There are regional differences in the use of draught animals, partly based on the crops cultivated in the area. So far, draught animals are mainly used for cultivation, seeding and transportation. For groundnuts, draught animal power is used for harvesting. It was reported in a study by Haque *et al.,* (2000) that only three operations were performed by draught animals in Adamawa State and these were ridging, weeding and transportation. They also found that apart from the mouldboard ridgers, no other animal-drawn implement was used for cultivation in the area. This, according to the report, is because there is no specific animal-drawn implement available in the study area. In more arid areas, Starkey (1992) reported that farmers increasingly use cultivation tines for tillage. Also, Mishra and Pandey (2000) reported that operations such as ploughing, carting, threshing, irrigation, and cane crushing are performed by animals. About 60 % of the population in Southern African Development Community (SADC) countries depends at least in part on farm animals to cover their transport, draught, nutrition, energy, housing and income needs (Anonymous, 2005). Bansal *et al.,* (1992) reported that common implements used with draught animals are single-bottom moldboard plough, wooden country plough (araire), peg tooth harrow and tine harrow.

Animal-drawn implements used by farmers consist of plough and harrow for land preparation, planters or seeders for planting and carts for transportation. These implements are generally found in places where the use of draught animals has a long tradition, such as India, China, African countries and Southeast Asian countries (Upadhyay, 1989). The size and shape of these implements vary from region to region depending on cultural practices, soil type, and animal species used, but Upadhyay (1989) reported that the basic functional structure of the implements are similar, and there are no much differences among the implements meant for similar operation. Where the draught animal is common, a pair of oxen harnessed with wither yoke is normally operated with two or three people. Factory-made steel equipment is the main implement used, pulled on a traction chain, and attached to the yoke. Although these implements have been evolved by centuries of practical experience and need, and have stood the test of working in particular agronomic zones, most of the traditional implements do not make optimal use of the animal energy and cause considerable strain to both the animal and person at work (Goe and McDowell, 1980).

A model in its most general sense is a proxy. A model is a scaled replica of a system and a simplified representation of a complex system (Yusuf, 2001). It is one entity used to represent some other entity for some well-defined purpose. Mathematical modeling is the art of developing mathematical equations that describe a process. A model enables researchers to organize their theoretical believes and empirical observations about a system and to deduce the logical implications of the organization (Fishman, 1973). A model can incorporate most of the important aspects of the system under consideration and be effective in deducing logical conclusions. Once these equations are developed, they must be solved and the solutions then analyzed to determine what information they give about the process (Gordon, 1978). Models are developed and used to hypothesize, define, explore, understand, simulate, predict, design or communicate some aspect of original entity, for which the model is a substitute. One of the purposes of modeling a physical system as reported by Ndirika (2003) is to be able to better understand the fundamental mechanisms of that system and to establish optimum conditions for the construction and operation of the system for improved efficiency. According to Gajda and Biles (1979) optimum conditions are those that produce the most favorable or most beneficial result from a system.

1.2 STATEMENT OF THE PROBLEM

It was reported by Wilson (2003) that more than half of the world's population depends on draught power as its main source of energy. As the cost of energy for producing a crop becomes more important, agricultural machinery manufacturers need data to assist them in developing more efficient tillage implements. The study of engineering aspects of the animal draught processes has, to a large extent, been neglected in favour of the more recent, but inherently simpler, mechanized system based on the agricultural tractor (Macmillan, 1985). Even though the use of animal power has been static so far, Sharma *et al.,* (1987) reported that it is difficult to replace it by mechanical power due to the small size of land holdings and substantial investment required for buying farm machinery (tractors and implements). Also, energy crisis is perpetual and so there is need to utilize the animal power more efficiently by introducing implements suitable for various operations.

It has been reported that the intensity of mechanization of farming operations in Nigeria is still very low (Jekayinfa, 2006) and that the volume of tractors and implements in Nigeria is not commensurate with the work done by the machines on Nigerian farms due to frequent breakdown and lack of spare parts (Mijinyawa and Kisaiku, 2006). These problems have been traced to lack of data for the appropriate design of agricultural machines and implements and unsuitability of some imported machinery (Manuwa and Ademosun, 2007).

In many areas of the developing countries including Nigeria, almost all agricultural operations, from land preparation to produce transportation are still done manually by the peasant farmers who dominate the agricultural sector (Umar, 1994). The farmers use tools such as hoe, cutlass and matchet for cultivating their farm lands. These consume a lot of human energy, thus making their use tedious and tiresome, which subsequently limits agricultural production. Draught animal power can be economically and environmentally sustained and hence can go a long way towards increasing the productivity of labour, improve timeliness of field operations to exploit the short cropping sessions, and relieve the farmer from the drudgery of performing field tasks (Suleiman, 2000).

Many studies (Stafford, 1979; ASAE Standard, 1990; Grisso *et al.,* 1996 and Oram, 1996) were carried out on draught requirements on agricultural implements. Most of the draught data presented were based on soils of the USA (Al-Janobi and Al-Suhaibaini, 1998). Presently there is a shortage of data on draught requirements of agricultural implements operating in the study area. Lack of these data hinders farmers from selecting the appropriate size of animals and implements for a particular farm situation; otherwise, they go just for the available implements which are like something out of tradition. So, this study will determine the draught requirements of two selected animal-drawn tillage implements used in the upland soils of Samaru in northern Nigeria. This will assist in eliminating implement – animal mismatch for farm operations.

1.3 JUSTIFICATION OF THE STUDY

Optimal design, selection and utilization of soil tillage implements rely on knowledge of implements' behavior in various soil and conditions of operation. According to Starkey (1992), the technology can be used to reduce drudgery and intensify agricultural production thereby raising the living standard throughout rural communities. Therefore, according to

Loukanov *et al.,* (2005), animal traction technology in terms of draught power requirements is a crucial area of research and development.

In Africa, broad adoption of animal-drawn implements has been hindered by inappropriately designed equipment, inadequate extension work and the absence of support services (Kline, 1970). Usman (2002) cited Girma and Pascal (1997) reported that the field work rate of a man is about 72 to125 h/ha, which can be reduced to 25 h/ha if a pair of oxen and a suitable implement were used, and even to 14 h/ha on light soils using animal-drawn mouldboard plough for tillage operations. Gebresenbet (1995) in a study on the optimization of animal drawn tillage implements, reported that, the effective utilization of draught animals could be enhanced if their corresponding implements are studied in various agricultural soils to minimize draught and energy requirements while maximizing soil and water conservation requirements for good tilt.

The best criterion for the suitable tillage implement is the power requirement, which determines the size of the power source (animals or tractor). The determination of power requirements of tillage implements for proper selection of power source and implement-power source matching requires that the soil forces acting on the implement, and implement operational parameters be known (Al-Janobi and Al-Suhaibani, 1998). Draught and energy requirement under varying conditions of operation have long been recognized as essential data in attempts to match tillage implements to available source of power. Therefore, it is imperative that the implement manufacturer must be aware of the importance of the power requirements of various tillage implements so that implements could be designed and manufactured in accordance with size of its power source. This study can therefore provide a design details to the implement designer and selection details to the farmer. Many studies, (Bloome *et al.,* 1983; Bashford *et al.,* 1991; Al-Janobi and Al-Suhaibini, 1998; and Ahaneku *et al.,* 2004), were conducted on different draught characteristics such as speed of operation and depth of cut in many parts of the world. There is little information on this subject for Nigerian conditions in general and the upland soils of Samaru in particular, which has led to this study. Mathematical modeling is potentially a useful technique for understanding and managing complex agricultural systems. To optimize tillage operations and select appropriate tillage implements for Samaru soils, the knowledge of draught characteristics is essential.

1.4 AIMS AND OBJECTIVES

The general objective of this study is to develop a mathematical model for the draught characteristics (soil moisture content, bulk density, speed of operation, depth of operation, and mass of the implements) of two selected animal-drawn implements (mouldboard plough and mouldboard ridger) in the upland soils of Samaru, Nigeria.

The specific objectives are:

i. to measure the effects of soil physical properties on draught of the commonly used animal-drawn tillage implements (mouldboard plough and mouldboard ridger) in the upland soils of Samaru, Nigeria.

ii. to predict draught characteristics of the animal-drawn implements using developed mathematical models.

iii. to verify and validate the models developed on the draught characteristics of the animal-drawn implements.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Draught animals are being used all over the world to reduce drudgery and to intensify agricultural production. Small-scale farming is the most widely practiced type of agricultural production in most Sub-Saharan countries and about 80 % of the farmers in developing countries use human or animal power in the production of their food and income needs (Gebresenbet *et al.,* 1997). Before the introduction of tractors in the era of oil boom, animal power has had a long history in Nigerian agriculture (Gbadamosi and Magaji, 2004).

Up to 84 million draught animals are used for crop production and transportation purposes in India (Cartman, 1994). With 60 % of farmers having less than 4 ha, tractor ownership is not economically viable, leaving draught animal power as the only alternative (Dave, 1999). Draught animal power can be an appropriate and sustainable technology to intensify agriculture for small farmers in Africa. Starkey (1986) reported that draught animals are being actively promoted and there are now 8-10 million working animals in sub-Saharan Africa.

2.2 TYPES OF ANIMALS FOR DRAUGHT OPERATIONS

With the present economic situation in the country (financial incapacitation of the average populace) prices of tractors and their implements have increased beyond the reach of many farmers such that attention has been forced towards animal power mechanization in Northern Nigeria in particular (Gwani, 1990). In Nigeria the use of animal power is mainly restricted to primary and secondary tillage using different types of implements such as ploughs, harrows and ridgers operated by oxen. Draught animals are rarely, even if, used for irrigation in Nigeria, although in other countries such as Niger, Egypt and the Sudan, they are frequently used (Turner, 1977). Cattle, horses, mules and donkeys are the most commonly used draught animals but camels, dogs, and elephants have been used for traction in some parts of the world (Asota, 1996; Itodo, 2007). Oxen (castrated bulls) remain the dominant draught animals in West Africa. When relatively small numbers of draught animals are used in an area and where heavy draught work is required, oxen seem to be the obvious choice, and only a few farmers seriously consider other options (Starkey, 1988b). In some areas such as Northern Nigeria, uncastrated males (bulls) are used for work (Otchere *et al.,* 1988). In Senegal, Reh and Horst (1982) reported that, N'Dama cows are used for draught purposes and they had higher reproductive characteristics than similar cows kept in traditional herds. Elsewhere in the world, female animals are often used where high proportion of all large animals are worked and where it takes significant human or feed resources to maintain an animal during the year (Mathers *et al.,* 1985). In Bangladesh, about 30 % of the draught animals are females (Mettrick and James, 1981). The most commonly used draught animal is the cattle, but oxen are preferred because of its temperament and muscle ability. They are also well adapted to Savannah and Savannah forest lands but not to the rainforest due to incidence of trypanosomiasis and excessive plant roots/stumps (Asota, 1996). The precise number of draught animals in use in sub-Saharan Africa is difficult to estimate. Jahnke (1982) estimated that there were over 19.4 million draught animals in use in Africa by 1979 (both equines and bovines), while Starkey (1988a) estimated it to 18.6 million by 1985 (Table 2.1) as reported by Mrema and Mrema (1993).

Table 2.1: Total number (by estimates) of draught animal in use in sub-Saharan Africa

Source/ year of estimate	Oxen	Equines	Total
Jahnke/ 1979	13,431,000	6,001,000	19,432,000
Starkey/ 1985	11,315,000	7,315,000	18,630,000

Source: Mrema and Mrema (1993).

Horses have a very limited geographical range in Africa because they are often expensive, as a result of their high prestige value, their unsuitability for transport and their relatively low reproductive efficiency and survival rate. They are thus seldom used for agriculture in West Africa, with the very notable exception of west central Senegal where they are widely used to pull cultivation tines, seeders and ground nut lifters (Mathers *et al.,* 1985). Donkeys have a slightly greater rate of usage than horses, and generally have better rates of reproduction and survival. They are well-suited for pack transport and for pulling carts in relatively flat areas. However, they do not have great tractive power, and so their use for pulling ploughs is very limited (Starkey, 1988b). Camels are used mainly as pack animals in the countries bordering the Sahara desert. Small numbers are also used for land cultivation in semi-arid areas in Mali, Burkina Faso, Niger and Nigeria. It appears that the use of camels for land preparation in West Africa is increasing, although absolute numbers in use are still low (Blench, 1987). It was reported by many researchers (Bansal and El-Garras, 1987; Betker and Kutzbach, 1989; Awadhwal *et al.,* 1992; and Suleiman, 2000) that different types of animals are employed for draught purposes. They are used extensively for tillage, sowing, inter-row weeding and transportation (Haque *et al.,* 2000).

There are regional differences in the use of draught animals, partly based on the crops cultivated in the area. So far, draught animals are mainly used for cultivation and seeding. For groundnuts, draught animal power is used for harvesting. It was reported in a study by Haque *et al.,* (2000) that only three operations were performed by draught animals in Adamawa State and these are ridging, weeding and transportation. Stroud (1993) gave estimates of the number and type of draught animals used in various African countries as shown in Table 2.2.

Table 2.2: Estimated numbers and types of draught animals used in various African countries

Country	Number	Type
Ethiopia	6,000,000	Donkey, Zebu, Horse
Senegal	500,000	Donkey, Horse, Zebu, Taurine
The Gambia	30,000	Donkey, N'dama
Guinea	100,000	N'dama
Mali (Southern)	200,000	Oxen
Cote d'Ivoire	30,000	Cattle
Ghana (Northern)	20,000	Taurine
Kenya	700,000	Cattle
Tanzania	300,000	Cattle
Botswana	360,000	Cattle, a few donkeys
Madagascar	330,000	Cattle
Niger (Southern)	35,000	Cattle
Sudan (Southern)	105,000	Cattle
Burkina Faso (Central)	140,000	Cattle
Benin (Northern)	25,000	Cattle
Mozambique	10,000	Cattle
Cameroon (Northern)	40,000	Cattle

Source: Starkey (1985) and Pingali *et al.,* (1987) In: Stroud (1993)

2.3 DRAUGHT ANIMALS IMPLEMENTS

Haque *et al.,* (2000) reported that apart from the ridgers, no other animal-drawn implement is used for crop production in Adamawa state of Nigeria. In more arid areas, Starkey (1992) reported that farmers increasingly use cultivation tines for tillage. Also, Starkey (1989) reported that in certain areas, notably Nigeria, the ridger is often the only animal traction implement being used for primary cultivation, weeding and earthen up. The animal-drawn mouldboard plough is widely used for primary tillage in the developing countries of Africa (Loukanov *et al.* 2005).

Animal-drawn harrows are mainly used to crush clods and to level a seed bed after ploughing. Because of their design, these implements are used as a ride-on with the weight of the operator increasing the effectiveness of work (Usman, 2002). ITP (1985) reported that the animal-drawn harrows are widely used in India, but they are rarely seen in Africa. Cultivating tines may be used for primary land preparation, secondary cultivation (harrowing) and weeding. They are widely used in West Africa, and most are based on multipurpose frames to which tines are clamped (Starkey, 1989).

With the notable exception of Senegal and Mali in West Africa, animal-drawn seeders have seldom had the same degree of success as ploughs and cultivators (Starkey, 1989). This is because seeding can often be done quickly and effectively by hand while mechanical sowing devices are usually expensive and often require ideal working conditions (Hopfen, 1969 and Silsoe, 1986). Animal-drawn harvesting implement are not common, but groundnut lifters have had some success (Starkey, 1989). Groundnut lifters are generally simple implements and relatively easy to use, also their effectiveness is largely determined by soil conditions and the extent to which plants impede progress (Mathews and Pullen, 1974).

2.4 DRAUGHT ANIMAL SELECTION AND TRAINING

Draught (pulling capacity) and power are the most important considerations in selecting animals for work (Watson, 1981). Horses, mules and oxen are the preferred draught animals because they can pull loads over long distances at reasonable speeds (Asota, 1996). A generally accepted rule is that, an animal can exert a constant pull on a load (over an extended period rather than concentrated) which equals approximately 10 – 12 % of its body weight (Carruthers and Marc, 1992), 20 % for Ethiopian oxen while tilling the soil (Girma and Pascal, 1997) and up to 20 % (Kebede and Pathak, 1987). The satisfaction and challenge of working a yoke of oxen begins with the selection of well-matched animals. Conroy and Rice (1992) reported that a well matched team of carefully selected animals are a joy to work and can be used for a wide diversity of tasks. They further said that the ultimate challenge and measure of success in selecting and teaming oxen is to create a team that works well together and moves as a unit for a reasonable period of years.

Bulls are generally the best choice because they will work longer hours per day and require less harness equipment. In general, the selection of animal (s) for any farm operation depends on many factors. These are adaptability to climate, local feeds and diseases, availability, cultural acceptability (Suleiman, 2000), strength, intelligence, sound and trainability (Asota, 1996). Animals suited for traction should be stocky, short legged and broad-chested, with strong feet (Stroud, 1993). Finally, selecting a good draught animal is a matter of partially evaluating both physical and behavioral attributes of the animal.

Time should be allowed at the beginning of any study for draught animals to be trained and become accustomed to the required work so that they can be used to any procedure, particularly if the procedures themselves might affect the observations. Training of draught animals should begin when they are 3 – 4 years old (Stroud, 1993). This is because, if trained too young, animals will not develop fully; if too old, they become more difficult to train. It is possible to train for ploughing and harrowing within a 3 – week period, depending on the animal's character and condition and the skill and patience of the trainer. More skilled operations such as weeding and cart pulling take longer to learn. The trainer should be the person who is responsible for the animals and who will continue to be associated with them (Stroud, 1993), avoid cruel treatment and be consistent, firm, calm and patient (Asota, 1996). Itodo (2007) reported that animals can only produce the desired output for draught when properly trained. He also reported that animals for draught purposes can be trained by employing the following procedures:

i. The animals are first made accustomed to wearing harness and pulling very light weights at a quick pace, side-by-side with a familiar well trained older animal.
ii. The loads are increased gradually to avoid slowing down of the pace.
iii. The trained animals must be kept in training to maintain their strength and skill.

2.5 HARNESSING AND HITCHING OF DRAUGHT ANIMALS

The pulling power of draught animals is transmitted to implements by means of harnesses. These can be in the form of collars, breast bands or yokes. Since the introduction of draught animal power technology in Nigeria in the 1920s, yoke harnessing of a pair of work bulls is the only existing technique used by farmers (Hassan, 1998). Various types of harnesses are in use throughout the world, although they vary greatly in design and details (Bobobee, 2007). The most common traditional yokes are shoulder yoke, forehead, neck and head yokes used for short-necked oxen. Simple improvement is to add padding to the traditional shoulder yoke. Other improved techniques are three pad collars, breast bands, saddle, and breach straps harnessing techniques for oxen, donkeys, horses and camels (FAO 1972; AERLS 1983 and FAO 1994). The most effective type of harness depends on the species and breed of the animals. Suitable and comfortable methods of harnessing should be identified and methods that are not effective or which are inhumane should be actively discouraged (James and Krecek, 1999). Bovines (cattle and buffaloes) which constitute more than 75 % of working animals are better suited for yoke harnesses because of their strong shoulders (Mathews, 1986). The double withers yoke is usually simple in shape and construction, and is easy to make by rural farmers. However, it has the tendency to cause shoulder sores and other discomfort to the animals if not shaped or padded properly (Barwell and Ayre, 1982).

Since draught animals are sentient beings, a good and comfortable harness will reduce pain, improve welfare and increase the overall productivity of draught animals (Ramaswamy, 1998). Many problems associated with any harnessing system are not attributable to defects in the basic design, but are due to poor finishing or incorrect positioning and adjustment (Starkey, 1989). Controlled experimental work at the University of Edinburgh demonstrated that while there was not a great difference between the technical efficiency of various designs of yokes and collars, animals were certainly more willing to work if the harnessing system was comfortable (Lawrence, 1983).

2.6 VILLAGE ARTISANS AND PRODUCTION OF DRAUGHT-ANIMAL IMPLEMENTS

In most west African countries including Nigeria (Northern Nigeria in particular), there are medium/large scale factories or workshops and local artisans capable of producing steel ploughs, cultivators and other animal-drawn implements (Abubakar, 2008). Starkey (1990) reported that this kind of factories and local/village blacksmiths are theoretically capable of providing more implements than the national demand. This 'overcapacity' is hardly seen because most of the workshops are heavily constrained by limited capital, unreliable infrastructure such as electricity, fuel, etc or lack of raw materials. According to Starkey (1990) some West African factories constrained in this way include: COBEMAG (Cooperative Bemnoise de Material Agricole) in Benin Republic, Rolako Center in Sierra Leone, SMECMA (Societe Malienne d'Etude et de Construction de Materel Agricole) in Mali and USOA (Usine des Outillages Agricole) in Guinea. To address some of the problems in local production of draught animal implements, Bako and Ingawa (1990) stated that, some government agricultural establishments in Northern Nigeria such as Kano State Agricultural Authority (KNARDA), the Sokoto State agricultural and Rural Development Authority (SARDA), the National Livestock Development Project (NLDP) and some commercial banks have been making soft loans available to villager artisans of animal-drawn implements (local blacksmiths) and small holding farmers for the production and purchase of the implements with work bulls.

Bai (1990) stated that in Sierra-Leone, by using scrap metal, home-made tools and local charcoal, blacksmiths contribute about 80 % of the final value of the production themselves. He went further to assess the products in terms of various skills such as cutting, bending, forging, measurements and costing. The North East Arid Zone Development Programme (NEAZDP) has a successful animal-drawn tillage implements artisans' skill training programme (Hassan, 1998). From his findings Hassan (1998) reported that all artisans (blacksmiths, carpenters, fabricators, and ox-handlers) need to be assessed once they are trained on certain basic skills so as to confirm their degree of perfection. In a seminar on integrating mechanization into strategies for sustainable agriculture, held at Ouagadougou, Burkina Faso in 1997, Starkey (1998) reported that, blacksmiths were generally trained as apprentices by their artisanal families. These blacksmiths produced and repaired animal-drawn implements and other items. It was also reported that the blacksmiths are faced with constraints that includes lack of credit and high cost of raw materials for producing the implements.

2.7 BODY WEIGHT AND PULLING CAPACITY OF DRAUGHT ANIMALS

Animal capacity can be determined by using the time an animal can pull a load and the distance it can cover with this load. The dominant factor in assessing draught animal work is force. If the force required for moving an implement is greater than the force that the animals can produce, then the task cannot be carried out, and if the force is unacceptably high, the work cannot be sustained (O'Neill *et al.,* 1989). Bobobee (2007) reported that many studies were carried out to establish the relationship between body weight and pulling capacity of draught animals. Horses, donkeys and camels are reported to pull about 10 % and 25 – 34 % of their body weights respectively (Goe, 1989). Singerland (1989) used donkeys between 100 – 140 kg and reported the maximum pulled force to be 480 N, with an average force measured for 8 h continuous work to be 450 N and 5 – 10 min/h rest periods. Load levels and live weight ratios are linked to animal productivity. Speed, work and power of an animal are related with some parameters as shown below:

$$S = \frac{l}{t}, \text{ m/s} \tag{2.1}$$

$$W = f \times l, \text{ Nm or J} \tag{2.2}$$

$$P = f \times S, \text{ Nm/s or W} \tag{2.3}$$

Where: S = speed, m/s

l = distance, m

t = time, s

W = work, Nm

f = force, N

P = power, Nm/s

Since animals can pull different loads at different speeds, their capacities cannot be compared. Therefore, the power parameter, which includes both aspects of traction, is extremely suitable to compare animals even when they are of different species.

For a live animal, FAO (1994) reported that its body weight can be determined empirically as:

$$Weight = G^2 \times l \times 92.46, kg \tag{2.4}$$

Where: G = the heart girth, m

L = body length from front shoulder to the base of the tail, m.

Draft is therefore determined from the following relationship as given by Kumar (2010):

$$D = P \times cos\theta \tag{2.5}$$

Where D = draft, N

P = pull, N and

θ = angle between the chain and horizontal.

The pull depends mainly on species and body weight but is also influenced by condition, temperament, and training (Anonymous, 1992). In general, the optimum pull for bovines (ox, cow and buffalo) is about 10 – 12 % and for equines as about 12 – 15 % of body weight (Carruthers and Marc, 1992). Kebede and Pathak (1987) also reported that Ethiopian oxen were used to pulling up to 20 % of their body weight for tillage, while Girma and Pascal (1997), as quoted by Usman (2002), showed that the pulling force for donkeys can be increased up to 25 to 34 % of their body weight. Kaul and Egbo (1985) reported that draught animals have the capacity to be overloaded for short periods of time and can provide good traction even in difficult conditions. They further reported that, animals can generally pull loads that are many times heavier than those they can carry, with donkeys pulling about 80 % of its weight for short period and 10 – 15 % of its weight for sustained periods. A variety of ‘acceptable’ limits has been proposed over the years. For oxen, these have been in the region of 10 – 20 % of the animal’s body weight, as suggested by Denvani (1981), Premi (1981) and Maurya (1982).

Application of force and generation of power are fundamental to efficient draught performance. It was reported by Dave and Mukherjee (2001) that in Bastor region of India, a bullock pair weighing 453 kg developed 0.26 kW when draught loads of 8 % of body weight were applied, 0.28 kW at 10 %, 0.30 kW at 12 %, 0.33 kW at 14 % and 0.34 kW at 16 %. In Columbia, Rotriguez *et al.,* (1999) reported that animals applied the equivalent of 18.5 % of their weight as draught force to produce 0.82 kW power and were expected to work in a 6-hour day.

2.8 DRAUGHT AND POWER REQUIREMENTS OF ANIMAL-DRAWN IMPLEMENTS

In any given situation, interacting parameters relating to the animal(s), the implement, the harnessing system, the environment and the human operators will affect the amount of work that can be achieved. Starkey (1989) reported that, it is the implement (its size, weight, width, depth, etc) and the environment (soil condition, obstruction, etc) factors that together determine the draught force of an animal-drawn implement. These can be effected by the operator (settings for depth and width of work) and working condition of the implement.

The power requirement of tillage implements is an important design consideration, particularly for animal-drawn implements where the power is limited (Loukanov *et al.,* 2005). The draught requirements of an animal-drawn mouldboard plough is affected by the following factors: the type of soil, soil moisture content, speed of operation, depth and width of the furrow slice, type of the implement used, as well as soil-metal friction characteristics of the soil engaging components (Loukanov *et al.,* 2005). The draught of a disc plough is very enormous when compared with other tillage implements. For a given soil type and speed of travel, Scheruddin *et al.,* (1988) observed that disc plough has higher total and specific draught than other tillage implements.

Comparison of power requirements of various farming operations shows that a pair of draught animals can provide enough pulling power for most of the tasks performed in small farming conditions (Bansal *et al.,* 1992). For the draught animal operations to be sustained for several hours, the draught loads can be between 5 – 25 % of their body weight (CEEMAT/FAO, 1972; Watson, 1981; Pathak, 1984; Goe 1987; Kebede and Pathak 1987; and Kemp 1987). The draught of an implement may increase with the speed at which it is pulled, although at normal animal walking speeds, this source of variation will be slight. The draught power of an animal depends on the species, sex, size, body weight, nutrition and health, environment, training of work and terrain conditions. Srivastava (1989) reported that using local yokes/harnesses and in suitable working conditions of 6 to 8 hours, at different seasons, different animals performed as shown in Table 2.3.

Table 2.3: Draught equivalent to percentage of body weight

Animal	Summer (%)	Winter (%)	Duration of Work (hours)
Bullocks	12	14	7
Male buffaloes	10	12	6
Camels	15	16	7
Donkeys	32	34	6

Source: Srivastava (1989)

Inns (2003) carried out a study on matching tillage implements to draught animal potential. In the study, he limited the factors affecting the draught of animal-drawn tillage implements to the vertical load (V) on the implement and the angle of pull (α) and reported the implement draught equation as:

$$D = V / \tan \alpha \qquad (2.6)$$

Where:

D = implement draught, N

V = effective vertical force, N

α = the angle of pull, degrees.

Equation 2.6 is therefore of decisive importance in guiding the design of an implement and harnessing system to ensure that the implement draught matches the draught capability of the animals. For a particular soil type and conditions, different animal-drawn implements have different operational draught requirements. Abubakar *et al.,* (2005) carried out a study on the draught requirements of some locally used oxen drawn implements in Zaria. They reported that different implements (one bottom mouldboard plough, mouldboard ridger, tine harrow, planter and ground nut lifter) showed variation on their average draught requirements when tested on a sandy loam soil under same conditions using same pair of oxen.

2.9 DRAUGHT CHARACTERISTICS OF ANIMAL – DRAWN IMPLEMENTS

Draught forces can be measured with various types of dynamometer which are commonly based on expanding springs, hydraulic piston or load cells. It has been reported by Lawrence and Pearson (1985) that combining modern load cells with computers enable draught measurements to be recorded in the field many times each second, and the mean values calculated over specific distances or periods of time. There are numerous external factors that influence the draught requirement of implements. These are specific to a particular environment and the precise conditions under which the equipment is used. They include: type and composition of the soil; soil moisture content; previous tillage history; quantity and type of living plants growing in the soil; quantity and type of crop residues and trash; presence of roots, stones or stumps and slope of the land. The draught of an implement may slightly increase with speed at which it is pulled. Starkey (1989) reported that the implement speed will itself depend on many factors relating to the type and condition of the animals. In practice, the draught that animals exert to draw an implement constantly changes due to numerous interacting variations attributable to the animals, the operator, the soil, weather condition and the orientation of the implement.

Draught is an important parameter for measuring and evaluating implement performance for energy requirements. The specific draught of agricultural tools and implements varies widely under different conditions, being affected by such factors as the soil type and condition, operating speed, implement type and shape, operating depth, width of operation, type of attachments, and adjustment of the tool and attachments. A great deal of work has been done in evaluating these various factors and investigating possible means for reducing draught (Manuwa and Ademosun, 2007). Soil type and condition are by far the most important factors contributing to variations in specific draught. It has been reported by Upadhyaya *et al.,* (1984) that draught requirements of tillage implement is a function of implement width, operating depth, and the speed at which it is pulled. Ahaneku *et al.,* (2004) conducted a study on the effect of soil moisture and ploughing speed on draught and power requirements of disc plough and reported that, the power requirements for disc ploughing increased with speed but decreased at higher moisture levels. They also reported a linear relationship for predicting draught of disc plough under varying soil moisture content and plough speed.

Implement width, operating depth and speed are factors that affect draught of a tillage implement (Al-Janobi and Al-Suhaibaini, 1998). Draught also depends on soil conditions and geometry of the tillage implements (Upadhyaya *et al.,* 1984). The effect of speed on implement draught depends on the soil type and the type of implement. It has been widely reported that the draught forces on implements increase significantly with speed and the relationship varies from linear to quadratic function (Grisso *et al.,* 1996). It was reported in a study on estimating tillage draft by Harrigan and Roosenberg (2002) that, tillage draft standards published by the American Society of Agricultural Engineers (ASAE) can be used to predict draft for common ox-drawn tillage tools when adjusted for speed and depth of operation. Draught and energy requirements for agricultural implements are essential data when attempting to correctly match an agricultural implement with the power source (Grisso *et al.,* 1996; and Al-Janobi and Al-Suhaibaini, 1998), as well as for measuring and evaluating performance of tillage implements (Bashford *et al.,* 1991). The assessment of draught capacity of draught animals will help in developing/matching implements and carts for utilizing power without over-stressing the animals, therefore prediction of implement draught requirement is very important.

A study on draught and energy requirements of agricultural implements was carried out on the semi-arid regions of Morocco by Bashford *et al.,* (1991). They reported a simple linear function relating draught to travel speed and implement depth as:

$$Y = a + bS + cD \qquad (2.7)$$

Where: Y = draught per unit width of implement (kNm^{-1}),

a = intercept,

b, c= regression coefficients,

S = speed (kmh^{-1}), and

D = implement depth (m).

Many researchers, (Lawrence and Pearson, 1985; O'Neill and Kemp, 1988 and Pearson *et al.,* 1989), have reported the variations of the actual draught values under the same experimental conditions using same animals and implements. Taniguchi *et al.,* (1999) reported that the draught increased with increases in travel speed but that the rate of change differed with speed levels. A tillage implement moving at a constant speed is subject to forces such as weight of the implement (Oram, 1996); soil forces acting upon the implement and those acting between the implement and the animals. The resultant of all these forces is the pull of the animal upon the implement. Baloch *et al.,* (1991) reported that depth of cut; width of cut, tool shape; tool arrangement and travel speed are factors that affect draught and energy utilization. Iqbal *et al.,* (1994) also reported that depth and width of cut, shape and arrangement of tool and field speed are important factors that affect the draught requirements in different soil conditions. The effects of these parameters vary with different types of implements under various soil conditions.

Many studies, (Upadhyaya *et al.,* 1984; ASAE Standards, 1994; Harrigan and Rotz, 1994 and Grisso *et al.,* 1996), have been conducted to measure the draught and power requirements of tillage implements under various soil conditions. Upadhyaya *et al.,* (1984) published the following equation for draught requirements of a subsoiler:

$$D = B_o(CI \times W)d + B_1(\rho_w)d \times W \times S^2 \qquad (2.8)$$

Where: D = draught (F)

CI = Core index (FL^{-2})

W = Width of subsoiler cutting edge (L)

d = Depth of operation (L)

ρ_w = wet bulk density (ML^{-3})

S = Travel speed (LT^{-1})

B_0, B_1= Constants.

Grisso *et al.,* (1996) reported that the drawbar energy required to till a given area was dependent on tillage depth and implement travel speed. They finally suggested the following model for chisel plough and sweep plough draught requirements on silty loam and silty clay soils:

$$UD = \left(\frac{d}{r_d}\right)^n (a + bS) \qquad (2.9)$$

Where: UD = Specific draught (FL^{-1}),

r_d = reference depth of 8.26 cm (L),

S = travel speed (LT^{-1}),

d = depth of operation (L),

a, b = regression coefficients,

n = 1 for sweep plough and 2, for chisel plough.

The effect of travel speed on implement draught depends on the soil type and the type of implement. Randolph and Reed (1983) and Collins *et al.,* (1978) relate draught of a mouldboard plough to travel speed by a parabolic relationship for a travel speed in the range of 1.6 to 9.7 km/h. For chisel ploughs, Bloome *et al.,* (1983) concluded that the response of implement draught to speed is linear for a speed range of 4 to 10 km/h.

Depth of operation has an obvious effect on implement draught, although its relationship has only recently been investigated (Bashford *et al.,* 1991). Collins *et al.,* (1978) reported depth to be a linear function of draught for mouldboard and chisel ploughs. Garner and Wolf (1981) investigated different zone layers of soil for a sub-soiler. They showed that a linear relationship existed between draught and depth within each soil zone. Baloch *et al.,* (1991) also carried out field experiment and concluded that draught requirements of an implement increased with depth of penetration of the implement into the soil.

2.10 MATHEMATICAL MODELING

Models can broadly be classified in to two: Physical and Conceptual types. Physical models are the physical representation of the system; examples include prototype, pictures, etc while conceptual models are the representation of the idea or principles in operation of the system. Igbadun (2008) reported that a conceptual model can either be in empirical or mechanistic forms. An empirical model is a mathematical expression that shows input-output relationship of the system, and the mechanistic model is a set of mathematical expressions that explain causes and effects in the system, it can also be a set of general laws or theoretical principles governing the operation of the units or the entire process in the system. A conceptual model describing changes in soil physical status created by tillage is presented by Canarache (1991) as shown in Figure 2.1.

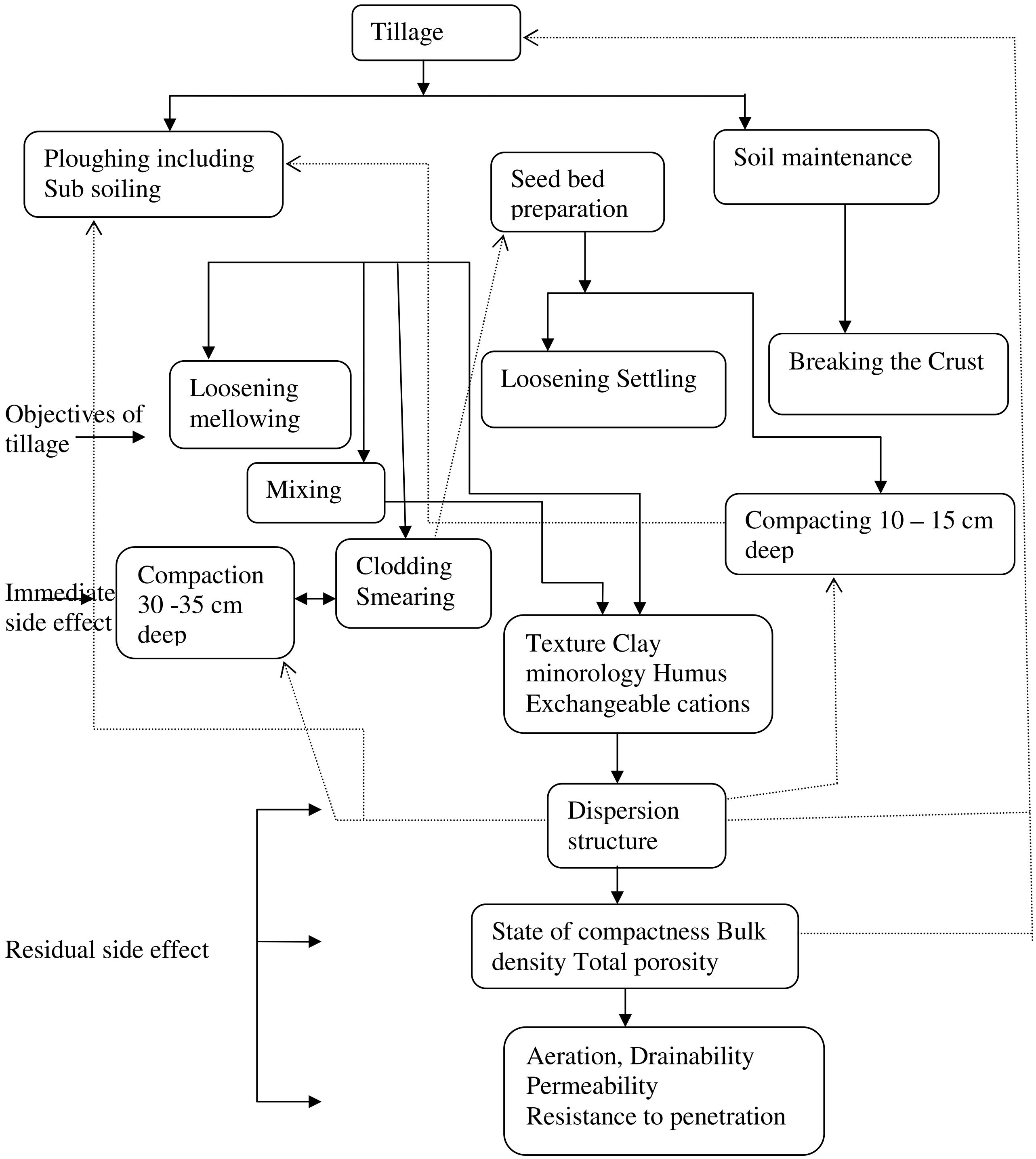

Figure 2.1: Conceptual model describing changes in soil physical status created by tillage
Source: Canarache (1991).

According to Duhovnik *et al.,* (2004) the selection of mathematical model is an important step in developing the procedure for the calculations of a numerical simulation as the correctness of simulation results considerably depends on it. Models are classified in various ways. Some of the terms used in literatures include empirical, stochastic, synthetic, deterministic, analog and process based. However, model used in any discipline can be categorized in to two: formal and material (Anderson and Woessner, 1992). Where different models are available for use in a study, Hesse and Keuper, (2001) gave four criteria that can be used to choose between alternative models. These are: accuracy of prediction, simplicity of the model, consistency of parameter estimates and sensitivity of results to change in parameter.

2.11 DRAUGHT PREDICTION MODELS

Models for draft requirement are in most cases developed from foundation engineering, and generally include cohesion as the main parameter to define soil strength (Arvidsson and Keller, 2011). Force prediction models have been developed directly or indirectly from theories of soil failure (Stafford, 1984). Zelenin (1950) developed empirical relations between the force of a cutting tool and physical conditions of the soil as measured by a penetrometer. He found that the draught and depth were parabolically related as:

$$P = kh^n \tag{2.10}$$

Where:

P = draught of a horizontal blade, N;

k = coefficient of soil resistance;

h = depth of operation, m;

n = constant.

From the wide range of soil types and soil moisture contents, Zelenin (1950) found that the value of n was approximately 1.35 and is constant. He further investigated the effect of the length of the cutting blade (L), angle of inclination of the blade (α) and the coefficient (β) whose value depends on the angle of sharpness of the cutting tool and the thickness of the sides of tool (S). He derived the equation of the form:

$$P = Ch^{1.35}(1 + 2.6L)(1 + 0.0075\alpha)(1 + 0.03S)\beta \qquad (2.11)$$

Where:

C = number of blows to penetrate a depth of 10 cm.

The general earth moving equation for describing the forces necessary to cut soil with a tool was proposed by Reece (1965) and has been widely used by most researchers engaged in predicting soil cutting force. The equation is given as:

$$P = (\gamma d^2 N_\gamma + cdNc + cadN_{Ca} + qdN_q)W \qquad (2.12)$$

Where:

P = total soil cutting force acting on blade (kN);

γ = soil bulk density (kNm^{-3});

d = tool working depth (m);

N_γ = gravity coefficient (dimensionless);

c = soil internal cohesion (kPa);

N = cohesion coefficient (dimensionless);

ca = soil-metal coefficient (kPa);

N_{Ca} = adhesion coefficient (dimensionless);

q = surcharge pressure at the soil surface (kPa);
N_q = surcharge pressure coefficient (dimensionless);
W = tool width (m).

According to Zhang and Kushwaha (1995) the success of equation 2.12 to predict the soil resistance not only depends on the accuracy of dimensionless N-factors but also on how these factors is obtained. They further reported that considerable work has been done to determine all these dimensionless numbers to predict the soil resistance.

Wang and Liang (1970) indicated that the draught of tillage tool in any chosen soil and operating at any chosen velocity can be obtained by single testing of a geometrically similar tool. They showed that for geometrically similar agricultural implements, the following dimensionless equations can be used to relate soil and implement variables as:

$$\frac{R}{\rho L^3} = F\left(\frac{V^2}{gL}, \frac{C}{gL}, \mu, \phi\right) \tag{2.13}$$

Where:

g = gravitational constant;

μ = apparent soil-metal friction angle;

C = apparent coefficient, FL^{-2};

V = velocity of tool, LT^{-1};

L = characteristic length, L;

R = draught force, F;

ρ = bulk density of soil, FL^{-3};

ϕ = soil-soil friction angle.

The above method has two important advantages over the existing techniques in soil dynamic work. These are:

i. the velocity of the prototype and model need not to be limited to “low values”, so forces due to velocity effects can be accounted for;

ii. soil properties except for initial friction angle, need not be closely maintained in soil-dynamic work.

Implement geometry can be described adequately with a set of characteristic lengths and angles. Therefore, a general function can be written for implement draught, D as reported by James *et al.,* (1996) below:

$$D = f\left(d, s, w, \tau_0, \tau_1, \mu, \rho, Gj, \alpha k\right) \quad (2.14)$$

Where: D = implement draught, F;

d = implement depth of operation, L;

s = forward speed, LT^{-1};

w = implement width, L;

τ_0 = static component of soil shear stress, FL^{-2};

τ_1 = dynamic component of soil shear stress, FTL^{-3};

ρ = soil mass density, FT^2L^{-3};

μ = soil-metal friction coefficient, dimensionless;

Gj = set of characteristics lengths describing implement geometry, L;

αk = set of characteristics angles describing implement geometry, radians.

A general expression for the draught of any implement can be written as (James *et al.,* 1996):

$$\frac{D}{\tau_0 w^2} = f^{'}\left(\frac{d}{w}, \frac{\tau_1 s}{\tau_0}, \frac{\rho s^2}{\tau_0}, \frac{Gj}{w}, \alpha K, \mu\right) \tag{2.15}$$

For a specific implement, the geometric lengths and angles are absorbed into the function of equation 2.15, and can be written for given implement (ith implement) as:

$$\frac{D_i}{\tau_0 {w_i}^2} = h_i^{'}\left(\frac{d}{w_i}, \frac{\tau_1 s}{\tau_0}, \frac{\rho s^2}{\tau_0}, \mu\right) \tag{2.16}$$

Where the function h_i reflects the geometric characteristics of the ith implement. Subscript i stand for the ith implement. In equation 2.15, the terms (d/w), ($\tau_1 S/\tau_0$), ($\rho s^2/\tau_0$), and μ represent depth, strain rate, inertial and surface function effects respectively.

CHAPTER 3

THEORETICAL DEVELOPMENT: MODELING FACTORS AFFECTING DRAUGHT

3.1 MODEL AND TYPES OF MODELS

Model is a structure which has been built purposely to exhibit features and characteristics of some other object such as a DNA model in biology and a building model in civil engineering (Anonymous, 2011). It is also defined as a scaled replica of a system and a simplified representation of a complex system (Yusuf, 2001). Also, Igbadun (2008) defined model as a simplified representation of a real world which is defined as a system. Models are based on theory, in research models help to test theory by making predictions that can be compared with observations.

Model can be classified as static (cross-section) or dynamic (time series), deterministic or stochastic, discrete or continuous, iconic or analog or symbolic. Models can further be:

i. Mathematical, which is the set of equations that represent interconnections in a system, and can be worked out either by hand or a computer (Muthuri, 2004). The equations are written in terms of mathematical objects that correspond directly to physical quantities. A typical model will consist of formulae that link some responses or quantities of interest with inputs, or things that affect them, or

ii. Conceptual, which is the representation of the idea or principles in operation of the system. It is a set of mathematical expression that explain causes and effects in the system; a set of general laws or theoretical principles governing the operation of the units or the entire process in the system.

A model enables researchers to organize their theoretical beliefs and empirical observations about a system and to deduce the logical implications of the organization (Fishman, 1973). It can also be used in predicting or as forecasting tools that, according to Muthuri (2004), help users make sensible educated guesses about future behavior. These can be used in planning and impact analysis. Models are build to improve understanding and communication, experimentation and standardization for analysis (Anonymous, 2011).

3.2 MODELING PROCESS

In order to formulate effective models, the following phases were considered:

i. Constructing mathematical functions of decision variables;
ii. Model calibration;
iii. Model verification; and
iv. Model validation.

3.3 MODEL FORMULATION

Variables and equations are used to construct mathematical models. The common features of a mathematical model according to Anonymous (2011) include:

i. Abstraction, are details overlooked?
ii. Computability, can the model be manipulated with ease?
iii. Inputs, data requirements and
iv. Uncertainty, are inputs and relationships between them uncertain?

In this study, modeling of the effects of several pertinent factors (such as soil moisture content, soil bulk density, speed of operation, depth of soil tillage, and implement mass) that affect implement draught was carried out. Draught, being a function of various factors, is being affected by soil type and condition, implement type and shape, and animals which pull the implements. In addition to these, depth of operation, operating speed, power requirement, weight of the implement, soil moisture content and density of the soil affect the modeling of the draught of animal-drawn implements.

3.4 ASSUMPTIONS

Assumptions were made in order to reduce the number of parameters involved in draught determination to a manageable level, thereby reducing the complexity. The following assumptions are therefore made for this study:

i. Soil in the test plots is assumed to be of homogenous type.
ii. The tillage treatments considered are economical of optimum draught characteristics with minimum labour requirements.
iii. The animals used in this study are experienced in carrying out field operations.
iv. The operators are also well experienced in using draught animals.

3.5 DECISION VARIABLES

Decision variables capture the level of activities that the model studies. Mathematical model of the implement draught can be represented as a function of dependent variable. The ‘effect’ (draught) could be hypothesized as a function of the ‘cause’ (draught characteristics) such as mass of the implement, depth of operation, speed of operation, soil bulk density and moisture content. Abstracting from error terms, the ‘cause-effect’ function could be expressed as:

$$f(D, M, \rho, d, S, I_m) = 0 \quad (3.1)$$

Where:

D = draught, N;

I_m = implement mass, kg;

S = speed of operation, m/s;

d = depth of operation, m;

M = soil moisture content, %;

ρ = soil bulk density, kg/m^{-3}; and

f = functional relationship between the variables.

Zelenin (1950) developed an empirical relation between the force of a cutting tool and physical conditions of the soil. He reported that the draught and depth of operation are related in a parabolic function as:

$$P = kh^n \quad (3.2)$$

Where:

P = draught of a horizontal blade, N;

k = coefficient of soil resistance;

h = depth of operation, m; and

n = constant.

For a model to improve system understanding there is the need for detail, relevant and simple model which incorporates significant variables that can easily be determined for the system being investigated. This important facet of modeling is lacking in equation 3.2

above as very few variables were considered. Considering some pertinent factors affecting draught, the model could further be developed with the following features that have not been considered by Zelenin (1950):

i. Mass of the implement weight, kg
ii. Speed of operation, m/s
iii. Soil dry bulk density, ρ
iv. Soil moisture content, %.

The draught model of Zelenin (1950) was used as the base model in this study. Considering equations 3.1 and 3.2 with additional variables, the relationship between draught and pertinent factors affecting the draught can be represented as follows:

$$D = f(M, \rho, d, S, I_m) \tag{3.3}$$

All terms are as defined in equation 3.1.

3.6 CONCEPT OF BUCKINGHAM PI THEOREM

Mathematical models, using dimensional analysis, were used to characterize the draught consideration. Simonyan *et al.,* (2006) quoted Dergirmencioglu and Srivastava (1996) who described dimensional analysis as a useful tool for developing prediction equations of various systems. Dimensional analysis could therefore be used as an analytical tool from a consideration of the dimensions in which each of the pertinent variables involved in the system is expressed.

According to Giles (1975) the following steps can be followed in using the Buckingham Pi theorem to derive a relationship between various physical quantities:

i. List the n physical quantities q entering in to a particular problem, noting their dimensions and the number k of fundamental dimensions. There will be (n-k) π-terms.

ii. Select k of these quantities, none dimensionless and no two having the same dimension. All fundamental dimensions must be included collectively in the quantities chosen.

iii. The first π-term can be expressed as the product of the chosen quantity to an unknown exponent, and one other quantity to a known power (usually taken as one).

iv. Retain the quantities chosen in (2) as repeating variables and choose one of the remaining variables to establish the next π-term. Repeat this step for the successive π-terms.

v. For each π-term, solve for the unknown exponents by dimensional analysis.

The general relationship between the dependent and the independent variables may be as expressed in equation 3.3 and represented below:

$$D = F(M, \rho, d, S, I_m)$$

From the equation above, D is the dependent variable where as I_m, M, ρ, d and S are the independent variables considered in this study.

$$D = F(M, \rho, d, S, I_m) \text{ or}$$

$$F(D, M, \rho, d, S, I_m) = 0 \qquad (3.4)$$

Here, there are six variables and three basic dimensions; mass (M), length (L) and time (T). The Buckingham Pi Theorem can be used to express the equation 3.4. The Theorem states that the number of dimensionless and independent quantities required to express a relationship among the variables in any phenomenon is equal to the number of quantities involved, minus the number of dimensions in which those quantities may be measured (Buckingham, 1914 and Glenn, 1950). In equation form, the Pi Theorem is expressed as:

$$N_p = n - b \tag{3.5}$$

Where:

N_p = number of Pi terms;

n = total number of quantities involved;

b = number of basic dimensions involved.

The variables and their corresponding dimensions used in model development are given in Table 3.1.

Table 3.1: Variables and their corresponding dimensions

Variables	Symbol	Unit	Dimensional symbol (M,L,T)
Draught	D	N	MLT^{-2}
Soil moisture content	M	%	$M^0L^0T^0$
Soil bulk density	ρ	Kg/m^3	ML^{-3}
Depth of operation	d	m	L
Operating speed	S	m/s	LT^{-1}
Mass of the implement	I_m	Kg	M

In this case, six variables and three basic dimensions have been identified. The Pi terms can be determined by considering the corresponding dimensional expression of equation 3.5:

$$N_p = n - b = 6 – 3 = 3.$$

M is dimensionless, hence it will be excluded from the dimensional exercise, should be added as a pi-term when other dimensionless terms are formed (Simonyan *et al.,* 2006).

We consider S, ρ and d as repeating quantities.

For π_1:

$$\pi_1 = f(S, \rho, d, D) = f\,[S]^a\,[d]^b\,[\rho]^c\,[D] \qquad (3.6)$$

Equating the dimensions and solving for the exponents:

$M^0L^0T^0 = [LT^{-1}]^a\ [L]^b\ [ML^{-3}]^c\ [MLT^{-2}]$

$$M: 0 = c + 1 \qquad (3.7)$$

$$L: 0 = a + b – 3c + 1 \qquad (3.8)$$

$$T: 0 = - a – 2 \qquad (3.9)$$

From equation 3.7, c = - 1

From equation 3.9, a = - 2

Therefore, from equation 3.8, 0 = a + b - 3c +1 = (-2) + b – 3(-1) + 1 = b + 2

So, b = -2.

Substituting the exponents in equation 3.6:

$$\pi_1 = k_1\,[S^{-2}\rho^{-1}d^{-2}D] = k_1\,\frac{D}{S^2\rho d^2} = \frac{MLT^{-2}}{[LT^{-1}]^2[L]^2[ML^{-3}]} \text{ which is dimensionless.}$$

For π_2:

$$\pi_2 = f(S, \rho, d, I_m) = f\,[S]^a\,[\rho]^b\,[d]^c\,[I_m] \qquad (3.10)$$

Equating the dimensions and solving for the exponents:

$M^0L^0T^0 = [LT^{-1}]^a\ [ML^{-3}]^b\ [L]^c\ [M]$

M: $0 = b + 1$ (3.11)

L: $0 = a - 3b + c$ (3.12)

T: $0 = -1a$ (3.13)

From equation 3.11, b = - 1

From equation 3.13, a = 0

Therefore, from equation 3.12, $0 = a - 3b + c = (0) - 3(-1) + c = c + 3$

So, c = -3.

Substituting the exponents in equation 3.10:

$\pi_2 = k_2\ [S^0\rho^{-1}d^{-3}\ I_m] = k_2 \frac{I_m}{\rho d^3} = \frac{M}{[ML^{-3}][L]^3}$ which also a dimensionless.

For π_3: M is a dimensionless parameter, so $\pi_3 = k_3M = M^0L^0T^0$ another dimensionless term.

The general solution can therefore be written from the dimensional analysis which gives three dimensionless groups characterizing this phenomenon as:

$$\phi = \left(\frac{D}{S^2 d^2 \rho}, \frac{I_m}{\rho d^3}, M \right) \tag{3.14}$$

and $$\frac{D}{S^2 d^2 \rho} = F\left(\frac{I_m}{\rho d^3}, M \right) \tag{3.15}$$

Hence the three Pi terms required and the equation can be written as:

$$\pi_1 = F\ (\pi_2, \pi_3) \tag{3.16}$$

These Pi terms specify the requirements for similarity and therefore included ratios defining geometric and dynamic similarities for the variables which are relevant to this problem. From the field results obtained, and a plot of π_1 against π_2, the relationship:

$$(\pi_1)_{\bar{3}} = f_1(\pi_2, \bar{\pi}_3) \qquad (3.17)$$

in which the bar denotes constant values that could be established. From the results too, a plot of π_1 against π_3 could be obtained as:

$$(\pi_1)_{\bar{2}} = f_2(\bar{\pi}_2, \pi_3) \qquad (3.18)$$

3.7 METHOD OF SOLUTION

Graphs of π_1 against π_2 and π_1 against π_3 from the data collected in the first two years (2008 and 2009) field work provided the data for deriving the model following the procedure of dimensional analysis. The third year (2010) data was used to verify the model. The model was verified by comparing the predicted and observed results to find out their level of agreement.

CHAPTER 4

MATERIALS AND METHODS

4.1 INTRODUCTION

This chapter describes the instruments (materials) used and procedures followed in the conduct of the research work. It first describes in details the type and characteristics of tools and equipment used. These are followed by a precise description of the test procedures and methods of data collection adopted, sampling techniques and the treatments conducted.

In order to carry out this study, field experiments and laboratory works were conducted for three years between June and October (2008 to 2010) cropping season. Laboratory experiments to determine the soil physical properties were conducted in the processing laboratory of Agricultural Engineering Department, ABU Zaria and soil science laboratory of Soil Science Department, University of Maiduguri. Soil samples of the top soil (0 – 15 and 15 – 30 cm) were sampled from the experimental field by the use of auger, core samplers, cutting blade and nylon bags for the laboratory tests where the soil properties were determined. The soil samples randomly collected were subjected for the laboratory determination of percentage organic matter, particle size analysis, bulk density and soil moisture content.

Field experiments were conducted using the following materials: two white Fulani bulls, this is because of their ease of control and response to verbal command. The implements considered in this study were animal-drawn mould board plough and Emcot ridger. This is because they are the most commonly used in the study area and in Northern Nigeria as a whole. Also same harnessing system was used throughout the study. Other equipments used include: spring type dynamometer, stop watches, measuring tape, and electronic weighing balance of 0.001g sensitivity. Common methods of data collection and analysis were applied to all the experimental treatments and maize crop (Sammaz – 12) variety which is commonly used by farmers in the study area was used as the test crop.

4.2 EXPERIMENTAL SITE

The field study was conducted on sandy loam soil at Samaru (11^{o} 11´ N, 07^{o} 38´E and 685 m above sea level), Zaria. Samaru is in the Northern Guinea savanna zone of Nigeria with an average rainfall of the area is 1,100 mm and is spread between May and October (Yusuf, 2003). The soil is classified as an alfisol (Moberg and Esau, 1989). It is formed from drift materials and cropped mainly with maize, sorghum, millet, cotton and groundnut. The surface is always hard and compact, on account of the high proportion of find sand, and therefore is particularly prone to sheet erosion because of their compactness (Klinkenberg and Higgins, 1968).

4.3 DRAUGHT ANIMALS

A pair of white Fulani bulls of the Mechanization Unit of IAR, ABU Zaria, was used for the application of the tillage treatment. They are favored for this work because of their strength and healthy condition. The bulls are between 270 – 285 kg live weights. They are also judged positively for draft and harsh climatic endurance. These particular bulls have been observed to be having good dietary and medical attention. They are also well built with correct legs, necks, backs, chest and shoulders. They are also even-tempered, alert and responsive to verbal commands. They were between the ages of five and six years with two years tillage working experience. The body measurements and draught capacity of the bulls are presented in Table 4.1. The equation given by FAO (1994) was used to determine the animal's body weight:

$$W = 92.49 \times G^2 L \tag{4.1}$$

Where: W = animal's body weight, N

G = body girth width, m

L = body length from shoulder to base of tail, m.

Table 4.1: Anthropometric Measurements of the bulls used for the field experiments

Bull	Age (years)	Body dimensions (m)					Estimated body weight (N)	Estimated tractive effort (N)
		L	G	H	H_f	H_r		
A	6	1.28[a] (2.74 %)[b]	1.49 (1.69%)	1.55 (2.33 %)	0.45 (2.22 %)	0.52 (1.92 %)	2,577.54	309.30
B	5.5	1.20 (1.73 %)	1.57 (1.61 %)	1.50 (1.33 %)	0.41 (2.44 %)	0.49 (2.04 %)	2,678.93	321.46
Pair							5,256.47	630.78

Where: a = mean value of five measurements;

b = coefficient of variation

L = body length from shoulder to base of tail, m;

G = heart girth, m

H = overall height from ground level to the back of the bull, m

H_f = height of front knee from ground level, m; and

H_r = height of rear knee from ground level, m

Estimated tractive effort is taken as 12 % of the body weight.

4.4 ANIMAL – DRAWN EMCOT RIDGER

A 50 cm, 1 – bottom Emcot ridger manufactured by John Holt Engineering Company, Zaria, was used as one of the implements for application of the tillage treatment. This ridger consists basically of depth control wheel, mouldboard and handle, all made of steel. Breasts with tailpieces fitted to the mouldboard for furrow width adjustment (Figure 4.1). During operation, slice of soil is cut, half ridge on each side of the mouldboard; one of the half ridges is completed and another half made when the ridger returns, surface trash buried and a furrow is formed.

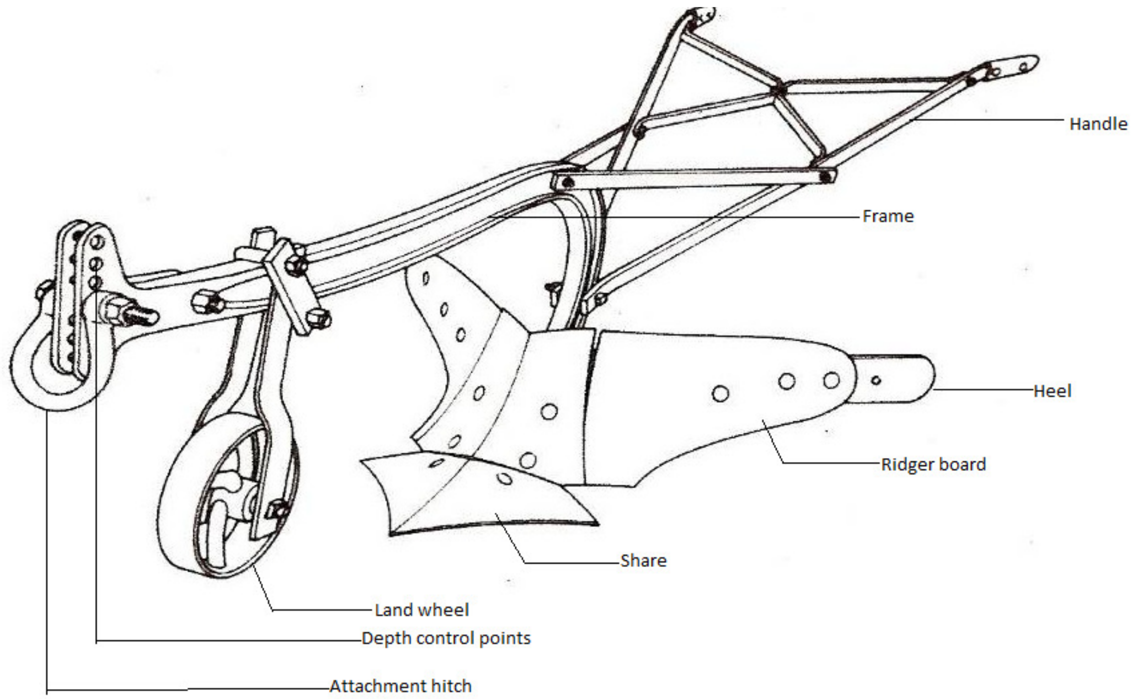

Figure 4.1: Animal – drawn Emcot ridger

4.5 ANIMAL – DRAWN EMCOT PLOUGH

A 25 cm, 1– bottom mouldboard plough, also, of Holt Engineering Company, Zaria, was used in applying the tillage treatments (Figure 4.2). It consists of mouldboard, share, coulter, land wheel and handle. The mouldboard is attached to the frog by bolts and nuts and supported at the rear by brace. The share, triangular in shape, cuts the slice of soil horizontally. The coulter is a steel cutting blade with a triangular section and cuts the soil vertically along the furrow wall. The handle enables the operator to control the plough during operation. This implement operates by continually turning the soil over in to each previous furrow, covering both weeds and surface trash in one operation.

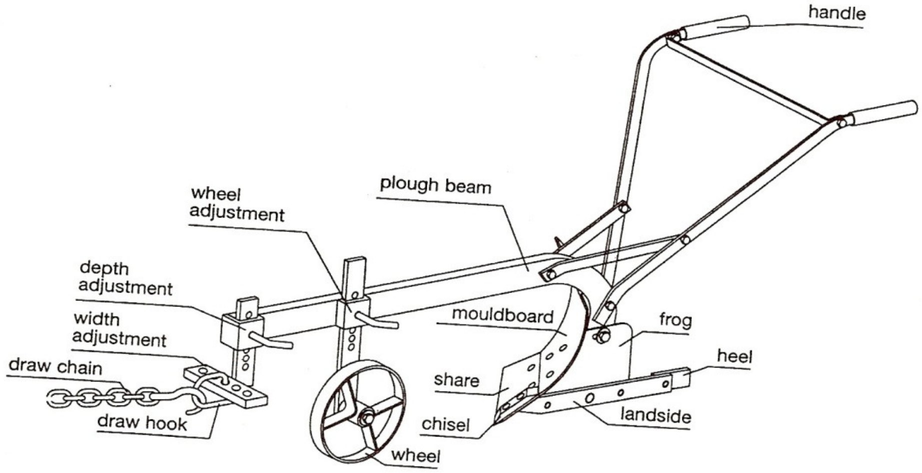

Figure 4.2: Animal – drawn mould board plough

4.6 EXPERIMENTAL INSTRUMENTATION

The major instruments used in the research work were spring dynamometer, measuring tape, weighing machine, meter rule and stop watches. All these instruments were used during the field experiment to determine the draft requirements of the animal draft implements. The particular use of each is as reported below.

4.6.1 Measuring Tape

This is a 100 m fibre tape graduated both in meters and feet. It is pulled out of its plastic house (frame) during use and rolled back in to the frame for storage. The tape was used for layout and marking of the experimental field in to the required plots. It was also used to take the anthropometric measurements of the bulls used during the research work.

4.6.2 Spring Dynamometer

The spring-type dynamometer has already been described by Abubakar *et al.,* (2000) as an instrument that could be used to measure the pull exerted on an implement by the power source (tractor or work animals). For the purpose of this research work, the spring dynamometer was used to measure the pull on the two implements at the three varying depths and speeds of operation.

Other instruments used for this research work were:

i. Stop watch used to measure and record the time taken to cover each run in seconds for each treatment during operation

ii. Meter rule used for measuring the depth of operation and plant height during growth period.

iii. Weighing machine, this is an electronic machine that was used to measure the weight of soil sample both before and after oven-drying for moisture content and bulk density determinations.

4.7 EXPERIMENTAL TREATMENTS

4.7.1 Tillage Treatments

The tillage implements described in sections 4.4 and 4.5 were used to determine their draught requirements based on various operational parameters. These are speed and depth of operation. The range selected for this study were based on literature reports and seemed to be applicable commonly by farmers in the study area.

Deep tillage (deeper than 25 cm) is only profitable in special circumstances. Only sugarcane requires a tillage depth of about 20 cm (IAR, 1997). Therefore, for this study, the following ranges of tillage depths were considered during the field trial: d_1 = 5 – 10 cm, d_2 = 11 – 15 cm and d_3 = 16 – 20 cm. Payne (1990) reported that 0.69 ms^{-1} and 1.11 ms^{-1} as the low and high working speeds of bulls with drawn implements while ploughing respectively. Based on this, the following values were used as speed of operation during field trials:

S_1 = 0.69 ms^{-1}, S_2 = 0.97 ms^{-1} and S_3 = 1.25 ms^{-1}.

The combination of the implements, speed and depth gave eighteen different treatments that were imposed on the field as follows:

$T_1 = I_1S_1d_1$ $T_2 = I_1S_1d_2$ $T_3 = I_1S_1d_3$ $T_4 = I_1S_2d_1$ $T_5 = I_1S_2d_2$ $T_6 = I_1S_2d_3$

$T_7 = I_1S_3d_1$ $T_8 = I_1S_3d_2$ $T_9 = I_1S_3d_3$ $T_{10} = I_2S_1d_1$ $T_{11} = I_2S_1d_2$ $T_{12} = I_2S_1d_3$

$T_{13} = I_2S_2d_1$ $T_{14} = I_2S_2d_2$ $T_{15} = I_2S_2d_3$ $T_{16} = I_2S_3d_1$ $T_{17} = I_2S_3d_2$ $T_{18} = I_2S_3d_3$

Where: I_1 = Animal – drawn Emcot ridger

I_2 = Animal – drawn mouldboard plough

S_1 = Speed of 0.69 ms^{-1}

S_2 = Speed of 0.97 ms^{-1}

S_3 = Speed of 1.25 ms^{-1}

d_1 = Operating depth of 5 – 10 cm

d_2 = Operating depth 0f 11 – 15 cm

d_3 = Operating depth of 16 – 20 cm.

Before the actual field experiments for the research work, retraining and rehearsals were conducted on a different field for three days. This was to train the operators and the work animals in the variations in depth and speed of operation required during field work. To achieve this, the implements were operated for ten runs of 5 m each, targeting each of the three working depths and speeds. The data on the response of this retraining is presented in Appendix A.

The treatments were randomly assigned in 2 x 3 x 3 factorial experiment arranged in a randomized complete block design in three replications. Each plot size was 5 m wide x 10 m long. The area of land used for the study was 0.36 ha. The randomization of the treatments and field plot layout are shown in Appendix B.

4.7.2 Planting and Fertilizer Application

All the treatments were planted by placing maize seeds into a hole dug by a hand hoe, covering the seeds and slightly compacting the soil with heels. At three weeks after planting (WAP), fertilizer NPK (45:15:15) and urea were applied at equal rate to all the treatments. NPK was applied at the rate of 400 $kgha^{-1}$, (2 kg per plot) and urea at the rate of 200 $kgha^{-1}$, (1 kg per plot). This was followed by NPK at the rate of 200 $kgha^{-1}$ at six WAP as described by Anonymous (1989).

4.8 FIELD OPERATIONS AND MEASUREMENTS

Two white Fulani bulls were fitted with the implements, one at a time in carrying out the treatments. A dynamometer, Dillon spring type of 500 kg capacity was fitted in to the towing arrangement (between the animals and the implements) as shown in Figure 4.3 to measure the draught values. The draught value was read at minimum of three times and maximum of five times along a row for each treatment. This was due to the variations in speed of operation. The mean values were recorded as the case for each treatment.

Figure 4.3: Draught animals during operation with dynamometer fitted

Soil samples were collected from the field each day before and after tillage treatments. The samples were placed into an air-tight nylon bags and carried to the laboratory for soil moisture content and bulk density determination. The depth of soil cut was measured with plastic ruler to ascertain the average depth obtained for each treatment. Time of operation was recorded with stop watches. Two stop watches were used as follows: First one for each run along a plot and the second for total time taken to carry out operation on each plot. The total time taken in a day was recorded by wrist watch. All other farm management practices including planting, weeding and fertilizer application were carried out on the same basis for all treatments. These also conformed to the practices of farmers that grow maize in the study area.

4.9 DETERMINATION OF SOIL AND PLANT PHYSICAL PROPERTIES

In order to define the initial soil conditions, samples were collected from each plot and relevant soil properties determined. The soil properties determined were moisture content, bulk density, penetration resistance, swell factor, and particle size.

4.9.1 Particle Size Analysis

Hydrometer method, as described by Bouyoucos (1951), was used for the determination of the soil particle size. Air dried soil sample of 40 g was put into a 600 ml beaker. 100 ml of distill water and 5 ml of 30 % (H_2O_2) was added into the beaker. The beaker was covered with its contents using a watch glass and heated on a hot plate. Calgon solution (50 ml) was put in to a 1l cylinder and the cylinder was filled up with distill water. This suspension was well mixed and allowed to cool to room temperature. Hydrometer was lowered in to the suspension carefully and the reading was recorded as the blank reading (R_L).

50 ml of 5 % Calgon solution was added in to the beaker while shaking every fifteen minutes followed by heating for one hour and allowed to cool. The content was transferred in to a dispensing cup and dispersed for five minutes. The suspension was transferred into a 1l cylinder. All the particles were washed with water in to the cylinder and it was filled up with water. The sedimentation cylinder was tightly closed using a stopper and shacked well until the soil was brought in to suspension.

Immediately after mixing, hydrometer was carefully lowered again and the reading recorded at 40 seconds after mixing. The hydrometer was rinsed and wiped up to dry. After the suspension was left to stand for 3 to 8 hours, the hydrometer was lowered again and readings recorded at each period. The following equation as stated by Bouyoucous (1951) was used to calculate the soil particle percentages:

$$S_p = \left(\frac{R - R_L \pm r}{w} \right) \times 100, \% \qquad (4.1)$$

Where: S_p = percentage of particles on suspension

R = sample reading for hydrometer

R_L = blank reading for hydrometer

r = temperature correction factor = 0.36

w = weight of sample used, g.

The percentage of soil particles obtained was used to determine the textural class using the USDA soil textural triangle (Dunn *et al.,* 1980).

4.9.2 Organic Matter Content

Carbon is the major element present in soil organic matter, comprising about 48 – 58 % of the total weight (Page *et al.,* 1982). Therefore, recommended that, organic carbon determinations are often used as the basis for organic matter estimates.

Organic carbon was calculated by using Walkley-Black procedure as described by Walkley and Black (1934). Soil sample of 1 g that is <0.5 mm was put in to 50 ml wide-mouth Erlenmeyer Flask. 10 ml of Potassium dichromate solution (1 $NK_2Cr_2O_7$) was added into the flask and swirled gently to disperse the soil in the solution. 20 ml of concentrated sulphuric acid (H_2SO_4) was added and the flask swirled and allowed to stand on an asbestos sheet for 30 minutes. 100 ml distill water; 10 ml phosphoric acid and a pinch of sodium fluoride (NaF) were added in to the flask and allowed to cool. Five drops of indicator solution was added and titrated with ferrous sulphate solution while the mixture was being stirred. Near the end point, the brown colour becomes violet blue and titration slowed down. At the end point, the colour sharply changed to green.

The following equation as stated by Walkley and Black (1934) was used for calculating the percentage carbon:

$$C = m \times \frac{V_1 - V_2}{S} \times 0.39 \times mcf \text{ , \%} \tag{4.2}$$

Where:

C = organic carbon,

mcf = moisture correcting factor,

m = molarity of ferrous sulphate solution (from blank titrate),

V_1 = volume of ferrous sulphate required for blank, cm^3

V_2 = volume of ferrous sulphate required for sample, cm^3 and

S = weight of air dried soil, g.

The percentage organic matter was calculated from the equation given by Walkley and Black (1934) as shown below:

$$o.m = C \times 1.723, \% \qquad (4.3)$$

Where o.m = organic matter, %

4.9.3 Soil Bulk Density

The dry bulk density of a soil gives an indication of the soil's strength and thus the resistance presented to tillage implement or plant roots as they penetrate the soil. The soil bulk density was determined by the core sampler method as described by Blake and Hartge (1986). For determination of this parameter, three soil samples were randomly taken from each plot and taken to the laboratory. After oven drying for 24 hours at 105^{o}C, the samples were weighed by an electric balance. The average values recorded for each treatment. Core sampler has the following dimensions: 4.35 cm diameter, 9.90 cm long and volume of 147.13 cm^3. The following relationship was used in determining the bulk density as given by Blake and Hartge (1986):

$$D_b = \frac{M}{V} \tag{4.4}$$

Where: D_b = Oven dried bulk density, Mgm^{-3}

M = Mass of dried soil sample, Mg

V = Volume of core sampler, m^3

4.9.4 Soil Moisture Content

Sampling of soil for moisture determination was done adjacent to the core sampled points. This is to ensure uniform conditions for the determination of these parameters. Soil moisture content was taken in order to assess moisture differences among the tillage treatments.

The soil moisture content was determined by gravimetric method as described by Gardner (1986). Three soil samples were taken randomly from each plot up to 20 cm depth depending upon the range of tillage for the treatment considered. The samples were weighed and oven dried for 24 hours at 105°C. The mean values recorded as the percentage moisture content for each treatment. The following relationship as described by FAO (1994) was used:

$$M_c = \frac{W_2 - W_3}{W_3 - W_1} \times 100 \tag{4.5}$$

Where: M_c = Moisture content (dry weight basis), %;

W_1 = Weight of container, g

W_2 = Weight of container plus wet soil, g; and

W_3 = Weight of container plus oven dried soil, g

4.9.5 Plant Height

The seedlings emerged 6 – 8 days after planting on all the treatments. The plant height was measured using a meter rule from soil surface to the tip of the last leaf. Three plants were randomly selected from each treatment and the mean recorded. Plant heights were measured as from 3 weeks after planting and followed in two weeks interval up to 9 weeks after planting. This because at 3 WAP all plants are fully established and the plants were more than 50 % tasseled at 10 WAP.

4.9.6 Leaf Area and Leaf Area Index

Estimation of leaf area is an essential component of plant growth analysis and evapotranspiration studies (Bhatt and Chanda, 2003). Leaf area is important for crop light interception and therefore has a large influence on growth (Boote *et al.,* 1988), transpiration (Enoch and Hurd, 1978) and growth rate (Leith *et al.,* 1986). Montgomery (1911) first suggested that the leaf area of a plant can be calculated from linear measurement of leaves using a general relationship: $A = b \times L \times W$ where b is a coefficient. Such a mathematical equation for estimating leaf area reduces sampling effort and cost, may increase precision where sample of leaf size are difficult to handle. This measurement is normally done on forth night basis.

Leaf Area (LA) of individual leave was estimated by the equation given by Saxena and Singh (1965) and reported by Yusuf (2001) as:

$$LA = 0.75 \times Length \times Breath \qquad (4.6)$$

Leaf Area Index (LAI) was calculated using the equation given by Watson (1952):

$$LAI = \frac{Total\ LA}{Total\ land\ area} \quad (4.7)$$

4.9.7 Grain Moisture Content

A Protimeter Grain Moisture Meter (GRN 3000S) was used to determine the grain moisture content at harvest. This meter is a manually operated machine that measures the moisture content of different crops. During operation, the grain was grounded by the machine and after setting to corn (maize), moisture content value was read from a digital scale on the machine. The grain was harvested at an average moisture content of 15 %.

4.9.8 Maize Grain Yield

Grain yield was determined after harvesting the crop by hand at the grain moisture content of about 15 %. The harvested maize grain was shelled manually and the grain for each plot was weighed to estimate the grain yield for that plot.

4.10 STATISTICAL ANALYSIS

The field and laboratory data collected were analyzed statistically by using Analysis of Variance (ANOVA) technique (Appendix C) as described by Gomez and Gomez, (1984). All regression analyses were conducted by the use of the General Linear Models (GLM) procedure (Statistical Analysis Systems [SAS] Institute Inc., 1989). The standard error of each mean was calculated and presented in form of figures and/or tables.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 SOIL CONDITION

The physical properties and organic matter content of soil samples are presented in Appendix D. The texture of the soil surface is sandy loam (USDA triangle) in which the sand fraction constitute high percentage (62.8 – 67.8 %) in the constituent components. This result confirms the observation of Yusuf (2001). There is no considerable variation in the sand, silt and clay fractions in the 3 – year study. Soil organic matter content greatly influence soil properties and plant nutrition and is an important source for CO_2 (Etana *et al.,* 1999). The soil profile indicates moderate percentage of organic matter content. The soil organic matter decreased with increase in depth of soil profile as shown in Appendix D. Similar observation was reported by Tsimba *et al.,* (1999). The 0 – 15 cm depth of soil profile recorded values between 1.18 to 1.43 % of the organic matter content while the corresponding value in 15 – 30 cm depth was 0.92 to 1.26 %. The level of soil organic matter is moderate and this resulted in to high maize grain yield during the study.

5.2 WEATHER CONDITION

The annual rainfall and air temperature data (1978 – 2010) as presented in Figure 5.1 and Table 5.1 respectively were obtained from the Agro-metrological Service Unit of the Institute for Agriculture Research, Ahmadu Bello University, Zaria.

The rainfall varied consistently from 608 mm to 1322 mm per annum (S.D: 12.904 to 18.798; C.V: 1.349 to 1.489 %). The annual air temperature ranges from 24.6^{o}C to 26.4^{o}C with slight variation (S.D: 2.626 to 3.572; C.V: 9.963 to 14.485 %). During the study periods (2008 to 2010), annual rainfall in 2008 was 1139.9 mm which was higher than the three 10 – year averages of 939.6 mm in 1978 – 1987, 948.6 mm in 1988 – 1997 and 1086.6 mm in 1998 – 2007 by 200.3 mm, 191.3 mm and 53.3 mm respectively as shown in Table 5.1. The table also showed same trend of variation in rainfall during the 2009 and 2010 study periods. The precipitation during the three years of study was higher than the 30 – year average (1005 mm) with 134.9 mm, 273 mm and 122.3 mm in 2008, 2009 and 2010 respectively as shown in Figure 5.1. The evenly distributed rainfall during the study season (June – September) in 2009 resulted in to highest maize grain yield of 5.03 t/ha with average of 3.81 t/ha. The rainfall distribution was poor in 2008, particularly during the seedling emergence and grain filling stages. This poorly distributed rainfall contributed to the low average maize grain yield of 3.46 t/ha with range from 1.56 to 4.55 t/ha. The average yield in 2010 was 3.75 t/ha with range between 2.11 and 4.90 t/ha. During the period of study (June to September), the average rainfall in 2010 was 899.9 mm which was higher than the corresponding value in 2008 (883.1 mm). This might have resulted to a higher yield 2010 as compared to 2008. Yusuf (2001) quoted Lindstrom and Voorhees (1994) who reported that crop response to soil properties depend greatly on the weather conditions. Average air temperatures during the study period (2008 to 2010) remain relatively constant at 24^{o}C with an annual mean temperature of about the same value (26^{o}C). The mean air temperatures during cropping seasons were higher than the air mean temperature of 1978 – 1987 and 1988 – 1997 and almost same as that of 1998 – 2007.

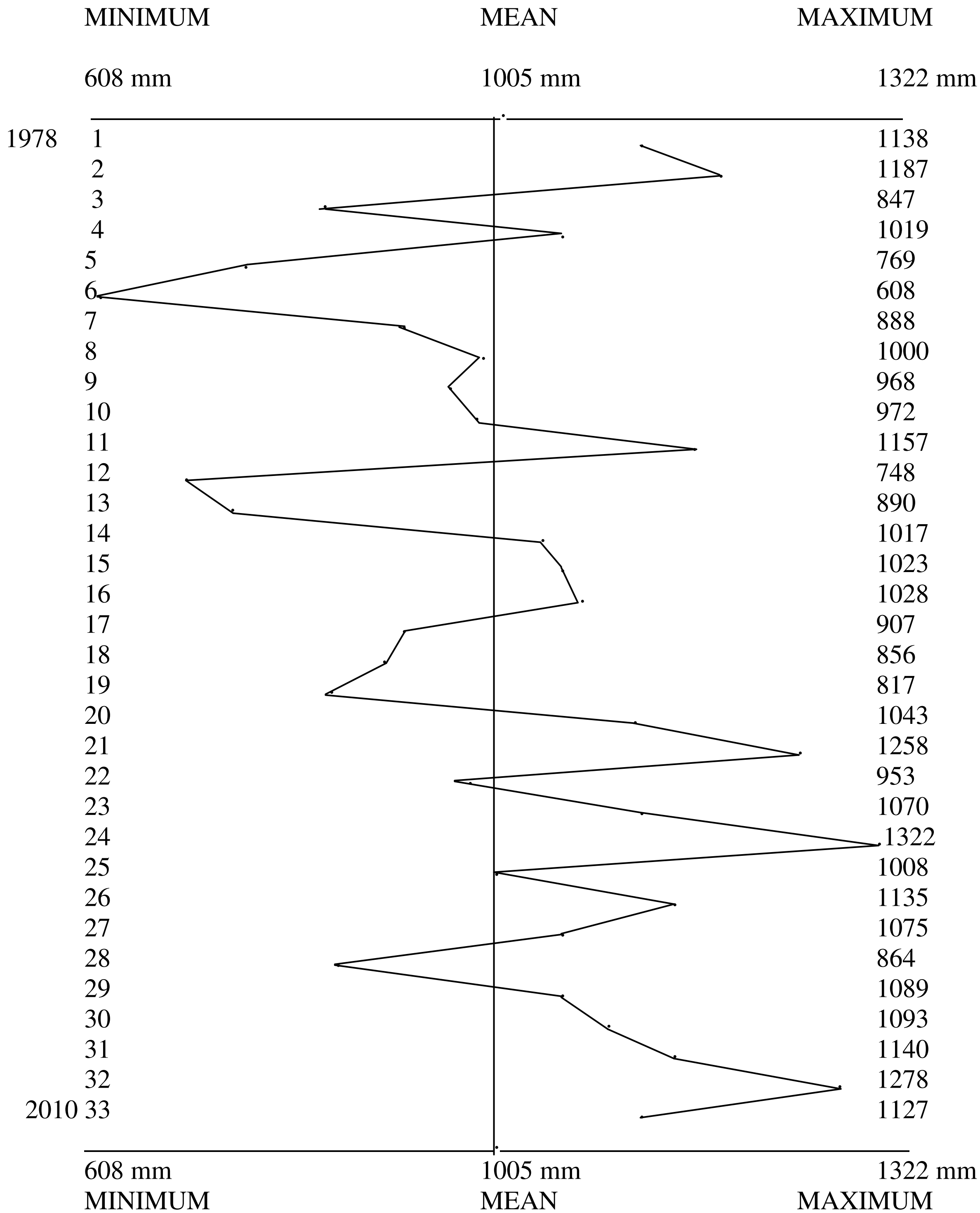

Figure 5.1: Annual rainfall pattern in Zaria, 1978 – 2010

Source: Agro-metrological Service Unit of the I.A.R, A.B.U Zaria.

Table 5.1: Mean temperature and precipitation (June – September and Annual) for the periods 1978 – 1987, 1988 – 1997, 1998 – 2007, and 2008, 2009 and 2010 at the study area

Period	Mean temperature (^{O}C)[a]		Average precipitation (mm)	
	June – September	Annual	June – September	Annual
1978 – 1987	24.430	24.644	757.620	939.640
	(1.422, 5.756)	(3.215, 12.973)	(14.011, 1.871)	(13.800, 1.489)
1988 – 1997	24.623	24.658	746.910	948.580
	(1.397, 5.669)	(3.572, 14.485)	(12.674, 1.704)	(12.904, 1.360)
1998 – 2007	26.221	26.620	880.460	1086.550
	(2.165, 8.257)	(3.251, 12.215)	(14.701, 1.678)	(14.648, 1.349)
2008	26.295	25.848	883.100	1139.900
	(1.922, 7.308)	(3.023, 11.694)	(18.455, 2.090)	(16.908, 1.483)
2009	25.963	26.356	1020.900	1278.000
	(1.552, 5.979)	(2.626, 9.963)	(18.719, 1.834)	(18.798, 1.471)
2010	25.586	26.315	899.700	1127.300
	(1.437, 5.616)	(2.852, 10.839)	(15.269, 1.697)	(14.224, 1.262)

[a]Values in parenthesis are standard deviation and coefficient of variation in percentage

Source: Agro-metrological Service Unit of the I.A.R, A.B.U, Zaria.

5.3 CROP ASSESSMENT PARAMETERS

5.3.1 Leaf Area Index

Leaf Area Index (LAI) increased from 3 Weeks after planting (WAP) to the peak at 9 WAP. Increase in depth of tillage resulted to increased in LAI (Figures 5.2 to 5.4). Similar result was reported by Yusuf (2001) and Rahman *et al.,* (2004). LAI was significantly affected ($P \leq 0.01$) by the tillage depth investigated in this study as presented in Tables 5.2 to 5.4 for the three years of study. Mould board ploughing at depth d_3 (T_{18}) showed superiority in the LAI values throughout the study years (2008 – 2010) over other tillage treatments. The implement type and tillage depth significantly ($P \leq 0.01$) affected the LAI in the 3 years of study. The implement x depth and speed x depth interactions showed significant effect ($P \leq 0.01$) on LAI in the study years. However, the implement x speed x depth interaction was significant in 2008 and 2009 but was not significantly ($P \leq 0.05$) affected in 2010. The combined analysis of variance of the 3 – year study showed significant effect ($P \leq 0.01$) of implement x speed, implement x depth, speed x depth on the LAI. However, the interaction of implement x speed x depth on LAI was not significant (Table 5.5).

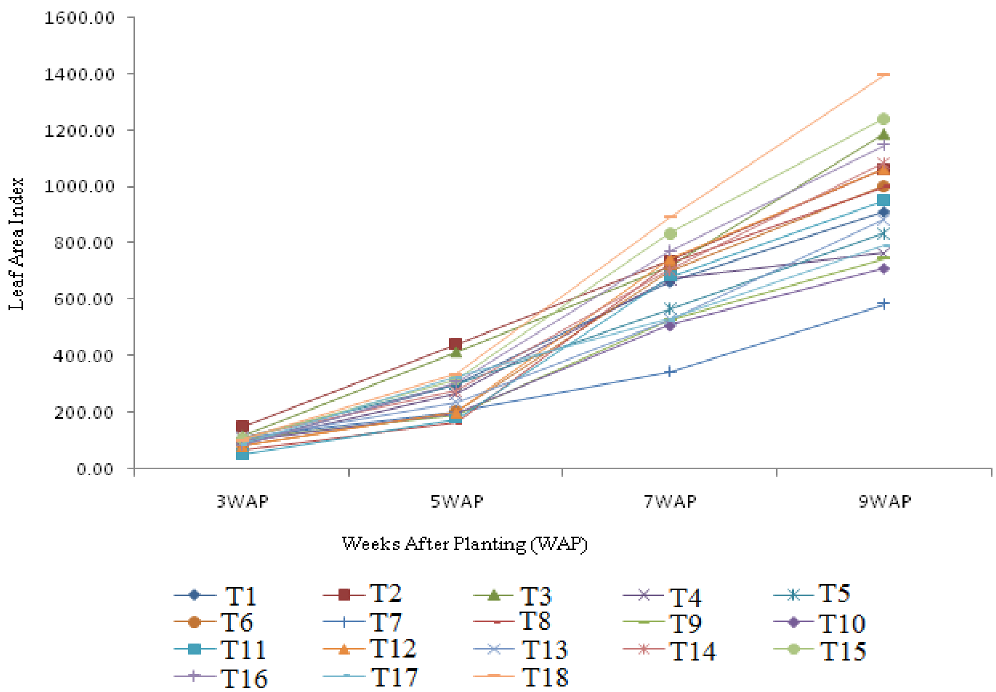

Figure 5.2: Effect of differnt tillage practices on
LAI of maize at different WAP in 2008

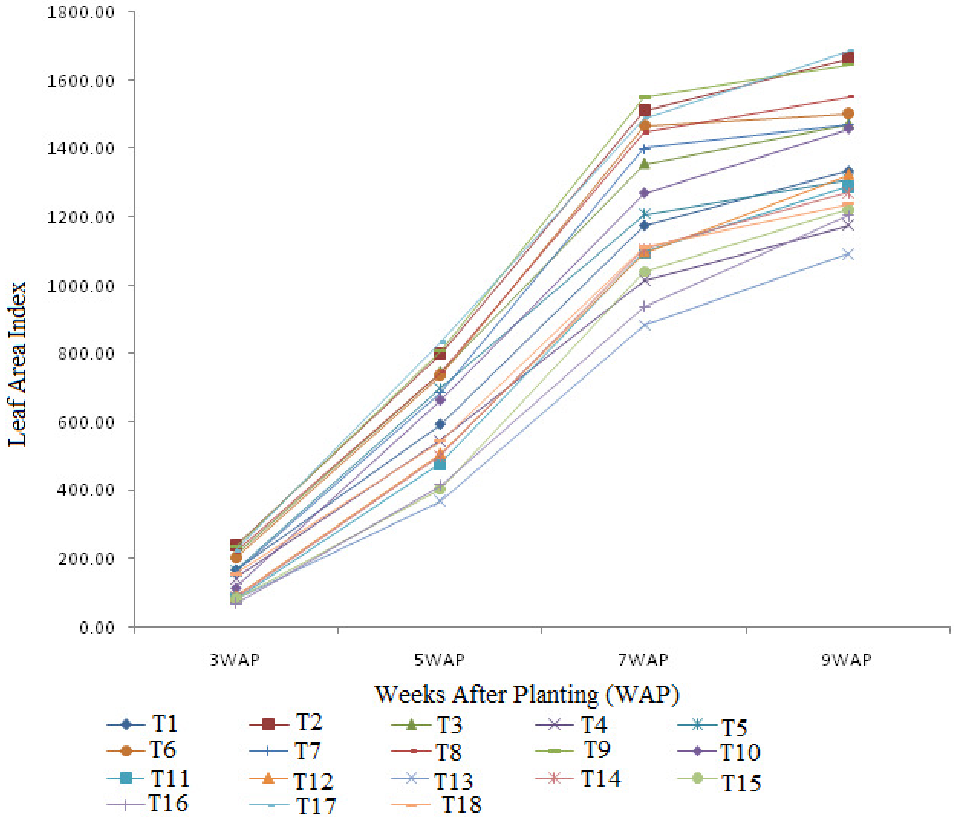

Figure 5.3: Effect of different tillage practices on LAI of maize at different WAP in 2009

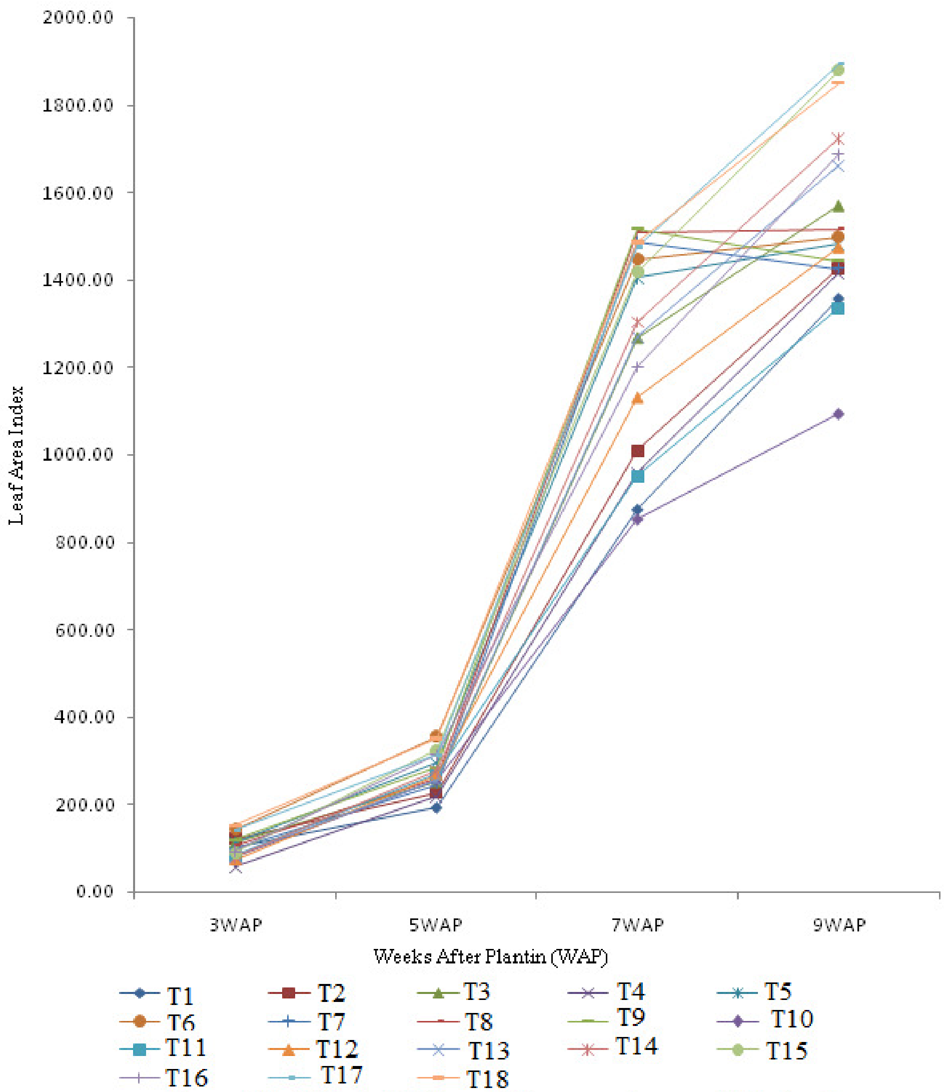

Figure 5.4: Effect of different tillage practices on LAI of maize at different WAP in 2010

Table 5.2: Analysis of variance of leave area index for 2008 year of study at 9 WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	28395.4801	14197.7401	1.87
Implement (I)	1	230918.0078	230918.0078	30.46**
Speed (S)	2	13295.3633	6647.6816	0.88^{ns}
Tillage depth (d)	2	663691.9048	331845.9524	43.78**
I x S	2	550796.4536	275398.2268	36.33**
I x d	2	179675.3481	89837.6741	11.85**
S x d	4	44689.6133	11172.4033	1.47^{ns}
I x S x d	4	515517.8720	128879.4680	17.00**
Error	34	257743.2050	7580.6830	
Total	53	2484723.2480		

** = significant at 0.01 probability level; ^{ns} = not significant

Table 5.3: Analysis of variance of leave area index for 2009 year of study at 9 WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	267.5879	133.7939	0.23
Implement (I)	1	297558.0718	297558.0718	507.98**
Speed (S)	2	414752.7979	207376.3990	354.03**
Tillage depth (d)	2	279048.0054	139524.0027	238.19**
I x S	2	6182.9331	3091.4666	5.28**
I x d	2	114286.7022	57143.3511	97.55**
S x d	4	154989.7990	38747.4498	66.15**
I x S x d	4	356673.5975	89168.3994	152.23**
Error	34	19915.9440	585.7630	
Total	53	1643675.4390		

** = significant at 0.01 probability level

Table 5.4: Analysis of variance of leave area index for 2010 year of study at 9 WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	2609.3312	1304.6656	0.56
Implement (I)	1	353302.4447	353302.4447	150.89**
Speed (S)	2	738125.6466	369062.8233	157.62**
Tillage depth (d)	2	300925.8535	150462.9267	64.26**
I x S	2	668222.1277	334111.0639	142.69**
I x d	2	51766.3218	25883.1609	11.05**
S x d	4	99047.0678	24761.7669	10.58**
I x S x d	4	14115.7732	3528.9433	1.51^{ns}
Error	34	79609.6830	2341.4610	
Total	53	2307724.2490		

** = significant at 0.01 probability level; ^{ns} = not significant

Table 5.5: Combined analysis of variance for leave area index 2008 – 2010 at 9 WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	3627.725	1813.862	0.50
Year (Y)	2	9581962.117	4790981.059	1319.37**
Implement (I)	1	93436.613	93436.613	25.73**
Speed (S)	2	229843.156	114921.578	31.65**
Tillage depth (d)	2	1020005.196	510002.598	140.45**
I x Y	2	788341.911	394170.956	108.55**
d x Y	4	223660.568	55915.142	15.40**
S x Y	4	936330.652	234082.663	64.46**
I x S	2	752389.815	376194.908	103.60**
I x d	2	17446.324	8723.162	2.40^{ns}
S x d	4	81719.220	20429.805	5.63**
I x S x d	4	39345.256	9836.314	2.71^{ns}
I x S x Y	4	472811.699	118202.925	32.55**
I x d x Y	4	328282.048	82070.512	22.60**
S x d x Y	8	217007.260	27125.908	7.47**
I x S x d x Y	8	846961.987	105870.248	29.16**
Error	106	384913.510	3631.260	
Total	161	16018085.050		

** = significant at 0.01 probability level; ^{ns} = not significant

5.3.2 Plant Height

The effects of tillage treatment on plant height vary from year to year through the 3 – year study (Table 5.14). Maize plant height varied with the implement used and the depth of tillage considered in the study. Increased in tillage depth for both implements resulted in increased plant height. Tilling with the mould board plough at depth d_3 (15 – 20 cm) in 2009 field study produced the highest maize plant height when compared with other treatments. Plant height increased with the advancement of growth stages in 2008 and 2010. There is variation to this result in 2009. At 9 WAP, treatment T_{10} gave the highest value of plant height. A similar result on tillage treatment was obtained by Olofintoye (1989). Relatively high soil temperature enhanced plant growth with resultant increased in plant height.

Analysis of variance (Tables 5.6, 5.7 and 5.8) for the 2008, 2009 and 2010 years of study respectively, showed that the implement, speed and depth of tillage significantly affected ($P \leq 0.01$) the plant height at 9 WAP. Also the interaction of implement, speed and the tillage depth significantly affected ($P \leq 0.01$) the maize plant height. The combined analysis of variance (Table 5.9) also showed that the various parameters and their interactions significantly ($P \leq 0.01$) affected the plant height in this study. Yusuf (2001) also reported that tillage treatments significantly affected ($P \leq 0.01$) the plant height of maize. Similar result was also reported by Rahman *et al.,* (2004) on a sandy loam soil in Mymensingh, Bangladesh.

Table 5.6: Analysis of variance of maize plant height for 2008 year of study at 9 WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	49.141605	24.570802	0.83
Implement (I)	1	261.946996	261.946996	8.88**
Speed (S)	2	510.228642	255.114321	8.65**
Tillage depth (d)	2	2240.493704	1120.246852	37.98**
I x S	2	479.886584	239.943292	8.14**
I x d	2	779.682757	389.841379	13.22**
S x d	4	3541.399506	885.349877	30.02**
I x S x d	4	4944.142551	1236.035638	41.91**
Error	34	1002.808770	29.494380	
Total	53	13809.731110		

** = significant at 0.01 probability level

Table 5.7: Analysis of variance of maize plant height for 2009 year of study at 9 WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	4.193868	2.096934	1.81**
Implement (I)	1	10.607490	10.607490	9.13**
Speed (S)	2	45.028436	22.514218	19.38**
Tillage depth (d)	2	251.037078	125.518539	108.04**
I x S	2	117.885473	58.942737	50.74**
I x d	2	215.569424	107.784712	92.78**
S x d	4	1201.630453	300.407613	258.59**
I x S x d	4	2314.916872	578.729218	498.16**
Error	34	39.498724	1.161727	
Total	53	4200.367819		

** = significant at 0.01 probability level

Table 5.8: Analysis of variance of plant height at 9 WAP for 2010 field study at 9 WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	8.599794	4.299897	1.47
Implement (I)	1	3921.358539	3921.358539	1343.13**
Speed (S)	2	1515.620535	757.810267	259.56**
Tillage depth (d)	2	663.931399	331.965700	113.70**
I x S	2	60.120041	30.060021	10.30**
I x d	2	47.600041	23.800021	8.15**
S x d	4	32.464650	8.116163	2.78**
I x S x d	4	40.014527	10.003632	3.43**
Error	34	99.265391	2.919570	
Total	53	6388.974918		

** = significant at 0.01 probability level

Table 5.9: Combined analysis of variance for plant height for the 3 – year period at 9 WAP

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	21.834362	10.917181	0.98
Year (Y)	2	4014.782016	2007.391008	180.07**
Implement (I)	1	621.477099	621.477099	55.75**
Speed (S)	2	220.143374	110.071687	9.87**
Tillage depth (d)	2	2602.421276	1301.210638	116.72**
I x Y	2	3572.435926	1786.217963	160.23**
d x Y	4	553.040905	138.260226	12.40**
S x Y	4	1850.734239	462.683560	41.50**
I x S	2	526.842634	263.421317	23.63**
I x d	2	693.784239	346.892119	31.12**
S x d	4	2797.754609	699.438652	62.74**
I x S x d	4	4807.059053	1201.764763	107.80**
I x S x Y	4	131.049465	32.762366	2.94^{ns}
I x d x Y	4	349.067984	87.266996	7.83**
S x d x Y	8	1977.740000	247.217500	22.18**
I x S x d x Y	8	2492.014897	311.501862	27.94**
Error	106	1181.67379	11.147870	
Total	161	28413.85586		

** = significant at 0.01 probability level; ^{ns} = not significantly different

5.3.3 1000 – kernel Weight

The 1000 – kernel weight for the 3 years of study (2008 to 2010) is presented in Table 5.14. From the table, it is shown that, for the Emcot ridger, treatment T_8 ($I_1S_3d_2$) had higher 1000 – kernel weight than other treatments. Also for the mould board plough, treatment T_{15} ($I_2S_3d_2$) had the corresponding higher value. This may probably be due to good soil tilt which leads to small soil aggregates of the seed beds. Analysis of variance showed that, the depth of tillage and the interaction of implement, speed and tillage depth significantly affected ($P \leq 0.01$) the 1000-kernel weight for the three years of study (Tables 5.10, 5.11 and 5.12). The combined analysis of variance of 1000-kernel weight over the 3 – year period of study also showed significant effect ($P \leq 0.01$) of the implement, speed and depth of tillage interaction on 1000-kernel weight (Table 5.13). However, there is no significant effect of the implement on the 1000-kernel weight in the combined analysis of variance.

Table 5.10: Analysis of variance for 1,000 – kernel weight in the 2008 study period

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	1542.733515	771.366757	11.44
Implement (I)	1	1197.729459	1197.729459	17.77**
Speed (S)	2	693.721890	346.860945	5.15*
Tillage depth (d)	2	5691.453477	2845.726739	42.22**
I x S	2	1302.099531	651.049766	9.66**
I x d	2	2393.617181	1196.808591	17.76**
S x d	4	4222.849967	1055.712492	15.66**
I x S x d	4	1764.262813	441.065703	6.54**
Error	34	2291.687720	67.402580	
Total	53	21100.155560		

* = significant at 0.05 probability level; ** = significant at 0.01 probability level

Table 5.11: Analysis of variance of 1,000 – kernel weight in the 2009 field experiment

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	37.174044	18.587022	4.31
Implement (I)	1	1082.129712	1082.129712	250.85**
Speed (S)	2	709.234094	354.617047	82.20**
Tillage depth (d)	2	204.544711	102.272356	23.71**
I x S	2	2424.510999	1212.255500	281.01**
I x d	2	1086.095355	543.047677	125.88**
S x d	4	7273.141728	1818.285432	421.49**
I x S x d	4	1753.708616	438.427154	101.63**
Error	34	146.673780	4.313930	
Total	53	14717.213040		

** = significant at 0.01 probability level

Table 5.12: Analysis of variance of 1,000 – kernel weight in 2010 field experiment

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	11.713457	5.856728	3.70
Implement (I)	1	107.244630	107.244630	67.81**
Speed (S)	2	241.157901	120.578951	76.24**
Tillage depth (d)	2	1160.697160	580.348580	366.93**
I x S	2	58.963827	29.481914	18.64**
I x d	2	76.181605	38.090802	24.08**
S x d	4	606.280864	151.570216	95.83**
I x S x d	4	1502.521605	375.630401	237.50**
Error	34	53.775432	1.581630	
Total	53	3818.536481		

** = significant at 0.01 probability level

Table 5.13: Combined analysis of variance of 1,000 – kernel weight over the 3 – year period (2008 to 2010)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	597.095662	298.547831	9.08
Year (Y)	2	8203.010398	4101.505199	124.69
Implement (I)	1	24.902846	24.902846	0.76^{ns}
Speed (S)	2	482.409170	241.204585	7.33*
Tillage depth (d)	2	4369.239095	2184.619547	66.42**
I x Y	2	2362.200955	1181.100477	35.91**
d x Y	4	2687.456254	671.864064	20.43**
S x Y	4	1161.704715	290.426179	8.83**
I x S	2	1432.356588	716.178294	21.77**
I x d	2	1361.670342	680.835171	20.70**
S x d	4	8219.185952	2054.796488	62.47**
I x S x d	4	3050.558499	762.639625	23.19**
I x S x Y	4	2353.217769	588.304442	17.89**
I x d x Y	4	2194.223799	548.555950	16.68**
S x d x Y	8	3883.086608	485.385826	14.76**
I x S x d x Y	8	1969.934534	246.241817	7.49**
Error	106	3486.662290	32.893040	
Total	161	47838.915470		

* = significant at 0.05 probability level; ** = significant at 0.01 probability level; ^{ns} = not significant

5.3.4 Maize Grain Yield

The effects of tillage treatments and depth of tillage on maize grain yield were investigated. Increased in depth of tillage resulted to increase of maize grain yield as shown in Table 5.14. For the Emcot ridger, treatment T_8 ($I_1S_3d_2$) resulted in the highest average grain yield (4.71 t/ha) for the 3 – year study and the least treatment in terms of average maize grain yield is T_7 (1.89 t/ha). For the mould board plough, the highest average maize grain yield was obtained in treatment T_{15} ($I_2S_2d_3$) as 4.89 t/ha and the least was in treatment T_{10} with average value of 2.66 t/ha for the 3 – year study. This may be because of the good seed and seedling environment created by the tillage treatment which enhanced crop growth and improved maize grain yield. Gomez (2011) also reported that ploughing depth significantly influenced maize grain yield.

Analysis of variance (Tables 5.15, 5.16 and 5.17) showed that, maize grain yield was significantly ($P \leq 0.01$) affected by the depth of tillage in the three years of study. The combined analysis of variance for the 3 – year study also showed the same trend (Table 5.18). The study also showed that the implement has significant ($P \leq 0.01$) effect on the maize grain yield in 2009 and 2010. However, no significant ($P \leq 0.05$) was observed for implement on grain yield in 2008. The combined analysis of variance showed that, the implement significantly ($P \leq 0.01$) affected the maize grain yield. The maize grain yield was also significantly ($P \leq 0.01$) affected by the interactions of the implement x speed x tillage depth in each of study year and in the 3 – year combined analysis.

Table 5.14: Means and standard deviation of crop assessment parameters as affected by tillage treatment in the 3-year study (2008 – 2010)

Treatments	Crop assessment parameters[a]									
	Plant height[b] (cm)			1000-Kernel weight[c] (g)			Maize grain yield[c] (t/ha)			Average yield (t/ha)
	2008	2009	2010	2008	2009	2010	2008	2009	2010	
T_1	132.43±6.21	150.47±2.01	116.06±1.90	166.93±9.25	160.30±5.90	164.91±1.05	4.00±5.76	4.48±1.12	3.71±4.00	4.06
T_2	132.00±8.40	134.31±1.60	119.10±1.64	182.95±14.57	177.00±5.18	164.74±1.83	2.82±13.01	3.17±2.35	3.10±3.02	3.03
T_3	144.67±2.85	147.11±1.54	120.17±2.07	166.37±16.20	172.94±1.78	174.22±1.22	4.48±0.83	4.60±3.09	4.32±4.84	4.47
T_4	119.77±3.38	131.29±0.54	119.04±1.47	148.23±6.04	170.02±0.85	168.86±1.32	3.38±12.41	3.87±2.43	3.77±2.41	3.67
T_5	129.56±4.25	138.29±1.01	124.29±2.16	156.07±13.99	146.95±0.67	171.28±1.68	3.29±11.67	3.76±2.24	3.87±1.94	3.64
T_6	153.39±0.37	153.08±0.52	129.26±1.40	156.12±14.64	196.53±2.17	183.37±1.89	4.42±4.34	4.77±4.62	4.68±1.73	4.62
T_7	132.29±1.80	144.50±1.80	127.28±3.68	134.33±3.59	147.73±1.74	155.10±1.15	1.56±8.28	2.01±2.21	2.11±3.37	1.89
T_8	134.94±0.73	143.28±0.62	127.43±1.04	200.54±3.96	192.21±0.76	180.44±1.02	4.61±1.16	4.97±0.71	4.61±7.42	4.71
T_9	105.78±0.78	132.04±1.13	131.82±1.35	141.95±6.80	141.31±0.71	173.18±1.89	2.81±5.37	2.97±1.17	3.90±0.92	3.23
T_{10}	96.49±7.19	132.86±0.81	127.94±0.37	148.25±7.62	185.96±1.08	161.11±1.30	2.54±10.55	2.71±0.99	2.74±1.81	2.66
T_{11}	143.76±0.71	152.93±0.75	132.83±1.13	140.86±9.15	171.80±1.10	182.54±0.50	4.53±3.51	4.90±2.18	4.64±1.77	4.69
T_{12}	131.86±5.90	134.59±0.75	138.47±2.10	157.26±11.14	186.21±1.36	169.04±1.05	2.71±10.90	2.91±2.21	3.23±2.08	2.95
T_{13}	113.88±5.95	127.81±1.53	135.49±1.87	122.97±7.15	166.84±2.76	164.06±0.76	2.71±7.77	2.80±3.09	2.98±4.98	2.83
T_{14}	137.08±3.20	146.04±0.69	142.36±1.32	158.52±15.46	149.30±0.60	171.84±1.89	3.33±12.16	3.72±1.56	3.59±3.48	3.55
T_{15}	142.98±2.24	142.88±0.31	144.88±1.82	169.64±6.47	171.91±1.81	188.20±0.83	4.55±3.35	5.03±1.41	4.90±1.71	4.89
T_{16}	133.09±6.75	147.06±0.41	142.97±1.16	138.74±7.23	186.41±0.96	180.83±1.74	4.19±13.98	4.89±5.74	4.38±2.43	4.49
T_{17}	102.24±6.09	127.33±0.97	147.20±1.22	169.70±7.95	190.51±0.70	170.63±0.87	3.11±5.67	3.51±1.12	3.48±2.04	3.37
T_{18}	143.81±12.43	154.89±0.78	155.70±0.92	162.89±11.04	176.65±0.47	173.20±1.03	3.19±4.27	3.60±1.15	3.54±1.75	3.44
$\bar{x}$	129.45	141.15	132.35	156.80	171.70	172.09	3.46	3.82	3.75	3.67
SD	15.82	9.03	11.10	18.41	16.88	8.58	0.88	0.93	0.75	0.84
CV (%)	12.218	6.396	8.385	11.740	9.832	4.985	25.394	24.396	20.043	22.876

Table 5.15: Analysis of variance of maize grain yield for the 2008 field experiment

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	660.56917	330.28459	5.16
Implement (I)	1	111.76929	111.76929	1.75[ns]
Speed (S)	2	3220.53647	1610.26823	25.14**
Tillage depth (d)	2	10564.68804	5282.34402	82.48**
I x S	2	5930.42204	2965.21102	46.30**
I x d	2	2242.73977	1121.36989	17.51**
S x d	4	17060.07246	4265.01811	66.59**
I x S x d	4	59085.75247	14771.43812	230.64**
Error	34	2177.51020	64.04440	
Total	53	101054.05990		

** = significant at 0.01 probability level; [ns] = not significant

Table 5.16: Analysis of variance of maize grain yield for the 2009 field experiment

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	4.01854	2.00927	0.30
Implement (I)	1	116.41436	116.41436	17.43**
Speed (S)	2	2535.43234	1267.71617	189.79**
Tillage depth (d)	2	8462.70524	4231.35262	633.48**
I x S	2	9782.18371	4891.09185	732.25**
I x d	2	735.12419	367.56209	55.03**
S x d	4	20489.55366	5122.38841	766.88**
I x S x d	4	68013.33923	17003.33481	2545.59**
Error	34	227.10380	6.67950	
Total	53	110365.87510		

** = significant at 0.01 probability level

Table 5.17: Analysis of variance of maize grain yield for the 2010 field study

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	15.67797	7.83899	0.72
Implement (I)	1	155.76547	155.76547	14.37**
Speed (S)	2	3084.88720	1542.44360	142.29**
Tillage depth (d)	2	16145.58141	8072.79071	744.71**
I x S	2	1823.54711	911.77355	84.11**
I x d	2	2074.42715	1037.21358	95.68**
S x d	4	8752.63316	2188.15829	201.86**
I x S x d	4	40265.99083	10066.49771	928.62**
Error	34	368.56834	10.84025	
Total	53	72687.07865		

** = significant at 0.01 probability level

Table 5.18: Combined analysis of variance of maize grain yield over the 3 – year (2008 to 2010) experiments

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	196.2132	98.1066	3.19
Year (Y)	2	9768.1299	4884.0649	158.94**
Implement (I)	1	381.7660	381.7660	12.42**
Speed (S)	2	7621.7981	3810.8990	124.02**
Tillage depth (d)	2	34020.9826	17010.4913	553.57**
I x Y	2	2.1831	1.0916	0.04^{ns}
d x Y	4	1151.9921	287.9980	9.37**
S x Y	4	1219.0579	304.7645	9.92**
I x S	2	15366.6529	7683.3264	250.04**
I x d	2	4689.5917	2344.7958	76.31**
S x d	4	44319.6415	11079.9104	360.57**
I x S x d	4	163983.2295	40995.8074	1334.12**
I x S x Y	4	2169.5000	542.3750	17.65**
I x d x Y	4	362.6994	90.6749	2.95^{ns}
S x d x Y	8	1982.6177	247.8272	8.07**
I x S x d x Y	8	3381.8530	422.7316	13.76**
Error	106	3257.2349	30.7286	
Total	161	293875.1435		

** = significant at 0.01 probability level; ^{ns} = not significant

5.4 SOIL MOISTURE CONTENT

The effects of soil moisture content on the draft of animal-drawn implements were studied. The study showed that the draft increased with increase in moisture content for the two implements considered (Table 5.27). This may be because of the cohesive forces that tend to hold the soil particles together at lower moisture levels. It can also be due to the rapid acceleration of any soil that is moved appreciably. This result is supported by the work of Kushwaha and Linke (1996) who conducted a study on draft – speed relationship on sandy soil and reported that there is increased in draft with increase in soil moisture content. Kumar (2010) also reported that draught of tillage implements increase with increase in speed of operation. Analysis of variance showed that there was a significant ($P \leq 0.01$) effect of moisture content on the draft of the animal-drawn implements considered in this study (Tables 5.19, 5.20 and 5.21) for the 2008, 2009 and 2010 years respectively. Analysis of variance for the interactions between the implement and depth of tillage, implement and speed of operation, and implement, speed of operation and depth of tillage for the three years of study were significantly ($P \leq 0.01$) affected by soil moisture content. Combined analysis of variance for the draught in the 3 – year study was also significantly ($P \leq 0.01$) affected by the soil moisture content (Table 5.22).

Table 5.19: Analysis of variance of soil moisture content for 2008 field experiment

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	0.08637232	0.04318616	1.05
Implement (I)	1	53.39426312	53.39426312	1299.51**
Speed (S)	2	3.34522022	1.67261011	40.71**
Tillage depth (d)	2	12.90797957	6.45398979	157.08**
I x S	2	6.94582084	3.47291042	84.52**
I x d	2	48.36901387	24.18450694	588.60**
S x d	4	4.20430805	1.05107701	25.58**
I x S x d	4	5.22777588	1.30694397	31.81**
Error	34	1.39699510	0.0410881	
Total	53	135.87774900		

** = significant at 0.01 probability level

Table 5.20: Analysis of variance of soil moisture content for the 2009 field experiment

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	0.30595874	0.15297937	1.14
Implement (I)	1	4.29868301	4.29868301	32.02**
Speed (S)	2	7.07138051	3.53569025	26.33**
Tillage depth (d)	2	21.12783556	10.56391778	78.68**
I x S	2	2.72321569	1.36160785	10.14**
I x d	2	17.54633400	8.77316700	65.34**
S x d	4	3.69114985	0.92278746	6.87**
I x S x d	4	12.59774865	3.14943716	23.46**
Error	34	4.56510694	0.13426785	
Total	53	73.92741295		

** = significant at 0.01 probability level

Table 5.21: Analysis of variance of soil moisture content for the 2010 year of study

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	0.03147100	0.01573550	0.13
Implement (I)	1	9.07839316	9.07839316	73.79**
Speed (S)	2	18.19805367	9.09902683	73.96**
Tillage depth (d)	2	76.39521290	38.19760645	310.47**
I x S	2	11.65812791	5.82906395	47.38**
I x d	2	14.40795990	7.20397995	58.55**
S x d	4	20.42850222	5.10712556	41.51**
I x S x d	4	13.87796358	3.46949090	28.20**
Error	34	4.18312120	0.1230330	
Total	53	168.25880550		

** = significant at 0.01 probability level

Table 5.22: Combined analysis of variance of soil moisture content for the 2008, 2009 and 2010

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	0.1339801	0.0669901	0.68
Year (Y)	2	234.9046730	117.4523365	1193.09**
Implement (I)	1	13.5147096	13.5147096	137.28**
Speed (S)	2	21.3722439	10.6861219	108.55**
Tillage depth (d)	2	9.3714580	4.6857290	47.60**
I x Y	2	53.2566297	26.6283148	270.49**
d x Y	4	101.0595700	25.2648925	256.64**
S x Y	4	7.2424105	1.8106026	18.39**
I x S	2	9.9264228	4.9632114	50.42**
I x d	2	28.4149447	14.2074724	144.32**
S x d	4	10.9055574	2.7263893	27.69**
I x S x d	4	14.9883044	3.7470761	38.06**
I x S x Y	4	11.4007416	2.8501854	28.95**
I x d x Y	4	51.9083631	12.9770908	131.82**
S x d x Y	8	17.4184028	2.1773003	22.12**
I x S x d x Y	8	16.7151837	2.0893980	21.22**
Error	106	10.4350452	0.0984438	
Total	161	612.9686404		

** = significant at 0.01 probability level

5.5 SOIL BULK DENSITY

The effects of soil bulk density on the draft of animal – drawn implements were considered in this study. Soil bulk density is a critical soil physical property as it controls the penetration resistance, water retention, aeration and hydraulic conductivity (Khan *et al.,* 1999). In the 3 – year study, the results showed that, at any given depth of tillage (d), there was increase in draft with increase in soil bulk density. It has also shown that there is increased in soil bulk density with increase in depth of tillage (Table 5.27). This could primarily be due to the movement of smaller soil fraction into the lower soil layer which makes them denser and also, due to the compactive effect of the implements. This agrees with the report of Tsimba *et al.,* (1999) which said that bulk density increase with increased in soil depth as a result of low organic matter and pressure exerted by overlaying layers. Yusuf (2001) also reported that low values of soil dry bulk density was obtained in the tilled near surface of 0 – 15cm depth and greater values in the deeper profile (15 – 30cm). The result also conforms to that of Unger *et al.,* (1991) which say that lower bulk density was found at depth of 15 – 30cm than 30 – 50cm with mould board plough.

Analysis of variance (Tables 5.23, 5.24 and 5.25) for the 2008, 2009 and 2010 years of study respectively showed that the draught of the animal – drawn implements was significantly ($P \leq 0.01$) effected by the soil bulk density in the three years of study. The interactions between implement and speed of operation, implement and tillage depth, and implement, speed of operation and tillage depth are also significantly different for the implements used in this study. The 3 – year combined analysis of variance also showed similar relationship (Table 5.26).

Table 5.23: Analysis of variance of soil bulk density for the 2008 field study

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	0.00040428	0.00020214	1.19
Implement (I)	1	0.19380508	0.19380508	1141.99**
Speed (S)	2	0.03423280	0.01711640	100.86**
Tillage depth (d)	2	0.06935286	0.03467643	204.33**
I x S	2	0.03074880	0.01537440	90.59**
I x d	2	0.19756947	0.09878474	582.09**
S x d	4	0.12729373	0.03182343	187.52**
I x S x d	4	0.05769402	0.01442351	84.99**
Error	34	0.00577008	0.00016971	
Total	53	0.71687112		

** = significant at 0.01 probability level

Table 5.24: Analysis of variance of soil bulk density for the 2009 field experiment

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F Value
Replication	2	0.00003195	0.00001597	0.32
Implement (I)	1	0.05187899	0.05187899	1034.99**
Speed (S)	2	0.04372169	0.02186084	436.13**
Tillage depth (d)	2	0.04430787	0.02215393	441.97**
I x S	2	0.03517076	0.01758538	350.83**
I x d	2	0.01681283	0.00840641	167.71**
S x d	4	0.09574065	0.02393516	477.51**
I x S x d	4	0.03128338	0.00782084	156.03**
Error	34	0.00170425	0.00005013	
Total	53	0.32065235		

** = significant at 0.01 probability level

Table 5.25: Analysis of variance of soil bulk density for 2010 field study

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	0.00125476	0.00062738	0.97
Implement (I)	1	0.00210120	0.00210120	3.24*
Speed (S)	2	0.00036651	0.00018325	0.28^{ns}
Tillage depth (S)	2	0.18779023	0.09389511	144.61**
I x S	2	0.02824365	0.01412182	21.75**
I x d	2	0.07241873	0.03620936	55.77**
S x d	4	0.00669362	0.00167340	2.58^{ns}
I x S x d	4	0.16286094	0.04071524	62.71**
Error	34	0.02207551	0.00064928	
Total	53	0.48380514		

** = significant at 0.01 probability level; ^{ns} = not significant

Table 5.26: Combined analysis of variance of soil bulk density for 2008 to 2010 field experiment

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	0.00049459	0.00024729	0.85
Year (Y)	2	0.24117817	0.12058908	415.74**
Implement (I)	1	0.12902926	0.12902926	444.84**
Speed (S)	2	0.05529170	0.02764585	95.31**
Tillage depth (d)	2	0.09630301	0.04815150	166.01**
I x Y	2	0.11875601	0.05937800	204.71**
d x Y	4	0.20514794	0.05128699	176.82**
S x Y	4	0.02302929	0.00575732	19.85**
I x S	2	0.01251489	0.00625745	21.57**
I x d	2	0.09282199	0.04641099	160.01**
S x d	4	0.13158842	0.03289710	113.42**
I x S x d	4	0.07536691	0.01884173	64.96**
I x S x Y	4	0.08164831	0.02041208	70.37**
I x d x Y	4	0.19397904	0.04849476	167.19**
S x d x Y	8	0.09813958	0.01226745	42.29**
I x S x d x Y	8	0.17647143	0.02205893	76.05**
Error	106	0.03074624	0.00029006	
Total	161	1.76250678		

** = significant at 0.01 probability level

Table 5.27: Draft and soil physical properties for the three years of study

Treatment	Year								
	2008			2009			2010		
	Draft (N)	Moisture content (%)	Bulk density (g/cm^3	Draft (N)	Moisture content (%)	Bulk density (g/cm^3	Draft (N)	Moisture content (%)	Bulk density (g/cm^3
T_1 ($I_1S_1d_1$)	246.83	3.54	1.22	243.38	7.66	1.38	251.25	6.62	1.47
T_2 ($I_1S_1d_2$)	262.88	5.08	1.58	251.27	6.74	1.61	268.92	10.03	1.48
T_3 ($I_1S_1d_3$)	288.45	5.12	1.45	268.32	6.69	1.54	274.52	8.32	1.76
T_4 ($I_1S_2d_1$)	356.47	3.34	1.37	241.36	6.55	1.64	288.86	5.26	1.70
T_5 ($I_1S_2d_2$)	274.94	5.47	1.52	280.53	5.31	1.51	275.63	10.67	1.46
T_6 ($I_1S_2d_3$)	286.04	5.05	1.36	286.76	6.66	1.67	265.08	10.18	1.68
T_7 ($I_1S_3d_1$)	254.57	5.15	1.36	246.72	9.43	1.48	252.98	8.82	1.59
T_8 ($I_1S_3d_2$)	293.52	4.81	1.55	291.27	6.74	1.57	294.30	11.72	1.44
T_9 ($I_1S_3d_3$)	300.39	6.58	1.54	296.55	5.78	1.59	286.55	11.58	1.64
T_{10} ($I_2S_1d_1$)	384.46	9.50	1.51	375.94	7.57	1.53	378.06	6.68	1.64
T_{11} ($I_2S_1d_2$)	392.49	6.08	1.50	381.21	5.50	1.60	390.44	11.09	1.52
T_{12} ($I_2S_1d_3$)	394.76	6.94	1.51	388.04	8.06	1.62	382.84	7.25	1.54
T_{13} ($I_2S_2d_1$)	390.59	8.51	1.76	403.32	7.59	1.64	393.63	7.81	1.43
T_{14} ($I_2S_2d_2$)	398.19	4.74	1.50	409.98	5.90	1.57	402.27	8.44	1.54
T_{15} ($I_2S_2d_3$)	408.78	6.18	1.54	422.35	8.36	1.60	406.09	8.77	1.64
T_{16} ($I_2S_3d_1$)	403.47	7.83	1.53	415.96	7.18	1.66	456.36	8.14	1.60
T_{17} ($I_2S_3d_2$)	408.23	5.09	1.63	424.03	7.29	1.61	415.96	8.38	1.56
T_{18} ($I_2S_3d_3$)	426.36	7.17	1.53	432.14	9.19	1.73	422.48	9.26	1.62

5.6 DRAFT REQUIREMENTS OF THE IMPLEMENTS STUDIED

The statistical analysis on the draft requirements of the animal – drawn implements for the 3 years of study are presented in Appendices E, F and G. The means (Appendix E) showed that, in 2008, the highest draft mean (400.8 N) was obtained from the mouldboard plough while the lowest draft (284.9 N) was obtained from the Emcot ridger. Same trends were observed in 2009 and 2010 (Appendices F and G) respectively. Similarly, for the tillage depth, it was shown that the lower the depth of tillage, the lower will be the draft of the animal drawn implements used and vice versa. The highest draft (350.8 N in 2008, 349.0 N in 2009 and 403.8 N in 2010) was obtained at depth d_3 (15 – 20 cm). This shows that the more soil is cut and turned over by the implement operating at deeper range resulting in high draft values. Similar trend was reported by Abubakar (2008) on the Fadama soils of Samaru. The draft values for the interactions between the implements, speed and tillage depth shows, that (Appendices E, F and G) the highest draft value (426.4 N, 432.1 N and 422.5 N) in 2008, 2009 and 2010 respectively were obtained from the interaction effects of I_2 (Plough), S_3 (1.25 m/s) and d_3 (16 – 20 cm). The corresponding lowest values of the draft (246.8 N, 243.4 N and 251.2 N) were obtained from the interaction effects of I_1 (Ridger), S_1 (0.69 m/s) and d_1 (5 – 10 cm).

Analysis of variance (Tables 5.28, 5.29 and 5.30) for 2008, 2009 and 2010 respectively showed that, the draft was significantly ($P \leq 0.01$) affected by the parameters considered (implement, speed of operation and depth of tillage). Similar result was reported by Abubakar (2008) which say that the draft of animal-drawn tillage implement is significantly ($P \leq 0.01$) affected by tillage depth. The interactions between implement, speed and depth has significantly ($P \leq 0.01$) effected the draft requirement of the implements in the three years of study. The 3 – year combined analysis (Table 5.31) also showed that there was a significant ($P \leq 0.01$) effect of the parameters on the draft requirements of the animal-drawn implements. The interactions between these parameters also significantly ($P \leq 0.01$) affected the draft.

Table 5.28: Analysis of variance of the implement draft for 2008 field study

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	564.6775	282.3388	16.53
Implement (I)	1	181388.4112	181388.4112	10618.80**
Speed (S)	2	5914.3560	2957.1780	173.12**
Tillage depth (d)	2	1711.7244	855.8622	50.10**
I x S	2	3494.8631	1747.4315	102.30**
I x d	2	589.9352	294.9676	17.27**
S x d	4	8273.9249	2068.4812	121.09**
I x S x d	4	9016.1054	2254.0263	131.95**
Error	34	580.7824	17.0818	
Total	53	211534.7800		

** = significant at 0.01 probability level

Table 5.29: Analysis of variance of implement draft for 2009 field study

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	257.9702	128.9851	11.04
Implement (I)	1	259075.0131	259075.0131	22180.30**
Speed (D)	2	10304.4261	5152.2130	441.10**
Tillage depth (d)	2	7270.9807	3635.4904	311.25**
I x S	2	864.3162	432.1581	37.00**
I x d	2	1739.9792	869.9896	74.48**
S x d	4	737.8591	184.4648	15.79**
I x S x d	4	529.1099	132.2775	11.32**
Error	34	397.1333	11.6804	
Total	53	281176.7878		

** = significant at 0.01 probability level

Table 5.30: Analysis of variance of implement draft for 2010 field study

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	13.4873	6.7436	0.18
Implement (I)	1	220064.5675	220064.5675	5725.73**
Speed (S)	2	5085.1826	2542.5913	66.15**
Tillage depth (d)	2	1322.4001	661.2001	17.20**
I x S	2	1086.0988	543.0494	14.13**
I x d	2	149.4542	74.7271	1.94^{ns}
S x d	4	1330.2946	332.5736	8.65**
I x S x d	4	2405.5709	601.3927	15.65**
Error	34	1306.7662	38.4343	
Total	53	232763.8221		

** = significant at 0.01 probability level; ^{ns} = not significant

Table 5.31: Combined analysis of variance of the implement draft for the 3 – year study (2008 to 2010)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Calculated F
Replication	2	603.7708	301.8854	12.71
Year (Y)	2	1329.8413	664.9206	28.00**
Implement (I)	1	657073.5939	657073.5939	27671.20**
Speed (S)	2	19514.5953	9757.2976	410.91**
Tillage depth (d)	2	7243.0259	3621.5130	152.51**
I x Y	2	3454.3979	1727.1989	72.74**
d x Y	4	3062.0793	765.5198	32.24**
S x Y	4	1789.3694	447.3424	18.84**
I x S	2	2627.6888	1313.8444	55.33**
I x d	2	256.2077	128.1039	5.39**
S x d	4	5114.6013	1278.6503	53.85**
I x S x d	4	6869.7480	1717.4370	72.33**
I x S x Y	4	2817.5893	704.3973	29.66**
I x d x Y	4	2223.1609	555.7902	23.41**
S x d x Y	8	5227.4773	653.4347	27.52**
I x S x d x Y	8	5081.0381	635.1298	26.75**
Error	106	2517.0461	23.7457	
Total	161	726805.2311		

** = significant at 0.01 probability level

The maximum means of the draft requirements for the 3 – year field study for various parameters in comparison to the pair of work bull's combined draft capability is shown in Appendix H. When these maximum mean draft at each situation are compared to the work bull's estimated tractive effort (draft capability) as obtained from the physical anthropometric data of the bulls (Table 4.1), it was found that both implements tested are safe to be operated with only one bottom at all situations.

5.7 DRAFT PREDICTION EQUATIONS

The application of dimensional analysis, including the Pi theorem, leads to the formation of equation 3.16 in the form represented below:

$$\frac{D}{S^2 d^2 \rho} = F\left(\frac{I_m}{\rho d^3}, M\right)$$

which involved an unknown function F. Before a prediction equation can be formulated, the nature of the function must be established. The formation of the prediction equations involves the determination of the function for the general equation. This entitled conducting the following:

i. Determination of the component equations.
ii. Determination of the mode of combination to form the prediction equations.
iii. Determination of the value of the constant term for the mode of the combination.
iv. Formation of the general prediction equation.

The procedure for evaluating the function lies in arranging the observations by keeping one Pi – term constant and varying others to establish the relationship between them. This procedure is repeated for each of the π-terms (in the function) in turn, and the resulting relationship between π_1 and the other π-terms combined to give a general relationship.

In order to predict draft using the π-terms developed, dimensionless plots of π_1 against π_2 and π_1 against π_3 were performed for each of the two implements used in the study separately for the two years of study as shown in Figures 5.5 to 5.12. The values obtained were used in generating equations relating the different variables during the model development stage using dimensional analysis. In all the cases, there exists good relationship between π_1 and π_2, and π_1 and π_3 with coefficient of correlation (r) ranging from 0.62 to 0.82.

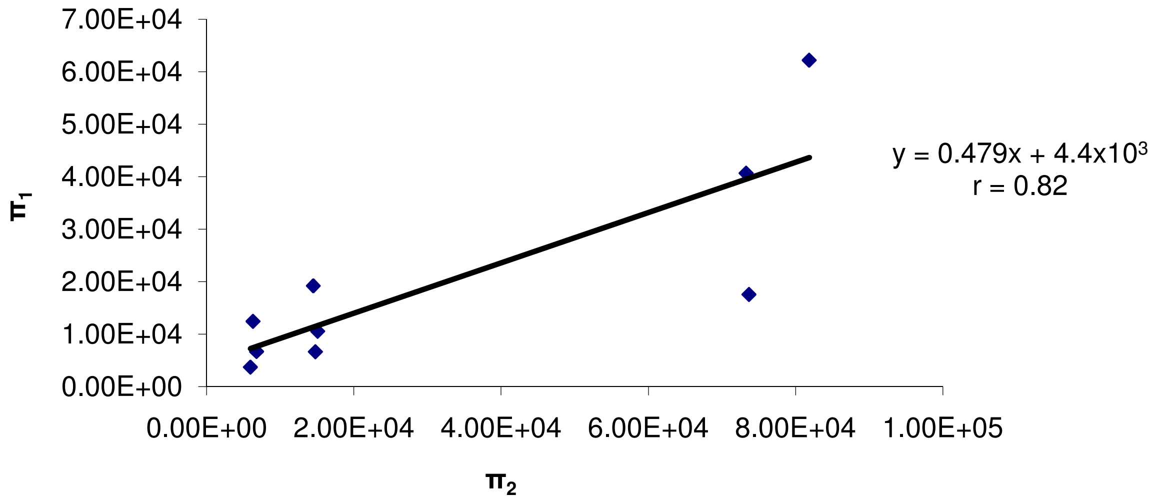

Figure 5.5: Plot of π_1 against π_2 for emcot ridger in 2008 field experiment

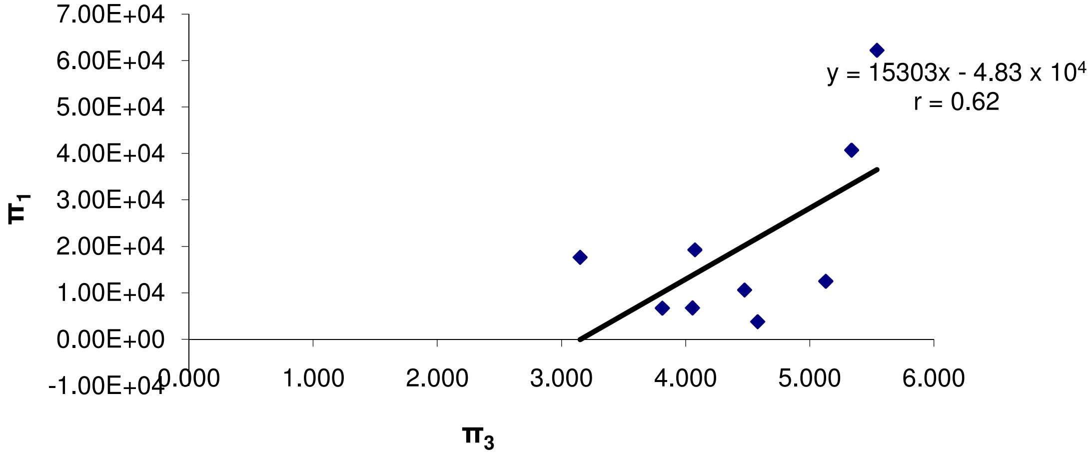

Figure 5.6: Plot of π_1 against π_3 for emcot ridger in 2008 field experiment

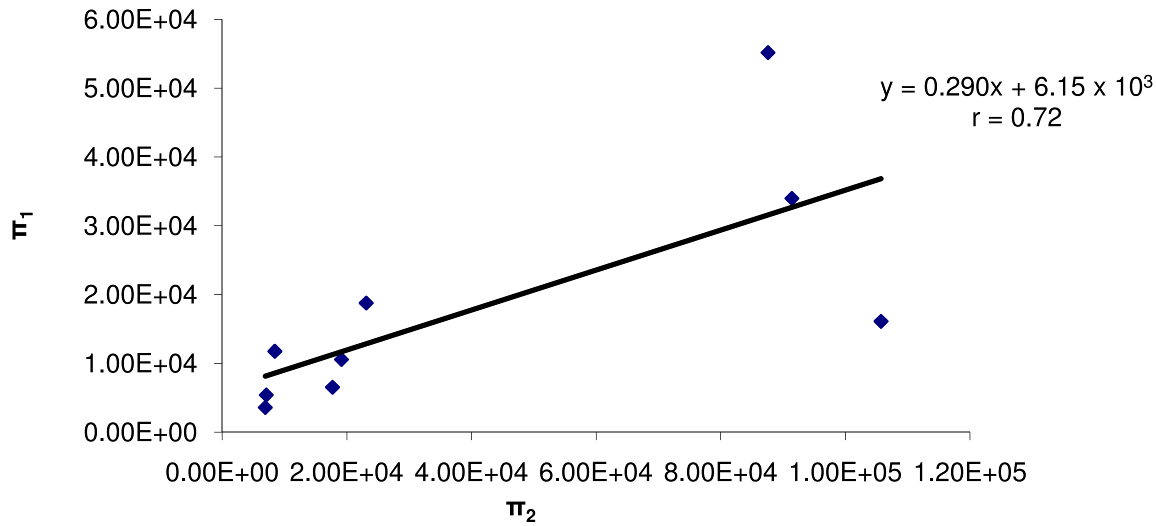

Figure 5.7: Plot of π_1 against π_2 for the emcot ridger in 2009 field experiment

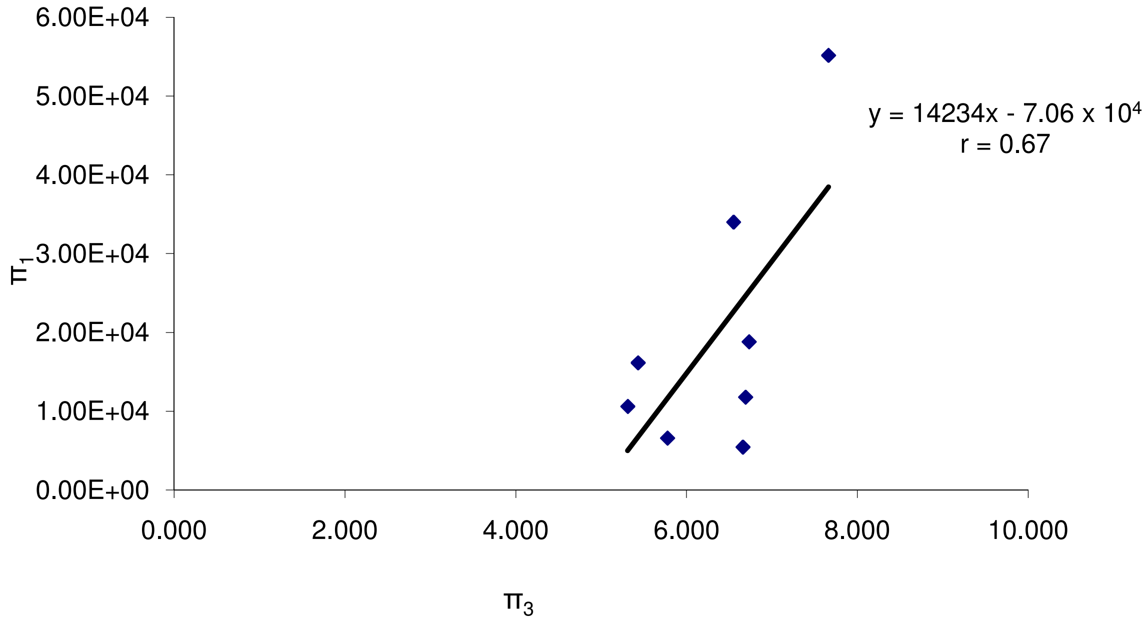

Figure 5.8: Plot of π_1 against π_3 for the emcot ridger in 2009 field experiment

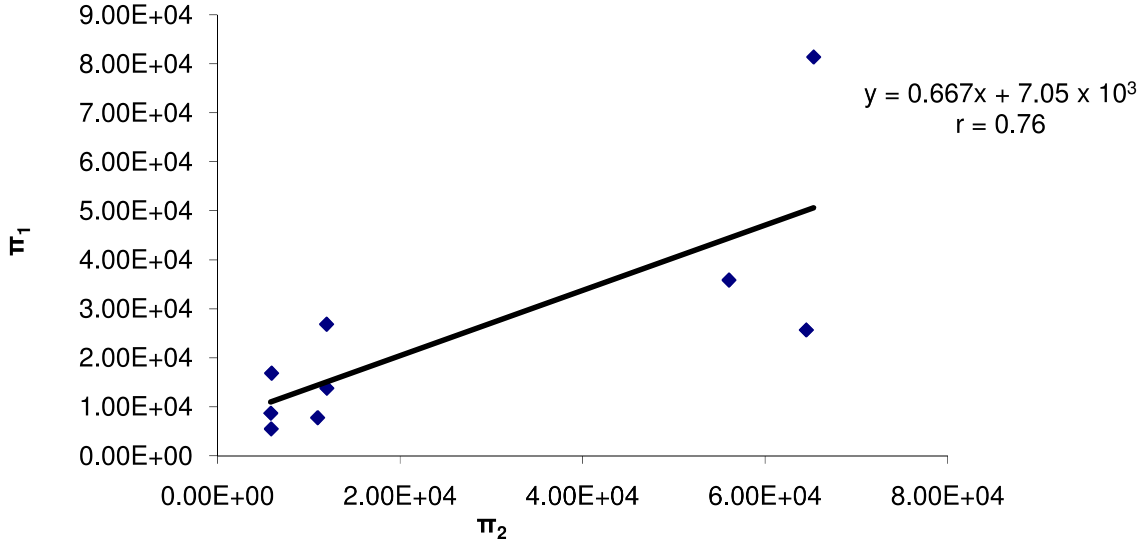

Figure 5.9: Plot of π_1 against π_2 for the mouldboard plough in 2008 field experiment

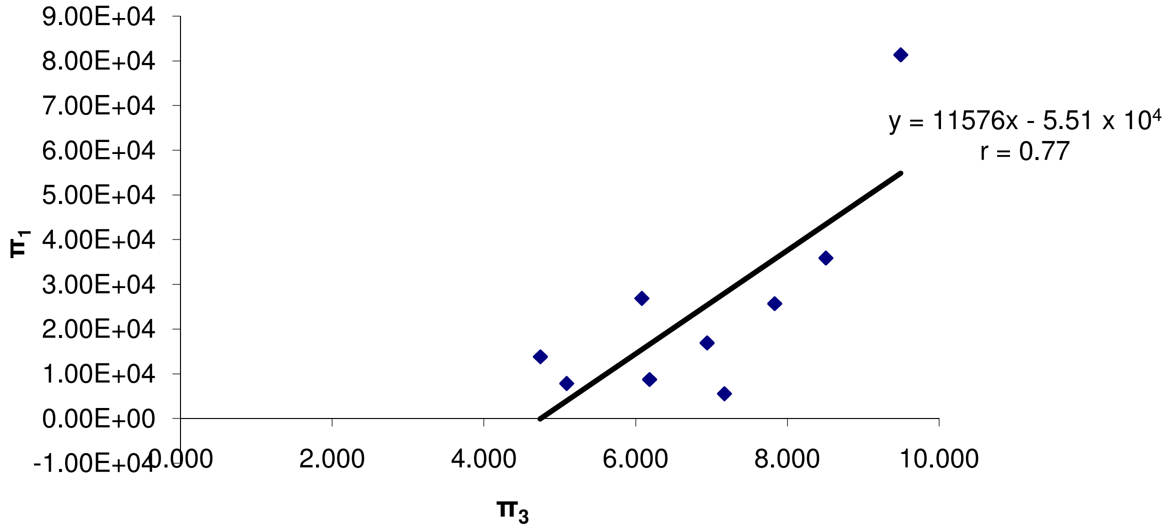

Figure 5.10: Plot of π_1 against π_3 for mouldboard plough in 2008 field experiment

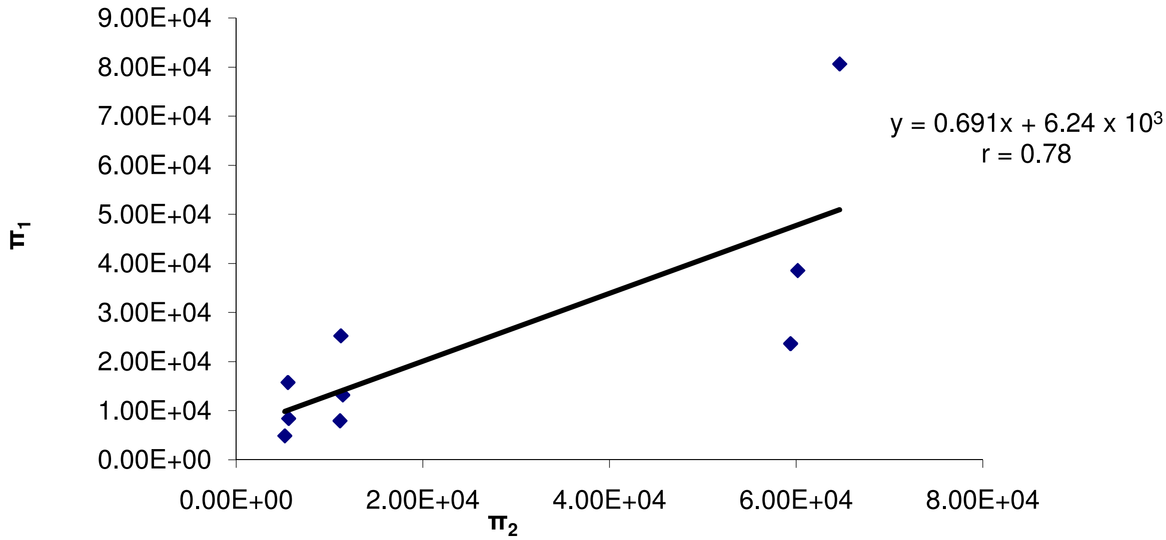

Figure 5.11: Plot of π_1 against π_2 for the mouldboard plough in 2009 field experiment

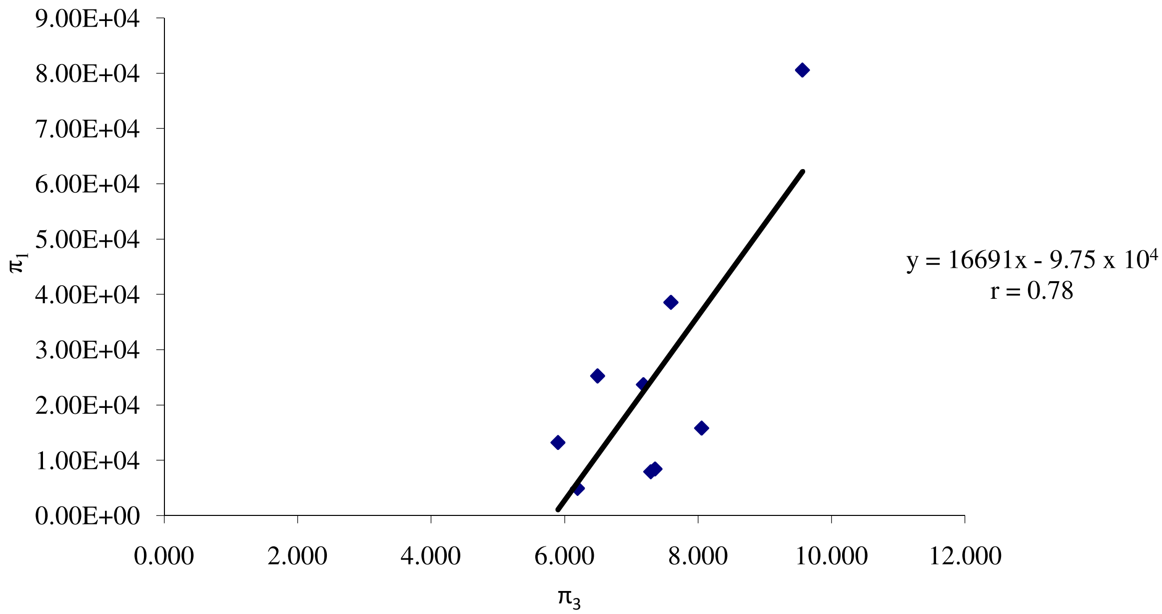

Figure 5.12: Plot of π_1 against π_3 for the mouldboard plough in 2009 field experiment

A dimensional analysis utilizing Pi theorem leads to the identification of some key variables which were investigated in the study. These variables were used in the formulation of two dimensionless equations, they are:

i. Product equation of Pi terms; and

ii. Sum equation of Pi terms.

The forms of component equation always give an insight on the likely condition of mode of combination. Mohammed (2002) quoted Murphy (1950) who explained that: when a set of component equations plot to form a plane surface on space (linear), such equations would be valid for combination as summation and will be of the form:

$$y = a + bx.$$

Whereas those equations that plot to form curved surface in space but form plane surface in logarithmic space, will be valid for combination as product and will be in the form:

$$y = ab^x.$$

5.7.1 Product Function of Pi Terms

Under certain conditions the component equations may be combined to form the general prediction equation by multiplication. The three π-terms used in the model formulation were π_1, π_2, and π_3 and were related as follows:

$$F = (\pi_{1,} \pi_3) \qquad (5.1)$$

Two component equations were established by plotting π_1 against π_2 holding π_3 constant and π_1 against π_3 holding π_2 constant as shown in Figures 5.5 – 5.12. They are respectively,

$$(\pi_1)_{\bar{3}} = f_1(\pi_2, \bar{\pi}_3) \quad (5.2)$$

and

$$(\pi_1)_{\bar{2}} = f_2(\bar{\pi}_2, \pi_3) \quad (5.3)$$

The component equations may be combined to form the general prediction equation by multiplication as:

$$\pi_1 = c(\pi_1)_{\bar{3}}(\pi_1)_{\bar{2}} \quad (5.4)$$

Where:

C = constant of multiplication.

To establish those conditions, the constant C in equation 5.4 must be determined. This can be done by assuming that the component equations are simply multiplied to form the general equation as:

$$F(\pi_2, \pi_3) = f_1(\pi_2, \bar{\pi}_3) f_2(\bar{\pi}_2, \pi_3) \quad (5.5)$$

For this to be true, the first set of Pi terms, with π_3 constant will give the second set of Pi terms with π_2 constant as:

$$F(\pi_2, \bar{\pi}_3) = f_1(\pi_2, \bar{\pi}_3) f_2(\bar{\pi}_2, \bar{\pi}_3) \quad (5.6)$$

from which,

$$f_1(\pi_2, \bar{\pi}_3) = \frac{F(\pi_2, \bar{\pi}_3)}{f_2(\bar{\pi}_2, \bar{\pi}_3)} \quad (5.7)$$

The second set of Pi terms, with π_2 constant (from equation 5.5) gives,

$$F(\bar{\pi}_2, \pi_3) = f_1(\bar{\pi}_2, \bar{\pi}_3) f_2(\bar{\pi}_2, \pi_3) \quad (5.8)$$

from which,

$$f_2(\bar{\pi}_2, \pi_3) = \frac{F(\bar{\pi}_2, \pi_3)}{f_1(\bar{\pi}_2, \bar{\pi}_3)} \quad (5.9)$$

The values of $f_1(\pi_2, \bar{\pi}_3)$ and $f_2(\bar{\pi}_2, \pi_3)$ from equations 5.7 and 5.9 respectively were substituted in to equation 5.5 and gives:

$$F(\pi_2, \pi_3) = \frac{F(\pi_2,\bar{\pi}_3)F(\bar{\pi}_2,\pi_3)}{f_2(\bar{\pi}_2,\bar{\pi}_3)f_1(\bar{\pi}_2,\bar{\pi}_3)} \quad (5.10)$$

However, the denominator of equation 5.10 was found from equation 5.5 with both π_2 and π_3 constant. Thus,

$$F(\bar{\pi}_2, \bar{\pi}_3) = f_2(\bar{\pi}_2, \bar{\pi}_3)f_1(\bar{\pi}_2, \bar{\pi}_3) \quad (5.11)$$

Therefore, equation 5.10 becomes:

$$F(\pi_2, \pi_3) = \frac{F(\pi_2,\bar{\pi}_3)F(\bar{\pi}_2,\pi_3)}{F(\bar{\pi}_2,\bar{\pi}_3)} \quad (5.12)$$

From equation 5.12 the value of the constant C in equation 5.4 determined as $1/F(\bar{\pi}_2, \bar{\pi}_3)$. Equation 5.12 gives the general prediction equation. This equation was determined by holding the π_3 constant. But if valid, it could also have been determined from another set of data if π_3 is held at another value of π_3 to give the following equation:

$$F(\pi_2, \pi_3) = \frac{F(\pi_2,\bar{\pi}_3)F(\bar{\pi}_2,\pi_3)}{F(\bar{\pi}_2,\bar{\pi}_3)} \quad (5.13)$$

Thus, for product combination of the component equation to be valid, the right-hand side of equation 5.12 must be equal to the right-hand side of equation 5.13. Hence,

$$\frac{F(\pi_2,\bar{\pi}_3)}{F(\bar{\pi}_2,\bar{\pi}_3)} = \frac{F(\pi_2,\bar{\pi}_3)}{F(\bar{\pi}_2,\bar{\pi}_3)} \quad (5.14)$$

5.7.2 Sum Function of Pi-Terms

For function to be sum, it should be assumed that:

$$F(\pi_2, \pi_3) = f(\pi_2) + g(\pi_3) \quad (5.15)$$

Then,

$$F(\bar{\pi}_2, \pi_3) = f(\bar{\pi}_2) + g(\pi_3) \quad (5.16)$$

from which,

$$g(\pi_3) = F(\bar{\pi}_2, \pi_3) - f(\bar{\pi}_2) \quad (5.17)$$

similarly,

$$f(\pi_2) = F(\pi_2, \bar{\pi}_3) - g(\bar{\pi}_3) \quad (5.18)$$

Therefore, equation 5.15 can be written as:

$$F(\pi_2, \pi_3) = F(\pi_2, \bar{\pi}_3) - g(\bar{\pi}_3) + F(\bar{\pi}_2, \pi_3) - f(\bar{\pi}_2)$$

$$= F(\pi_2, \bar{\pi}_3) + F(\bar{\pi}_2, \pi_3) - F(\bar{\pi}_2, \bar{\pi}_3) \quad (5.19)$$

Equation 5.19 shows that if the component equations are to be combined by addition to form the general prediction equation, a constant, C must be subtracted from the sum of the component equations.

5.7.3 Determination of the Component Equations

The component equations are formed from the experimental data on the π-terms. They represent the regression equations of the π-terms data which are presented in Appendices I and J for the Emcot ridger and mouldboard plough respectively. Each of the tables consists of data of the three π-terms required for the determination of the prediction equations.

5.7.3.1 *The Emcot Ridger Component Equations*

These consist of equations which were formed from the plots π_{1r} against π_{2r} and π_{1r} against π_{3r} from data presented in Appendix I for the 2008 and 2009 years field experiment. The graphs are respectively shown in Figures 5.5 to 5.8.

The regression equations representing the component equations are give as:

$$\pi_{1r} = 4.40 \times 10^3 + 0.479\pi_{2r} \quad (5.20)$$

$$\pi_{1r} = 1.53 \times 10^4 \pi_{3r} - 4.83 \times 10^4 \quad (5.21)$$

5.7.3.2 *The Mouldboard Plough Component Equations*

The π-terms data for the mouldboard plough is given in Appendix J for the 2008 and 2009 field experiment. The plots of π_{1p} against π_{2p} and π_{1p} against π_{3p} are respectively shown in Figures 5.9 to 5.12. The regression equations representing the component equations are given as:

$$\pi_{1p} = 7.05 \times 10^3 + 0.667\pi_{2p} \quad (5.22)$$

$$\pi_{1p} = 1.16 \times 10^4 \pi_{3p} - 5.51 \times 10^4 \quad (5.23)$$

5.7.4 The Component Equations Combination

The component equations may be combined by either summation or multiplication to form the general prediction equation. The selection of which depends on which criteria a set of component equations satisfies. The criteria as explained by Murphy (1950) and reported by Mohammed (2002) is given in section 5.7.

The plots of the π-terms (Figures 5.5 to 5.12) showed that each of the component equations formed a plane surface in linear space. The form of the equations can be seen in equations 5.20 to 5.23. These equations being linear, favoured combination by summation. The general condition for summation with respect to the three π-terms is given in equation 5.19. Its application in this study is as follows:

$$\pi_1 = F(\pi_2, \bar{\pi}_3) + F(\bar{\pi}_2, \pi_3) - F(\bar{\pi}_2, \bar{\pi}_3) \tag{5.24}$$

5.7.4.1 *Test for Summing the Emcot ridger Draft Component Equations*

One of the component equations for the Emcot ridger draft component is equation 5.20, given as:

$$\pi_{1r} = 4.40 \times 10^3 + 0.479\pi_{2r} = f_{1r}(\pi_2, \bar{\pi}_3)$$

Taking $\pi_{2r} = 6.12 \times 10^3$

$$f_{1r}(\bar{\pi}_2, \bar{\pi}_3) = 4.40 \times 10^3 + 0.479\pi_{2r}$$

$$= 4.40 \times 10^3 + 0.479(6.12 \times 10^3)$$

$$= 4.40 \times 10^3 + 2.93 \times 10^3$$

$$= 7.33 \times 10^3$$

A supplementary equation when π_3 is held at another value of π_3 is:

$$\pi_{1r} = 8.60 \times 10^3 + 0.396\pi_{2r} = f_{1r}(\pi_2, \bar{\pi}_3)$$

Using $\pi_{2r} = 7.51 \times 10^3$

$$f_{1r}(\bar{\pi}_2, \bar{\pi}_3) = 8.60 \times 10^3 + 0.396\pi_{2r}$$

$$= 8.60 \times 10^3 + 0.396(7.51 \times 10^3)$$

$$= 8.60 \times 10^3 + 2.97 \times 10^3$$

$$= 11.57 \times 10^3$$

Substituting the component and supplementary equations and their constant values in equation 5.24:

$$4.40 \times 10^3 + 0.479\pi_{2r} - 7.33 \times 10^3 = 8.60 \times 10^3 + 0.396\pi_{2r} - 11.57 \times 10^3$$

$$0.479\pi_{2r} - 2.93 \times 10^3 = 0.396\pi_{2r} - 2.97 \times 10^3 \tag{5.25}$$

Since the right hand side of equation 5.25 is approximately equal to its left hand side, it means that, the combination by summation of the Emcot ridger draft component equation is valid.

5.7.4.2 *Test for Summing the Mould board plough Draft Component Equations*

When the component equation 5.22 and a supplementary equation from the regression coefficients of the data (Appendix J) are considered:

$$\pi_{1r} = 7.05 \times 10^3 + 0.6676\pi_{2p} = f_{1p}(\pi_2, \bar{\pi}_3)$$

$$\pi_{2p} = 5.89 \times 10^3$$

$$f_{1r}(\bar{\pi}_2, \bar{\pi}_3) = 7.05 \times 10^3 + 0.667\pi_{2p}$$

$$= 7.05 \times 10^3 + 0.667(5.89 \times 10^3)$$

$$= 7.05 \times 10^3 + 3.93 \times 10^3$$

$$= 10.98 \times 10^3$$

A supplementary equation when π_3 is held at another value of π_3 is:

$$\pi_{1p} = 6.24 \times 10^3 + 0.691\pi_{2p} = f_{1p}(\pi_2, \bar{\pi}_3)$$

$$\pi_{2p} = 5.47 \times 10^3$$

$$f_{1p}(\bar{\pi}_2, \bar{\pi}_3) = 6.24 \times 10^3 + 0.691\pi_{2p}$$

$$= 6.24 \times 10^3 + 0.691(5.47 \times 10^3)$$

$$= 6.24 \times 10^3 + 3.78 \times 10^3$$

$$= 10.02 \times 10^3$$

Substituting the component and supplementary equations and their constant values in equation 5.24:

$$6.24 \times 10^3 + 0.691\pi_{2p} - 10.02 \times 10^3 = 7.05 \times 10^3 + 0.667\pi_{2p} - 10.98 \times 10^3$$

$$0.691\pi_{2p} - 3.78 \times 10^3 = 0.667\pi_{2p} - 3.93 \times 10^3 \qquad (5.26)$$

Since the right hand side of equation 5.26 is approximately equal to its left hand side, it means that, the combination by summation of the mould board plough draft component equation is valid.

5.7.5 Determination of the Constant of Summation

The constant of summation for the three π-terms is given in equation 5.19 as:

$$C = F(\bar{\pi}_2, \bar{\pi}_3)$$

Where,

C = constant of summation

and F = functional notation.

The constant term can either be:

$C = f_1(\bar{\pi}_2, \bar{\pi}_3)$, or $C = f_2(\bar{\pi}_2, \bar{\pi}_3)$

The constant can be evaluated from any of the component equations as each should give the same value as the other (Murphy, 1950 as cited by Mohammed, 2002). The component equations for the Emcot ridger are given in section 5.7.3.1 and the constant is evaluated as follows:

$$C_r = f_{1r}(\bar{\pi}_2, \bar{\pi}_3) = 4.40 \times 10^3 + 0.479\bar{\pi}_{2r}$$

From Appendix I: $\bar{\pi}_{2r} = 7.63 \times 10^4$

C_r = 4.40 x 10^3 + 0.479 (7.63 x 10^4)

= 4.40 x 10^3 + 3.65 x 10^4

= 40.9 x 10^3

Or

$C_r = f_{2r}(\bar{\pi}_2, \bar{\pi}_3) = 1.53 \times 10^4 \bar{\pi}_{3r} - 4.83 \times 10^4$

From Appendix I: $\bar{\pi}_{3r} = 5.86$

$C_r = 1.53 \text{ x } 10^4 (5.86) – 4.83 \text{ x } 10^4$

$= 8.97 \text{ x } 10^4 – 4.83 \text{ x } 10^4$

$= 41.4 \text{ x } 10^3$

The constants calculated from either of the component equations are approximately equal. Thus, it shows that the component equations are correct.

The constant of summation for the mould board plough equation is:

$C_p = f_{1p}(\bar{\pi}_2, \bar{\pi}_3)$ or $C_p = f_{2p}(\bar{\pi}_2, \bar{\pi}_3)$

$C_p = f_{1p}(\bar{\pi}_2, \bar{\pi}_3) = 7.05 \times 10^3 + 0.667 \bar{\pi}_{2p}$

From Appendix J: $\bar{\pi}_{2p} = 1.13 \times 10^4$

$Cp = 7.05 \text{ x } 10^3 + 0.667 (1.13 \text{ x } 10^4)$

$= 7.05 \text{ x } 10^3 + 7.54 \text{ x } 10^3$

$= 14.59 \text{ x } 10^3$

Or

$C_p = f_{2p}(\bar{\pi}_2, \bar{\pi}_3) = 1.16 \times 10^4 \bar{\pi}_{3p} - 5.51 \times 10^3$

From Appendix J: $\bar{\pi}_{3p} = 5.93$

$C_p = 1.16 \text{ x } 10^4 (5.93) – 5.51 \text{ x } 10^4$

$= 6.88 \text{ x } 10^4 – 5.51 \text{ x } 10^4$

$= 1.37 \text{ x } 10^4$

$= 13.7 \text{ x } 10^3$

Since the C_p calculated from either of the plough component equations are approximately equal, it shows also that the equations are correct.

5.7.6 Prediction Equations

The general prediction equation for a system or process involving three π-terms formed by addition of the component equations as given in equation 5.19 is:

$$\pi_1 = F(\pi_2, \bar{\pi}_3) + F(\bar{\pi}_2, \pi_3) - F(\bar{\pi}_2, \bar{\pi}_3)$$

Where, $F(\bar{\pi}_2, \bar{\pi}_3)$ is the constant C.

The general equation for Emcot ridger draft requirement and mould board plough draft requirement are obtained by summing the respective component equations respectively as:

$$\pi_{1r} = f_{1r}(\pi_2, \bar{\pi}_3) + f_{2r}(\bar{\pi}_2, \pi_3) - C_r \quad (5.27)$$

And

$$\pi_{1p} = f_{1p}(\pi_2, \bar{\pi}_3) + f_{2p}(\bar{\pi}_2, \pi_3) - C_p \quad (5.28)$$

Section 5.7.4 shows the algebraic summation of the component equations and the constant of summation (C_r and C_p) for the Emcot ridger and mould board plough draft respectively.

The results obtained are:

For Emcot ridger,

$$\pi_{1r} = (4.40 \times 10^3 + 0.479\pi_{2r}) + (1.53 \times 10^4\pi_{3r} - 4.83 \times 10^4) - 40.9 \times 10^3$$

$$= 0.479\ \pi_{2r} + 1.53 \text{ x } 10^4\ \pi_{3r} - 8.48 \text{ x } 10^4$$

Therefore:

$$\frac{D}{S^2d^2\rho} = 0.479\left(\frac{I_m}{\rho d^3}\right) + 1.53 \times 10^4(M) - 8.48 \times 10^4$$

$$D_r = 0.479\ I_mS^2d^{-1} + 1.53 \text{ x } 10^4\ S^2d^2\rho M - 8.48 \text{ x } 10^4\ S^2d^2\rho$$

$$D_r = S^2d^2 (0.479\ I_m d^{-3} + 1.53 \times 10^4 \rho M - 8.48 \times 10^4 \rho) \quad (5.29)$$

For the mould board plough,

$$\pi_{1p} = (7.05 \times 10^3 + 0.667\pi_{2p}) + (1.16 \times 10^4 \pi_{3p} - 5.51 \times 10^4) - 14.59 \times 10^3$$

$$= 0.667\pi_{2p} + 1.16 \times 10^4\ \pi_{3p} - 6.26 \times 10^4$$

Therefore,

$$\frac{D}{S^2d^2\rho} = 0.667\left(\frac{I_m}{\rho d^3}\right) + 1.16 \times 10^4(M) - 6.26 \times 10^4$$

$$D_p = 0.667\ I_m S^2 d^{-1} + 1.16 \times 10^4\ S^2d^2\rho M - 6.26 \times 10^4\ S^2d^2\rho$$

$$D_p = S^2d^2 (0.667\ I_m d^{-3} + 1.16 \times 10^4 \rho M - 6.26 \times 10^4 \rho) \quad (5.30)$$

Equations 5.29 and 5.30 are the required models for the draught requirement of the Emcot ridger and mould board plough implements respectively.

5.8 VERIFICATION OF THE MODEL EQUATIONS

Verification of any formulated model is very important before it can be applied in any research or design works. Model verification and validation are essential parts of model development process if the models are to be accepted and used to support decision making (Macal, 2005). For the purpose of utilization of the developed model for either determination of production possibilities, design, improving decision-making process or simple representation of a complex agricultural system, the model should be verified. This involves comparison of calculated model output with the experimental results of the existing process. The comparison should include the determination of the extent of agreement between the calculated model output and the physically measured data. A common statistical technique to judge the performance of models is to plot observed values against predicted values and fit a straight line through the data with a zero intercept. The slope and coefficient of determination (r^2) values are then used as indices of agreement with observed data (Reddy *et al.,* 1995). If both high correlation and no significant difference between the predicted and measured data are attained, the model is said to be good.

5.8.1 Comparison Technique

A good comparison of a model performance should involve the use of both qualitative and quantitative comparison techniques (Panse and Sukhatme, 1989). The qualitative technique involves the use of regression analysis where the coefficients of regression (slope and intercept) are determined. As the slope and intercept approach unity and zero respectively, the better the model performance (Alder and Roessler, 1977). The coefficient of determination (r^2) represents the quantitative measure of the correlation between the predicted and observed values (Mosteller *et al.,* 1970 and Walpole, 1982). It can be computed by squaring coefficient of correlation (r) or computed directly by calculating the variance of the data about the mean (Quenouille, 1950). By squaring r, the coefficient of determination is given as:

$$r^2 = \frac{\sum(x-\bar{x})^2(y-\bar{y})^2}{\sum(x-\bar{x})^2\sum(y-\bar{y})^2} \tag{5.31}$$

Where;

x = individual independent variable measurement,

y = individual dependent variable measurement,

$\bar{x}$ = mean independent variable measurement,

$\bar{y}$ = mean dependent variable measurement.

The significance of the r^2 value may be tested using t – table employing an expression given by Quenouille (1950) as:

$$t_{cal} = \sqrt{\frac{r^2(n-2)}{1-r^2}} \quad (5.32)$$

Where;

t_{cal} = calculated t – value,

n = number of paired variables,

r = correlation coefficient.

Coefficient of determination (r^2) varies between 0 and 1.0. An r^2 value of 0.8 is considered a good fit for agricultural research work involving plants or animals (Gregory and Fedler, 1986). The variability or spread of the points can be measured by Root Mean Square Error (RMSE), standard deviation or its square (covariance) (Alder and Roessler, 1977) as:

$$CV = \frac{\sum(x-\bar{x})(y-\bar{y})}{n-1} \quad (5.33)$$

Where;

CV = covariance,

n = number of observations,

other terms are as defined previously.

A student t – test was used to establish the statistical significance of the degree of association of the two groups of variables at a given level of significance. A paired t – test is calculated as:

$$t_c = \frac{\bar{x}_p - \bar{x}_m}{SE} \quad (5.34)$$

$$SE = \sqrt{\frac{SS}{n(n-1)}} \quad (5.35)$$

$$SS = CSS - \frac{[\sum(x_p - x_m)]^2}{n} \quad (5.36)$$

$$CSS = \sum(x_p - x_m)^2 \quad (5.37)$$

and $$RMSE = \sqrt{\frac{\sum(x_p - x_m)^2}{n}} \quad (5.38)$$

where;

t_c = calculated t value

x_m = individual measured value

x_p = individual predicted value

$\bar{x}_m$ = mean measured value

$\bar{x}_p$ = mean predicted value

SE = standard error

SS = sum of squares

CSS = crude sum of squares

n = number of paired variables

all other terms are as previously explained.

5.8.2 Verification of the Emcot ridger Draft Equation

The Emcot ridger model equation is given in equation 5.29. The computed output of the equation in terms of the dimensionless group π_{1r} representing ($D/S^2\rho d^2$) and the measured data are presented in Table 5.32. The computed output of the predicted was plotted against the measured result as presented in Figure 5.13. The regression analysis (Figure 5.13) gave the values of the slope and intercept as 0.904 and 2.469 x 10^2 respectively. The coefficient of determination (r^2) was found to be 0.967. A paired t-test was conducted and the result revealed that the calculated t-value (0.982) is less than the table value (2.898) at 0.01 significant levels. This shows that there is no significant ($P \leq 0.01$) difference between the predicted and measured π_1 values for the Emcot ridger draft requirement. The Root Mean Square Error (RMSE) was found to be 0.778. The coefficient of determination (r^2) was found to be highly significant using t table with the calculated value of 96.70 which is greater than the value of (2.898) at 0.01 probability levels and 17 degree of freedom.

Table 5.32: Predicted and measured π_1 values for the Emcot ridger draught requirement

S/No	Predicted π_{1r} values	Measured π_{1r} values
1	5.08×10^4	6.22×10^4
2	1.96×10^4	1.92×10^4
3	1.00×10^4	1.25×10^4
4	2.81×10^4	3.07×10^4
5	1.03×10^4	1.06×10^4
6	5.05×10^3	6.70×10^3
7	1.54×10^4	2.76×10^4
8	6.92×10^3	6.66×10^3
9	3.40×10^3	3.72×10^3
10	8.26×10^4	7.52×10^4
11	3.14×10^4	1.88×10^4
12	1.63×10^4	1.18×10^4
13	4.75×10^4	3.40×10^4
14	1.51×10^4	1.06×10^4
15	8.05×10^3	5.43×10^3
16	3.04×10^4	1.61×10^4
17	9.85×10^3	6.54×10^3
18	5.24×10^3	4.60×10^3

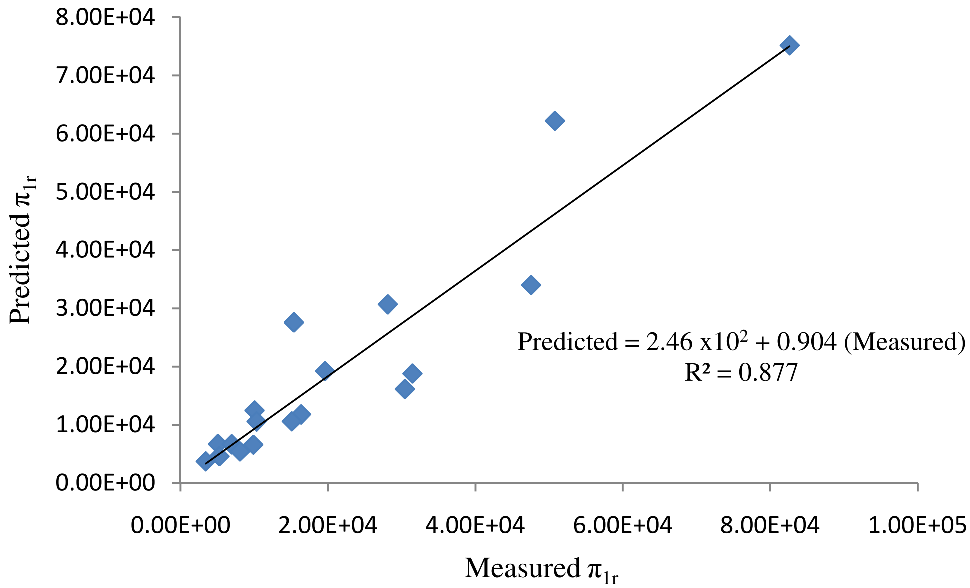

Figure 5.16 Plot of Predicted π_{1r} against Measured π_{1r} for Emcot ridger draft requirement

5.8.3 Verification of the Mould board Plough Draft Equation

The Mould board Plough equation is presented in equation 5.30. Table 5.33 gives the model equation in terms of the predicted results of π_1 against the measured π_1 values. The predicted output was plotted against the measured values as shown in Figure 5.14. Regression analysis (Figure 5.14) gave 0.945 and -0.78 x 10^2 respectively as the values of the slope and intercept. The coefficient of determination (r^2) was found to be 0.924. A paired t-test showed that the calculated t-value (1.015) is less than the table value (2.898) at 0.01 significant level. This result shows that there was no significant difference between the predicted and measured π_1 values for the mould board plough draft requirement. The variation using Root Mean Square Error (RMSE) was found to be 0.627. The test of significance of the coefficient of determination (r^2) using t table revealed that it is highly significant with calculated value of 114.51 which is greater than the value of (2.898) at 0.01 probability levels and 17 degree of freedom.

Table 5.33: Predicted and measured π_1 values for the mould board plough draught requirement

S/No	Predicted π_{1r} values	Measured π_{1r} values
1	8.80×10^4	8.14×10^4
2	2.97×10^4	2.69×10^4
3	1.41×10^4	1.69×10^4
4	3.91×10^4	3.59×10^4
5	1.54×10^4	1.38×10^4
6	7.72×10^4	8.71×10^4
7	2.60×10^4	2.57×10^4
8	9.67×10^3	7.81×10^3
9	4.97×10^3	5.51×10^3
10	7.89×10^4	8.06×10^4
11	2.89×10^4	2.52×10^4
12	1.61×10^4	1.58×10^4
13	4.65×10^4	3.85×10^4
14	1.46×10^4	1.32×10^4
15	7.91×10^3	8.40×10^3
16	2.59×10^4	2.37×10^4
17	8.92×10^3	7.92×10^3
18	5.03×10^3	4.88×10^3

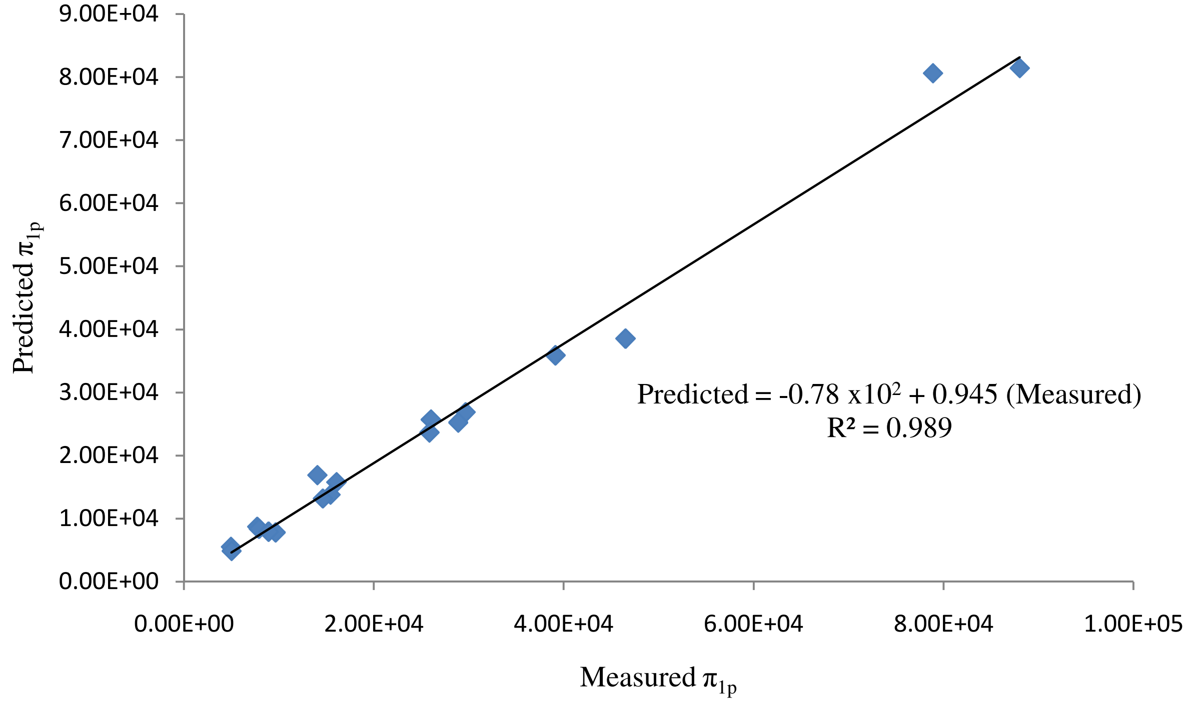

Figure 5.14 Plot of Predicted π_{1p} against Measured π_{1p} for Mould board plough draft requirement

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Using the model of Zelenin (1950) for draft requirement of tillage implements, models were developed to include the implement mass, speed of operation, soil moisture content and bulk density (as these were not considered in the referred model) for two animal – drawn implements in the upland soil of Samaru, Zaria. The developed models provide a highly simplified representation of the processes in soil tillage and the interactions of the draft characteristics and the implements. The simplication was necessary to meet the requirements of farmers in selecting draft animals for different implements in tilling soil for crop production. The models will be used in assisting farmers to avoid animal – implement mismatch in carrying field operations using draft animals. From the results of this study, the following conclusions are drawn:

1) Plant height varied with the implement used and depth of tillage considered, and that plant height increased with increase in tillage depth.
2) For Emcot ridger, the highest mean grain yield was obtained in treatment T_8 ($I_1S_3d_2$) and least in T_7 ($I_1S_3d_1$). However, the overall highest mean grain yield was obtained in treatment T_{15} ($I_2S_2d_3$) in the 3 – year study.
3) The soil moisture content and bulk density affected the draft of the animal – drawn implements positively. That is there is increase in draft with increased in the two soil physical properties at any particular depth considered.
4) Combined analysis of variance of the 3 – year study showed that the draft of the implements was significantly ($P \leq 0.01$) affected by the soil moisture content and

bulk density. The interactions of implement x speed x depth also showed significant ($P \leq 0.01$) effect of the soil moisture content and the bulk density on the draft.

5) Statistical analysis showed that the highest draft values were obtained in the interaction of implement x speed x depth as 426.4 N, 432.1 N and 422.5 N in 2008, 2009 and 2010 respectively with the mould board plough in treatment T_{18} ($I_2S_3d_3$). These values are within the animals' combined draft ability (630.8 N) at 12 % of their body weight.
6) Mathematical models for predicting the draft requirements of the two animal – drawn implements with regards to the effects of operating speed, tillage depth, implement mass, soil moisture content and bulk density were developed.
7) The models predicted experimental data very well with agreement between the predicted and measured values. Coefficient of determination (r^2) between the predicted and measured value were 0.967 and 0.924 for the ridger and plough respectively.
8) The calculated t – value (0.982 and 1.015) for the Emcot ridger and the mould board plough respectively. These values are less than the table (t – value, 2.898) at 0.01 levels of significance. This showed that, there is no significant ($P \leq 0.01$) difference between the predicted and measured values of the two implements.

6.2 RECOMMENDATIONS

Based on the outcome of the 3 – year study, the following recommendations can be made:

1) The developed models explained satisfactory the draft of the animal – drawn implements. However, the study was only on two of the many animal – drawn

implements available. Therefore, further researches are necessary to establish the draft requirements of the other implements.

2) Since the maximum draft of 432.1 N obtained at the critical combination of the parameters involved in this study is less than the animals' combined draft ability (630.8 N), implement designers could use the models in designing tool carriers that will include tillage implement and planter animal – drawn implement.
3) Farmers can also these results to avoid the mismatch of animal/implement selection for farm operation.
4) The developed models were validated using quantitative and qualitative methods only. It is therefore, recommended that, the mathematical relationships be tested using computer simulation.
5) It is also recommended that, penetration resistance be included in modeling the draft requirements of the two implements in further research work since it was not included in this study.

REFERENCES

Abubakar, L.G. (2008). Applicability and effectiveness of animal-drawn tillage implement in the 'Fadama' farming system. PhD seminar, Department of Agricultural Engineering, ABU, Zaria.

Abubakar, L.G., Mohammed, U.S and El-Okene, A.M. (2000). Development of a hydraulic dynamometer for draft measurements of tillage implements. Savanna Journal of Agricultural Mechanization **2** (1): 37 – 39.

Abubakar, L.G., Mohammed, U.S., Shani, B.B and Abdullahi, S. (2005). Draught requirements of some locally use ox-drawn tillage implements in Zaria. Proceedings of the 6th International Conference of the NIAE **27**: 46 – 50.

AERLS. (1983). Effective Training of Workbulls. Extension guide No.134, Engineering Series, No.16. Agricultural Extension and Research Liaisons Services.

Ahaneku, I.E., Onwualu, A.P., James, D and Oni, A.O. (2004). Effects of soil moisture and ploughing speed on draught and power requirements of disc plough. JAET **12**: 19 – 25.

Alder, H.L. and Roessler E.B. (1977). Introduction to probability and stastistics. 6th Edition. Dover Publications. Inc., United State of America.

Al-Janobi, A.A. and Al-Suhaibani, S.A. (1998). Draught of primary tillage implements in sandy loam soil. Transaction of the ASAE **14** (4): 343 – 348.

Andersson, M.P. and Woessner, W.W. (1992). Applied groundwater modeling. Academic Press Inc. pp381.

Anonymous (1992). Tools for agriculture. A guide to appropriate equipment for small holder farmers. CTA publication pp 238.

Anonymous (1989). Fertlizer use and management practices for crops in Nigeria. Fertilizer procurement and distribution division of the F.M.A.W.R. and R.D. Lagos.

Anonymous. (2005). Farm animals for the future. Spore Issue No. 118. Publication of the CTA. P.11.

Anonymous. (2011). Model Formulation. http://www.utdallas.edu/metin/Or6201/formulation.pdf. 21p. Cited on 14th February, 2011.

Arvidsson, J. and Keller, T. (2011). Comparing penetrometer and shear vane measurements with measured and predicted mould board plough draft in a range of Swedish soils. Soil and Tillage Research, **111**: 219 – 223.

ASAE Standards. (1990). Agricultural machinery management data. 37th ed. ASAE D497. St. Joseph, Michigan: 372 – 380.

ASAE Standards. (1994). Agricultural machinery management data. 41st Edn. St.Joseph, Michigan: ASAE. p343.

Asota, C.O. (1996). Animal Draught Technology: A viable mechanization alternative to tractorisation in small farms. Proceedings of the training programme held at IAR, Zaria, Nigeria, 18th September – 14th October, 1995 under the sponsorship of the Commonwealth Secretariat, UK: 26 – 47.

Awadhwal, N.L., Shetty, S.V.R, Wiangado, O. and Traore, M.B. (1992). Development and testing of a donkey-drawn cultivator-cum seeder. AMA **23**(2): 25-28.

Bai, H.K. (1990). Village level Engineering: the importance of blacksmith in supporting animal traction and agricultural production. Proceedings of the 3rd workshop of the WAATN, held at Saly, Senegal. Edited by Starkey, P. and A. Faye, 334 – 336.

Bako, S. and Ingawa, S. (1990). Animal traction in Nigeria: Impact, constraints and current initiatives. In: Starkey, P. and A. Faye (eds), Animal traction for agricultural development. A keynote paper in proceedings of the third WAATN workshop held July 1980, Saly, Senegal.

Baloch, J.M., Miram, S.N., Miram, A.N. and Bukhari, S. (1991). Power requirements of tillage implements. AMA **22**(1): 34-38.

Bansal, R.K. and El Garras, O. (1987). A report on small farm mechanization project 1986-87. BP 290, Seltat, Morocco: Centre Regional de la Recharche Agronomique.

Bansal, R.K., El Garras, O. and Hamilton, J.H. (1992). Performance of draught animal at work in Morocco: Draughtability and power output. AMA **23** (1): 65-70.

Barwell, L. and Ayre, M. (1982). The harnessing of draught animals. Intermediate Technology Publications, London.

Bashford, L.L., Byerly, D.V. and Grisso, R.D. (1991). Draught and energy requirements of agricultural implements in semi-arid regions of Morocco. AMA 22(3): 79-82.

Betker, J. and Kutzbach, H.D. (1989). Influence of design on the draught force characteristics of animal drawn carts. In: Hoffman *et al.,* (Eds.). Draught animals in rural development. Proceedings of the International research symposium, Cipanas, Indonesia, 3-7 July 1989.

Bhatt, M. and Chanda, S.V. (2003). Prediction of leaf area in Phaseolus Vulgris by non-destructive method. Bulg. J. Plant Physiol. **29** (1 – 2): 96 – 100.

Blake, G.R. and Hartge, K.H. (1986). Bulk density. In: A. Klute (ed.). Methods of soil analysis, part I. Am. Soc. of Agron. Inc., madison, USA.

Blench, R.M. (1987). Social determinants of animal traction in Central Nigeria. Agricultural Research Unit, World Bank, Washington DC, USA.

Bloome, P.D., Batchelder, D.G., Khalilian, A. and Riethmuller, G.P. (1983). Effects of speed on draught of tillage implements in Oklahoma soils. ASAE Paper No.83-1032. ASAE, St. Joshep, MI 49085.

Bobobee, E.Y.H. (2007). Performance Analysis of Draught Animal-Implement System to Improve Productivity and Welfare. PhD Thesis. Department of Biometry and Engineering, Swedish University of Agricultural Sciences, Uppsala. Pdf 40pp.

Boote, K.J., Jones, J.W. and Hoogenboom, G. (1988). Research and management application of the Pnut crop growth model. Proc. Am. Peanut Res. Edu. Soc. 20:57.

Bouyoucous, G.H. (1951). A recalibration of the hydrometer for making mechanical analysis of soils. Agron. J. **43**: 434 – 438.

Buckingham, E. (1914). On physically similar system. Physics Research, **4**: 345.

Canarache, A.O. (1991). Factors and indices regarding excessive compactness of agricultural soils. Soil and Tillage Research, **19**: 145 – 164.

Carruthers, I. and Marc, R. (1992). Tools for agriculture. Intermediate Technology Publications Ltd. South –Hampton, London.

Cartman. (1994). National Conference on Policies and Programmes for Modernization of draught animal power system. In: Dave, A.K. 1999. Draught animal utilization for agricultural work in the Baster Plateau Zone of India. DAN No.**30**: 6 – 9.

CEEMAT/FAO. (1972). The employment of draught animals in agriculture. Food and Agricultural Organization of the United Nations (FAO), Rome, Italy, 249p.

Chaundhury, M.S.U. and Musa, H.L. (1984). Agriculture and agricultural mechanization in Nigeria. AMA **15** (2): 60 – 65.

Collins, N.E., Kobomie, L.J. and Williams, T.H. (1978). Energy requirements for tillage on coastal plain soils. ASAE Paper No.81- 1572. ASAE, St. Joshep, MI 49085.

Conroy, D. and Rice, P. (1992). Selecting and Teaming Oxen. Tillers International, 10515 East OP Ave, Scotts, MI 49008 USA: 6p.

Dave, A.K. (1999). Draught animal utilization for agricultural work in the Baster Plateau Zone of India. DAN No. **30**: 6 – 9.

Dave, A.K. and Mukherjee, A.P. (2001). Study on draught capacity of bullocks in Bastar region, India. DAN No. **34**: 16 – 21.

Denvani, R.S. (1981). Mechanics of animal traction. J. Agricultural Engineering (India), **19**(3): 71 – 79.

Dergirmencioglu, A. and Srivastava, A.K. (1996). Development of screw conveyor performance models using dimensional analysis. In: Simonyan, K., Y.D. Yiljep and O.J. Mudiare. 2006. Modeling the grain cleaning process of a stationary sorghum thresher. Agricultural Engineering International: The CIGR Ejournal. Manuscript PM 06-012. Vol VIII. http://cigr-ejournal.tamu.edu pdf. 05/07/2007.

Duhovnik, J., Benedicic, J. and Bernik, R. (2004). Analysis and design parameters for inclined rotors used for manure disposal and broadcast spreaders for solid manure. Transactions of the ASAE **47**(5): 1389 – 1404.

Dunn, I. S., Anderson, L.R. and Kiefer, F.W. (1980). Fundamentals of Geotechnical Analysis. John Wiley and Sons, N.Y. pg 33.

Encarta Yearbook. (1997). Archieve article, Nigeria. Microsoft Student 2008 DVD.

Enoch, H.Z. and Hurd, R.G. (1978). The effect of elevated CO_2 concentration in the atmosphere on plant transpiration and water use efficiency: A study with potted carnation plants. Int. J. biometer, **23**: 343 – 351.

Etana, A., Hakansson, I., Zagal, E. and Bucas, S. (1999). Effects of tillage depth on organic carbon content and physical properties in five Swedish soils. Soil and Tillage Research, **52**: 129 – 139.

Fall, A. and Faye, A. (2010). Minimum tillage for soil and water management with animal traction in the West-African region. www.animaltraction.net/contil/contil-fall-westafrica. pdf cited on 23rd June, 2010.

FAO. (1972). The employment of draught animals in agriculture. Centre for Animals Experimentation, Rome, Italy.

FAO. (1994). Testing and evaluation of agricultural machinery and equipment: Principles and Practices. FAO Agricultural services Bulletin. No. 110, Rome. 153p.

FAO. (2001). Farming systems and poverty. Rome, FAO and Washington, DC, (World Bank). 62p.

Fishman, G.S. (1973). Concepts and methods in discrete event digital simulation. John Wiley and Sons, New York, pp150.

Gajda, W.T. and Biles, W.E. (1979). Engineering and computation. Houghton Mifflin company, Boston. In: Ndirika, 2003. A simulation of optimum power requirements of selected grain threshers. AZOJETE **3**: 1-11.

Gardner, H.W. (1986). Water content. In: A. Klute (ed.). Methods of soil analysis, Part I. Am. Soc. of Agron. Inc., Madison, USA.

Garner, T.H. and Wolf, D. (1981). Tillage energy versus hardpan configuration and tillage depth. ASAE Paper No.81- 1572. ASAE, St. Joshep, MI 49085.

Gbadamosi, L. and Magaji, A.S. (2004). Field study on animal draught power for farming in Zuguma village of Niger state, Nigeria. Proceedings of the NIAE, International conference, Ilorin, Nigeria.

Gebresenbet, G. (1995). Optimization of animal drawn tillage implement: Part I – Performance of a curved tillage implement. JAER, **62** (3): 173 – 184.

Gebresenbet, G., Gibbon, D. and Astatke, A. (1997). DAP-lessons from past research and development activities in Ethiopia and indicators for future needs. IRDC currents No.13/14, SLU.

Giles, G.W. (1975). The reorientation of agricultural mechanization for the developing countries: policies and attitudes, action programmes. In: Slingerland M.A. (1989). Draught animals in rural development. Proceedings of an International Research Symposium, Ciparas, Indonesia, 3-7 July 1989.

Girma, G. and Pascal, G.K. (1997). Comparative analysis of the field performances of a reversible animal drawn prototype and conventional moldboard plough pulled by a single donkey. Soil and tillage research **40**: 169 – 183.

Gleen, M. (1950). Similitude in engineering. The Royal Press Company, New York: 36 – 37.

Goe, M.R. and R.E. McDowell. 1980. Animal traction: Guideline for utilization. Ithaca, New York, Cornel International agriculture, Mimeograph No. 81.

Goe, M.R. (1987). Animal traction on small holder farms in the Ethiopian highlands. PhD Thesis (Cornell University), UMI Dissertation Information Service, Ann Arbor, Michigan, USA. 408p.

Goe, M.R. (1989). Overcoming constraints to animal traction through collaborative research work. In: Starkey, P.H., M.R. Goe and A Faye (Eds), Proceedings of the third workshop of WAATN, 7 -12 July 1998, Saly, Senegal. ILCA, Addis Ababa, Ethiopia.

Gomez, M. (2011). Ploughing depth and weed control treatment effects on maize performance and soil properties. A thesis submitted to the Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology in fulfillment of the requirements for the degree of Master of Philosophy. http://hdl.handle.net/123456789/2161.pdf. Cited on 18th February, 2011.

Gomez, K.A. and Gomez, A.A. (1984). Statistical procedures for agricultural research. 2nd ed. A Wiley – interscience publication, John Wiley and sons, New – York. 653pp

Gordon, G. (1978). Systems simulation, 2nd edn. In: Mc Graw-Hill encyclopedia of science and technology, Volume 10, 9th edn. 2002, USA.

Gregory, J. M. and Fedler, C.B. (1986). Model evaluation and research verification (M.E.R.V.), ASAE Paper No. 86-5032, St Joseph, MI 49085.

Grisso, R.D., Yasin, M. and Kocher, M.F. (1996). Tillage implements forces operating in silty clay loam. Transactions of the ASAE, **31** (6): 1977 – 1982.

Gupta, J.P. and Ahmed, R. (2003). Animal-drawn soil working four-in-one implements. AMA **34** (1): 21 – 25.

Gwani, E.S. (1990). Animal power for agricultural production in Nigeria. Proceedings of the third workshop of WAATN, Saly, Senegal: 376 – 380.

Haque, M.A., Umar, B. and Kawuyo, U.A. (2000). A preliminary survey on the use of animal power in agricultural operations in Adamawa state, Nigeria. Outlook on AGRICULTURE **29** (2): 123 – 127.

Harrigan, T.M. and Roosenberg, R. (2002). Estimating Tillage Draft. Tillers International. www.tillersinternational.org. Referred on 12th February, 2009. 6p.

Harrigan, T.M. and Rotz, C.A. (1994). Draught of major tillage and seeding equipment. ASAE, paper No. 94-1533. St. Joseph, Michigan: U.S.A.

Hassan, H.K. (1998). Performance evaluation of NEAZDP animal traction programme. Ph D Thesis. Department of Agricultural Engineering, ABU, Zaria (Unpublished).

Henriksson, M. and Lindholm, E. (2000). The use and role of animal draught power in Cuban agriculture: a field study in Havana province. Minor field studies. 100. Swedish University of agricultural sciences, Uppsala, Sweden. 46p.

Hesse, H. and Keuper, G. (2001). Mass flow-control on hydraulically driven disc spreaders. In: Duhovnik, *et al.,* (2004). Analysis and design parameters for inclined rotors used for manure disposal and broadcast spreaders for solid manure. Transactions of the ASAE **47**(5): 1389 – 1404.

Hopfen, H.J. (1969). Farm implements for arid and tropical regions (revised edition). Agricultural development Paper 91, FAO of the UN, Rome, Italy.

IAR. (1997). Performance evaluation of 'Troy-Bilt' rotary cultivator. A Cropping Scheme Report on Agricultural Mechanization Research Programme, IAR, ABU, Zaria. February, 1997, 3pp.

Igbadun, H.E. (2008). Towards the promotion of application of simulation models in Agricultural Engineering. Seminar paper presented to the Department of Agricultural Engineering, ABU samara, Zaria. ppt presentation, 23rd July, 2008.

ILCA. (1981). Animal traction in sub – Saharan Africa. Bulletin 14. International Livestock Centre for Africa, Addis-Ababa, Ethiopia. 17p.

Inns, F.M. (1990). The mechanics of animal-drawn cultivation implements. The Agricultural Engineer, **45**:13 – 17.

Inns, F.M. (2003). Matching tillage implements to draught animal potential. http://www.cipar.org.co. Referred on 15th May, 2007.

Iqbal, M., Sabir, M.S., Younis, M.D. and Azhar, A.A. (1994). Draught requirements of selected tillage implements. AMA **25** (1): 13-15.

Itodo, I.N. (2007). Agricultural Energy Technology. Aboki Publishers, Ibadan.

ITP. (1985). Tools for agriculture: a buyers' guide to appropriate equipment. Intermediate Technology Publications, London, UK, 264p.

Jaeger, K.W. (1984). Agricultural mechanization: The economics of animal traction in Burkina Faso. PhD Dissertation, IFPRI Stanford University.

Jahnke, H.E. (1982). Livestock production systems and development in tropical Africa. In: Mrema and Mrema (1993). Draught animal technology and agricultural mechanization in Africa: Its potential role and constraints. NAMA Newsletter **1** (2): 12 – 32.

James, L.G., Upadhyaya, K., Chancellor, W.J. and Rumsey, J.W. (1996). Prediction of agricultural implement effect using an instrumented analog tillage tool. Soil and Tillage Res. **37** (1): 47 – 65.

James, M. and Krecek, R.C. (1999). Management of draught animals: a welfare and health perspective in South Africa. Proceedings of ATNESA Workshop held 20 – 24 September 1999, Mpumalanga, South Africa. http://www.atnesa.org. pdf.

Jekayinfa, S.O. (2006). Energy consumption of selected mechanized farms in south western Nigeria. Agricultural Engineering International: The CIGR Ejournal. Manuscript EE 06-001. Vol VIII. http:// cigr-ejournal.tamu.edu pdf. Cited on 05/07/2007.

Jolly, C.M. and Gadbois, M. (1996). The effect of animal traction on labour productivity and food self sufficiency: The case of Mali. Agricultural Systems **51** (4):537 – 551.

Kaul, R.N. (1989). Animal powered equipment: factors affecting their design. Proceedings of the First Workshop on Animal Traction in Nigeria, Shika, Zaria.

Kaul, R.N. and Egbo, C.O. (1985). Introduction to agricultural mechanization. Macmillan International Agricultural Series, Hong Kong.

Kaushik, S.J. (1998). Animals for work, recreation and sport. In: Wilson, R.T. 2003. The environmental ecology of oxen used for draught power. Review. Agriculture, Ecosystems and Environment. Elsevier **97**: 21 – 37.

Kebede, A. and Pathak, B.S. (1987). Draught characteristics of Ethiopian oxen. DAN, No.8. Centre for Tropical Veterinary Medicine, University of Edinburgh, Scotland.

Kemp, D.C. (1987). Draught Animal Power: Some recent and current works. FAO World Animal Review. **63**: 7 – 14.

Khan, F.U.H., A.R. Tahir and I.J. Yule. (1999). Impact of different tillage practices and temporal factors on soil moisture and soil bulk density. Int. J. Agric. and Biol. **3**: 163 – 166.

Kline, C.D. (1970). Agricultural mechanization in equatorial Africa, East Rep. Michigan University.

Klinkenberg, K. and Higgins, G.M. (1968). An outline of Northern Nigerian soils. Nigeria J. Sci., **2**: 91 – 113.

Krause, R. and Poesse, G.J. (1997). The role of agricultural engineering in the development process. AMA **28** (2): 48 – 52.

Kushwaha, R.L. and Linke, C. (1996). Draft – speed relationship of simple tillage tools at high operating speeds. Soil and Tillage Research **39**: 61 – 73.

Kumar, Er.S. (2010). A numerical approach in Agricultural Engineering with objective (2nd revised edition). Kalyani Publishers, New Delhi. 718pp.

Lawrence, P.R. (1983). The energy costs of pulling loads. CTVM, University of Edinburgh, UK. DAN, **1**: 4 – 5.

Lawrence, P.R. and Pearson, R.A. (1985). Factors affecting the measurement of draught force, work output and power of oxen. J. Agric. Sci. Camb. **105**: 703 – 714.

Leith, J.H., Reynolds, J.P. and Rogers, H.H. (1986). Estimation of leaf area of soybeans grown under elevated carbon dioxide levels. Field crops Res. **13**: 193 – 203.

Lindstrom, M.J. and Voorhees, W.B. (1994). Response of temperate crops in North America to Soil compaction. Soil compaction problems in World agriculture. In: Yusuf, D.D. 2001. Mathematical modeling of tillage machine-soil integration effects on maize grain yield. PhD. Thesis. Department of Agricultural Engineering, ABU, Samaru, Zaria. (Unpublished), 241pp.

Loukanov, I.A., Uziak, J. and Michalek, J. (2005). Draught requirements of enamel coated animal drawn mouldbuard plough. Res. Agric. Engineering **51** (2): 56 – 62.

Macal, C.M. (2005). Model verification and validation. Workshop paper on “Threat Anticipation: Social Science Methods and Models” The University of Chicago and Argonne National Laboratory, Chicago, IL. Pdf cited on 12/6/2011.

Macmillan, R.S. (1985). Engineering problems in the measurement of draught animal performance. Proceedings of the ACIAR International workshop held at James Cook University, Townsville Qld. Australia, 10 – 16 July 1985.

Manuwa, S. and Ademosun, O.C. (2007). Draught and soil disturbance of model tillage tines under varying soil parameters. Agricultural Engineering International: The CIGR Ejournal. Manuscript PM 06-016. Vol IX. http:// cigr-ejournal.tamu.edu pdf. Cited on 10/07/2007, 18p.

Mathers, J.C., Pearson, R.A., Sneddon, J.C., Mathewman, R.W and. Smith, A.J. (1985). The use of draught cows in agricultural systems with particular reference to their nutritional needs. In: Smith A.J. (ed.), Milk production in developing countries. Proceedings of conference held 2-6 April 1984. Edinburgh University Press, UK.

Mathews, M.P.D. (1986). Harnessing for animal power. World Animal Review, **60**: 45 – 48.

Mathews, M.P.D. and Pullen, D.W.M. (1974). Groundnut cultivation trials with ox-drawn equipment: The Gambia 1973/1974. Report Series, Overseas Department, national Institute of Agricultural Engineering, Silsoe, UK, 127p.

Maurya, N.L. (1982). Draught ability of crossbred bullocks. Proceedings of National Seminar on draught animal power system in India, H.M, Bangalore, 16 – 17 July, 1982.

Mettrick, H.M. and James, D.P. (1981). Farm power in Bangladesh. Development study No. 20, Department of agricultural economics and management, University of Readings, UK. 158pp.

Mijinyawa, Y. and Kisaiku, O.O. (2006). Assessment of Edo state of Nigeria tractor hiring services. Agricultural Engineering International: The CIGR Ejournal. Invited overview paper No. 10. Vol VIII. http:// cigr-ejournal.tamu.edu pdf. Cited on 05/07/2007.

Mishra, A.K. and Pandey, A.S. (2000). Seasonality of bullocks power use in rain fed areas. DAN **32**: 11 – 13.

Moberg, J.P. and Esau, E.E. (1989). Characteristics and composition of soils in Northern Nigeria. Report submitted to the IAR, ABU, Zaria, Nigeria.

Mohammed, U.S. (2002). Performance modeling of the cutting process in sorghum harvesting. Ph D Thesis submitted to the Department of Agricultural Engineering, ABU, Zaria, 241pp.

Montgomery, E.G. (1911). Correlation studies in corn. Nebraska Agricultural Experimental Station. Annual Report. **24**: 108 – 159.

Mosteller, F., Rourke, R.E.K., and Thomas, G.B. (1970). Probability with statistics applications, 2nd Edition, Addison-Wesley Publishing Company, Inc., United State of America.

Mrema, G.C. and Mrema, M.J. (1993). Draught animal technology and agricultural mechanization in Africa: Its potential role and constraints. NAMA Newsletter **1** (2): 12 – 32.

Murphy, G. (1950). Similitude in engineering. In: Simonyan K., Y.D. Yiljep and O.J. Mudiare. 2006. Modeling the grain cleaning process of a stationary sorghum thresher. Agricultural Engineering International: The CIGR Ejournal. Manuscript PM 06-012.

Musa, H.L. (1989). Development and use of animal-drawn implements in Nigeria. Proceedings of the First national workshop on animal traction in Nigeria, Shika, Zaria.

Muthuri, C.W. (2004). Models. The Green Book: A geuide to effective graduate research in African agriculture, environment and rural development. Edited by Patel, B.K., K. Muir-Lerescher, R. Coe and S.D. Hainswort. African Crop Science Society, Kampala, Uganda.

Ndirika, V.I.O. (2003). A simulation of optimum power requirements of selected grain threshers. AZOJETE **3**: 1 – 11.

NEEDS. (2004). National Economic Empowerment and Development Strategy, Nigeria. National Planning Commission, Abuja. pp 188.

O'Neill, D.H. and Kemp, D.C. (1988). Research to improve the effectiveness of draught ox powered cultivation. Project R39069. Progress report OD/88/13. AFRC-Engineering, Silsoe, UK.

O'Neill, D.H., Hayton, S. and Sims, B. (1989). Measurement of draught animal performance. In: Hoffman D., J. Nari and R.J. Petheram (eds). Draught animals in rural development. Proceedings of an International research symposium, Cipanas, Indonesia, 3-7 July, 1989.

Okai, M. (1975). The development of ox-cultivation practices in Uganda. Eastern African Journal of rural development, **8**: 214.

Olofintoye, J.A. (1989). Effects of tillage and weed control methods on weed growth and performance of upland rice in the guinea savannah of Nigeria. Nigerian Journal of Agronomy. **2** and **3**: 82 – 87.

Oram, C.E. (1996). Pull angle and draught. In: Chawatama *et al.,* 2003. A simulation model of draught animal power in smallholder farming systems. Part I: Context and structural overview. Agricultural Systems, **76**: 415 – 440.

Otchere, E.O, Ahmed, H.U., Olorunju, S.A.S. and Kallah, M.S. (1988). Utilization and management of work oxen in northern guinea savanna environment in Nigeria; Initial results. In: Starkey, P. and F. Ndiame (eds). Animal power in farming systems. Proceedings of workshop held 17-26 September 1986 in Freetown, Sierra Leone. Vieweg for GTZ, Eschborn, Germany. 363pp.

Page, A.L., Miller, R.H. and Keeney, D.R. (1982). Methods of soil analysis, Part 2. Chemical and microbiological properties. Agronomy No. 9. American Society of Agronomy, (2^{nd} ed). Madison, WI, pp.573 – 581.

Panse, V.G. and Sukhatme, P.V. (1989). Statistical methods for agricultural workers, 6^{th} Edition, Publications and information Division, India Council of Agricultural Research, New Delhi- 1100112.

Pathak, B.S. (1984). The management and utilization of camels for work. Selection and application of draught animal equipment. In: Animal energy in agriculture in Africa and Asia. Animal production and health paper 41, FAO, Rome, Italy, 143p.

Payne, W.J.A. (1990). An introduction to animal husbandry in the tropics. 4^{th} ed. Longman Scientific and Technology, England.

Pearson, R.A. (2005). Contributions to Society: Draught and transport. Encyclopedia of Animal Science. Marcel Dakker Inc., USA: 248 – 250.

Pearson, R.A., Lawrence, P.R. and Ghimire, G. (1989). Factors influencing the work done by draught oxen: a study in the eastern hills of Nepal. Centre for Tropical Veterinary Medicine, Edinburgh, UK. In: Starkey, P. (1989b). Harnessing and Implements for Animal Traction. An Animal Traction Resource Book for Africa. Publication of the GATE in GTZ.

Phillips, D.O.A., Abalu, G.O.I., Aganga, A.A. and Adaku, A.O. (1990). Animal traction in northern Nigeria: A survey of constraints and a model of prospects. In: Anthony, P. (1994). Animal traction and sustainability of dryland farming system in Africa. AMA **25** (3): 67 – 73.

Pingali, P.L., Bigot, Y. and Binswanger, H.P. (1987). Agricultural mechanization and the evolution of farming systems in sub-Saharan Africa. Worl Bank, Washington, in association with Johns Hopkins Press, Baltimore, USA. 216p.

Premi, S.C.L. (1981). Power from bullocks. In: O'Neill D.H., S. Hayton and B. Sims. 1989. Measurement of draught animal performance. Proceedings of an International research symposium, Cipanas, Indonesia, 3-7 July, 1989.

Quenouille, M.H. (1950). Introductory statistics. 1st Edition, Pergomn press, Ltd, London.

Rahman, M.S., Haque, M.A. and Salam, M.A. (2004). Effect of different tillage practices on growth, yield and yield contributing characters of transplant amon rice (BRRI Dhan-33). Journal of Agronomy **3** (2): 103 – 110.

Ramaswamy, N.S. (1998). Draught animal welfare. Applied Animal Behaviour Science, **59**: 73 – 84.

Randolph, J.W. and Reed, I.F. (1983). Tests of tillage tools; Part II, effects of several factors on the reactions of fourteen – inch mouldboard ploughs. Agricultural Engineering, **19**: 29 – 33.

Reddy, K.R., Boone, M.L., Reddy, A.R., Hodges, H.F., Tuner, S.B. and McKinim, J.M. (1995). Developing and validating a model for plant growth regulator. Agronomy Journal, **87** (6/7): 1100 – 1105.

Reece, A.R. (1965). The fundamental equation of earthmoving machines. Symposium on Earthmoving Machinery, Institute of Mechanical Engineers, 179, Part3F, London. **179**: 8 – 14.

Reh, I. and Horst, P. (1982). Possibilities and limits of the use of trypanotolerant cattle for draught purposes. In: Kambe, E and E. Freitas (eds), Trypanotolerance: research and implementation. GTZ, Eschborn, Germany. 314pp.

Rijk, A. (1989). Agricultural mechanization policy and strategy, the case of Thailand. In: Bobobee, E.Y.H. 2007. Performance Analysis of Draught Animal-Implement System to Improve Productivity and Welfare. PhD Thesis. Department of Biometry and Engineering, Swedish University of Agricultural Sciences, Uppsala. Pdf, 40pp.

Rotriguez, R.A., Santoyo, J.C., Castillo, B. and Lozano, F. (1999). Soil preparation alternatives for the sugarcane production systems in the region of Gualiva (Cundinamarca). DAN **31**: 2 – 8.

Saror, D.T. (1995). National workshop Re-echoes needs for Appropriate Technology. ABU, Zaria News Bulletin, **32** (12): 1 – 3.

Saxena, M.L. and Singh, Y. (1965). A note on area estimation of intact maize leaves. Indian J. Agron. **10** (4): 437 – 439.

Scheruddin, B.B., Jan, M.B. and Allah, B.B. (1988). Performance of selected tillage implements. AMA **19** (4): 9 – 14.

Sharma, D.N., Agarwal, S.P. and Jain, M.L. (1987). A study of mechanism for measuring draught of single-bullock cart. AMA **18**(2): 50 – 52.

Silsoe. (1986). Animal-drawn implements:a study to assess the feasibility of local manufacture in Sudan. Consultancy report for Ministry of Finance and economic Planning, Sudan and Earopean development Fund, Belgium. Silsoe College, Silsoe, UK, 123p.

Simonyan, K., Yiljep, Y.D. and Mudiare, O.J. (2006). Modeling the grain cleaning process of a stationary sorghum thresher. Agricultural Engineering International: The CIGR Ejournal. Manuscript PM 06-012. Vol VIII. http:// cigr-ejournal.tamu.edu pdf. 05/07/2007.

Singerland, M.A. (1989). Selection of animals for work in sub-Saharan Africa: research at the ICRISAT Sahelian centre. In: Hoffmann, D., J. Nari and R.J. Petheran (eds), draught animals in rural development, ACIAR Proceedings series No.27, ACIAR, Canberra, 203 -210.

Srivastava, N.S.L. (1989). Research on draught animal power in India. In: Hoffmann *et al.,* (1989). eds. Draught animal in rural development. Proceedings of an International Research Symposium, Ciparas, Indonesia, 3-7 July 1989.

Stafford, J.V. (1979). The performance of a rigid tine in relation to soil properties and speed. J. Agric. Engineering Res. **24** (1): 41 – 56.

Stafford, J.V. (1984). Force prediction models for brittle and flow failure of soil by draught tillage tools. J. Agric. Eng. Res. **29** (1): 51 – 60.

Starkey, P.H. (1985). Animal traction research and extension in Africa: An overview. In: Animal traction in a farming perspective. A workshop held in Togo, 4-8 March 1985. Farming systems support project, University of Florida Gainesville, F1. 32611, USA. 187p.

Starkey, P.H. (1986). Draught animal power in Africa, Priorities for development, research and liaison. Farming systems support project. Networking paper No. 14. University of Florida, Florida, USA, 40p.

Starkey, P.H. (1988a.) The introduction, intensification and diversification of the use animal power in West African farming system – implication at farm level. Proceedings of the workshop of the WAATN, Freetown, Sierra Leone: 97 – 115.

Starkey, P.H. (1988b). Animal traction directory: Africa. GTZ Friedr. Vieweg and John. Braunschweig/Wiesbaden. 151pp.

Starkey, P.H. (1989). Harnessing and Implements for Animal Traction. An animal traction resource book for Africa. GATE publication GTZ, Germany. 395pp.

Starkey, P.H. (1990). Animal traction for agricultural development in West Africa: Production, impact, profitability and constraints. In: Starkey, P.H. and A. Faye (eds), Animal traction for agricultural development. A keynote paper in proceedings of the third WAATN workshop held July 1980, Sally, Senegal.

Starkey, P.H. (1992). A worldwide view of animal traction highlighting some key issues in eastern and southern Africa. Proceedings of the first workshop of the ATNESA held on 18 – 23 January, 1992 at Lusaka, Zambia.

Starkey, P.H. (Ed.). (1998). Integrating mechanization into strategies for sustainable agriculture. Technical Centre for Agricultural and rural Cooperation (CTA), Wageningen, the Netherlands.

Starkey. P.H., Jaiyesimi-Njobe, F. and Hanekom, D. (1995). Animal traction in South Africa, Overview of key issues. Empowering rural communities. In: James, M and R.C. Krecek. 1999. Management of draught animals: a welfare and health perspective in South Africa. Proceedings of ATNESA Workshop held 20-24 September 1999, Mpumalanga, South Africa. http://www.atnesa.org. pdf.

Statistical Analysis Systems Institute Inc. (1989). SAS/STAT User's guide, version 6. 4th Edition, Volume 1, SASA Institute Inc. N.C., 943pp.

Stroud, A. (1993). The use of animal draught. In: Dryland farming in Africa. Edited by Rowland J.R.J. 1993. CTA and Macmillan publication: 205 – 218.

Suleiman, M.L. (2000). Animal Traction: A viable mechanization alternative for small and medium scale farmers in Nigeria. A paper presented at an ANIMAL TRACTION: TRAIN-THE TRAINER WORKSHOP organized by federal ministry of agriculture and rural development, Garki, Abuja. Held at Animal Traction Training Centre Tambu, Daura, Katsina state and Darazo, Bauchi state, Nigeria, July 10-14, 2000.

Sutton, D.H. (1989). People and technology for development – The human factor in agricultural mechanization. Proceedings of the International Symposium on Agricultural Engineering (89 – ISAE), 12 – 15 September 1989, Beijing, **1**, 6pp.

Taniguchi, T., Makanga, J.T., Ohtomo, K. and Kishimoto, T. (1999). Draught and soil manipulation by a moldboard plough under different forward speed and body attachments. Transactions of the ASAE, Vol. **42** (6): 1517 – 1521.

Tsimba, R., Husseini, J. and Ndlovu, L.R. (1999). Relationship between depth of tillage and soil physical characteristics of sites farmed by smallholders in Mutoko and Chinyaka in Zimbabwe. In: Kaumbutho P.G and T.E. Simalanga (eds). 1999. Conservation tillage with animal traction. A resource book of ATNESA. Harare, Zimbabwe. http://www.atnesa.org.pdf. Cited on 18th February, 2011: 84 – 88.

Turner, B. (1977). The 'Fadama' land of central Northern Nigeria: their classification, spatial variation, present and potential use. In: Abubakar, L.G. 2008. Applicability and effectiveness of animal-drawn tillage implement in the 'Fadama' farming system. PhD seminar, Department of Agricultural Engineering, ABU, Zaria.

Umar, B. (1994). Animal draught: the underutilized source of power. Seminar presented at the Department of Agric. Engineering, University of Maiduguri, (Unpublished).

Unger, P.W., Cassel, D.K. and Allen, R. (1991). Tillage implements disturbance effects on soil properties related to soil and water conservation: a literature review. Soil and Tillage Research, **19**: 363 – 382.

Upadhyay, R.C. (1989). Performance limiting factors in draught animals: Can they be manipulated to improve output? In: Hoffman D., J. Nari and R.J. Petheram (eds). Draught animals in rural development. Proceedings of an International research symposium, Cipanas, Indonesia, 3-7 July, 1989.

Upadhyaya, S.K., Williams, T.H., Kemble, L.T. and Collins, N.E. (1984). Energy requirements for chiseling in coastal plain soils. Transactions of the ASAE, **27** (6): 1643 – 1649.

Usman, A.M. (2002). Design Construction and Evaluation of an Animal-Drawn Disc Harrow. M Sc (Agricultural Engineering). Department of Agricultural Engineering, University of Maiduguri, (Unpublished).

Walkley, A. and Black, I.A. (1934). An examination of the Degtjareff method for determining Soil Organic Matter and proposed modification of the chromic acid titration method. Soil Sci. **37**: 29 – 38.

Walpole, R.E. (1982). Introduction to statistics. 3rd Edition, Macmillan Publishing Company Inc. New York.

Wang, J.K. and Liang, T. (1970). A new technique for draught prediction. J. Agric. Eng. Res. **15** (2): 113 – 118.

Watson, D.J. (1952). The physiological basis of variation in yield. Adv. Agron., **41**: 101 – 145.

Watson, P.R. (1981). Farming with draught animals. Itranscentury Press, Washington D.C., USA. 150p.

Wilson, R.T. (2003). The environmental ecology of oxen used for draught power. Review. Agriculture, Ecosystems and Environment. Elsevier, **97**: 21 – 37.

Yusuf, D.D. (2001). Mathematical modeling of tillage machine-soil integration effects on maize grain yield. PhD. Thesis. Department of Agricultural Engineering, ABU, Samaru, Zaria. (Unpublished).

Yusuf, D.D. (2003). Development and validation of crop yield model. AZOJETE **3**: 12 – 2 1.

Zelenin, A.N. (1950). Basic physics of theory of soil cutting. McGraw-Hill International Book Company, Moscow. 353pp.

Zhang, J. and Kushwaha, R.L. (1995). A modified model to predict soil cutting resistance. Soil and Tillage Research, **34**: 157 – 168.

APPENDICES

Appendix A: Data on the response of animals re-training for depth of operation variations

Run	Measured depth (cm)								
	Day 1			Day 2			Day 3		
	d_1	d_2	d_3	d_1	d_2	d_3	d_1	d_2	d_3
1	5.8	11.5	16.5	6.3	11.8	16.8	7.4	11.3	16.3
2	6.5	11.9	17.2	7.4	12.2	17.4	7.8	11.6	16.7
3	7.3	12.6	17.5	7.7	12.5	17.8	8.3	12.3	17.2
4	7.8	12.8	17.8	8.1	13.1	18.1	8.5	12.6	17.8
5	8.1	13.5	18.4	8.4	13.6	18.6	8.7	13.1	18.2
6	8.5	13.9	18.5	8.7	13.7	18.9	8.9	13.2	18.8
7	8.9	14.0	18.7	9.1	13.8	19.1	9.0	13.5	19.2
8	9.2	14.1	18.9	9.3	14.1	19.3	9.1	13.9	19.4
9	9.3	14.2	19.1	9.4	14.3	19.3	9.4	14.2	19.5
10	9.5	14.3	19.1	9.5	14.5	19.5	9.6	14.6	19.6

Appendix B: Field layout of a 2 x 3 x 3 factorial experiment arranged in a randomized complete block design with two implements (I_1 and I_2), three operating speeds (S_1, S_2 and S_3), and three operating depths (d_1, d_2, and d_3) in three replications:

$I_2S_3d_3$ (T_{18})	$I_2S_1d_2$ (T_{11})	$I_2S_3d_1$ (T_{16})	$I_1S_1d_3$ (T_3)	$I_1S_3d_2$ (T_8)	$I_1S_1d_1$ (T_1)
$I_2S_2d_3$ (T_{15})	$I_2S_2d_2$ (T_{14})	$I_2S_2d_1$ (T_{13})	$I_1S_2d_3$ (T_6)	$I_1S_2d_2$ (T_5)	$I_1S_2d_1$ (T_4)
$I_2S_1d_3$ (T_{12})	$I_2S_3d_2$ (T_{17})	$I_2S_1d_1$ (T_{10})	$I_1S_3d_3$ (T_9)	$I_1S_1d_2$ (T_2)	$I_1S_3d_1$ (T_7)

Replication I

$I_1S_3d_2$ (T_8)	$I_1S_1d_1$ (T_1)	$I_1S_1d_3$ (T_3)	$I_2S_3d_3$ (T_{18})	$I_2S_1d_2$ (T_{11})	$I_2S_3d_1$ (T_{16})
$I_1S_2d_2$ (T_5)	$I_1S_2d_1$ (T_4)	$I_1S_2d_3$ (T_6)	$I_2S_2d_3$ (T_{15})	$I_2S_2d_2$ (T_{14})	$I_2S_2d_1$ (T_{13})
$I_1S_1d_2$ (T_2)	$I_1S_3d_1$ (T_7)	$I_1S_3d_3$ (T_9)	$I_2S_1d_3$ (T_{12})	$I_2S_3d_2$ (T_{17})	$I_2S_1d_1$ (T_{10})

Replication II

$I_1S_1d_3$ (T_3)	$I_2S_3d_1$ (T_{16})	$I_2S_1d_2$ (T_{11})	$I_1S_1d_1$ (T_1)	$I_1S_3d_2$ (T_8)	$I_2S_3d_3$ (T_{18})
$I_1S_2d_3$ (T_6)	$I_2S_2d_1$ (T_{13})	$I_2S_2d_2$ (T_{14})	$I_1S_2d_1$ (T_4)	$I_1S_2d_2$ (T_5)	$I_2S_2d_3$ (T_{15})
$I_1S_3d_3$ (T_9)	$I_2S_1d_1$ (T_{10})	$I_2S_3d_2$ (T_{17})	$I_1S_3d_1$ (T_7)	$I_1S_1d_2$ (T_2)	$I_2S_1d_3$ (T_{12})

Replication III

Appendix C: Analysis of variance for a 2 x 3 x 3 factorial experiment in a randomized complete block design

Source of Variation	Degree of freedom	Sum of square	Mean square	Computed F	Tabular F	
					5%	1%
Replication	r-1=2					
Implement (I)	i – 1 = 1					
Speed (S)	s- 1 = 2					
Tillage depth (d)	d – 1 = 2					
I x S	(i – 1) (s – 1) = 2					
I x d	(i – 1) (d – 1) = 2					
S x d	(s – 1) (d – 1) = 4					
I x S x d	(i – 1) (s – 1) (d – 1) = 4					
Error	(r – 1) (isd – 1) = 34					
Total	risd – 1 = 53					

Appendix D: Physical properties of soil sample and organic matter content (0 – 30 cm) depth of experimental site prior to the application of treatments at Samaru (2008, 2009 and 2010)

Depth of soil profile[a] (cm)	Sand (%)	Silt (%)	Clay (%)	Organic Matter (%)	Soil classification[b]
2008					
0 – 15	62.8	20.2	17.2	1.18	Sandy loam
15 – 30	67.8	17.5	14.7	0.92	Sandy loam
2009					
0 – 15	65.3	17.5	17.2	1.26	Sandy loam
15 – 30	64.1	18.7	17.2	1.09	Sandy loam
2010					
0 – 15	64.0	18.3	17.3	1.43	Sandy loam
15 – 30	65.9	17.9	16.2	1.26	Sandy loam

[a] = Each value is a mean of three measurements
[b] = USDA, triangle in: Dunn *et al.,* (1980)

Appendix E: Statistical analysis for animal-drawn implements draft requirement for 2008 field study

Class	Levels	Values
Implement	2	1 2
Speed	3	1 2 3
Tillage depth	3	1 2 3
Replication	3	1 2 3

Number of observations 54

Means

Implement	N	Draft
1	27	284.9
2	27	400.8

Speed	N	Draft
1	18	328.3
2	18	352.5
3	18	347.8

Tillage depth	N	Draft
1	18	339.4
2	18	338.4
3	18	350.8

Implement	Speed	N	Draft
1	1	9	266.1
1	2	9	305.8
1	3	9	282.8
2	1	9	390.6
2	2	9	399.2
2	3	9	412.7

Implement	Tillage depth	N	Draft
1	1	9	286.0
1	2	9	277.1
1	3	9	291.6
2	1	9	392.8
2	2	9	399.6
2	3	9	410.0

Speed	Tillage depth	N	Draft
1	1	6	315.6
1	2	6	327.7
1	3	6	341.6
2	1	6	373.5
2	2	6	336.6
2	3	6	347.4
3	1	6	329.0
3	2	6	350.9
3	3	6	363.4

Implement	Speed	Tillage depth	N	Draft
1	1	1	3	246.8
1	1	2	3	262.9
1	1	3	3	288.5
1	2	1	3	356.5
1	2	2	3	274.9
1	2	3	3	286.0
1	3	1	3	254.6
1	3	2	3	293.5
1	3	3	3	300.4
2	1	1	3	384.5
2	1	2	3	392.5
2	1	3	3	394.8
2	2	1	3	390.6
2	2	2	3	398.2
2	2	3	3	408.8
2	3	1	3	403.5
2	3	2	3	408.2
2	3	3	3	426.4

Appendix F: Statistical analysis for animal-drawn implements draft requirement for 2009 field study

Class	Levels	Values
Implement	2	1 2
Speed	3	1 2 3
Tillage depth	3	1 2 3
Replication	3	1 2 3

Number of observations 54

Means

Implement	N	Draft
1	27	267.4
2	27	405.9

Speed	N	Draft
1	18	318.0
2	18	340.7
3	18	351.1

Tillage depth	N	Draft
1	18	321.1
2	18	339.7
3	18	349.0

Implement	Speed	N	Draft
1	1	9	254.3
1	2	9	269.5
1	3	9	278.2
2	1	9	381.7
2	2	9	411.9
2	3	9	424.0

Implement	Tillage depth	N	Draft
1	1	9	243.8
1	2	9	274.4
1	3	9	283.9
2	1	9	398.4
2	2	9	405.1
2	3	9	414.2

Speed	Tillage depth	N	Draft
1	1	6	309.7
1	2	6	316.2
1	3	6	328.2
2	1	6	322.3
2	2	6	345.3
2	3	6	354.6
3	1	6	331.3
3	2	6	357.7
3	3	6	364.3

Implement	Speed	Tillage depth	N	Draft
1	1	1	3	243.4
1	1	2	3	251.3
1	1	3	3	268.3
1	2	1	3	241.4
1	2	2	3	280.5
1	2	3	3	286.8
1	3	1	3	246.7
1	3	2	3	291.3
1	3	3	3	296.5
2	1	1	3	375.9
2	1	2	3	381.2
2	1	3	3	388.0
2	2	1	3	403.3
2	2	2	3	410.0
2	2	3	3	422.4
2	3	1	3	416.0
2	3	2	3	424.0
2	3	3	3	432.1

Appendix G: Statistical analysis for animal-drawn implements draft requirement for 2010 field study

Class	Levels	Values
Implement	2	1 2
Speed	3	1 2 3
Tillage depth	3	1 2 3
Replication	3	1 2 3

Number of observations 54

Means

Implement	N	Draft
1	27	273.1
2	27	400.8

Speed	N	Draft
1	18	324.3
2	18	338.6
3	18	347.9

Tillage depth	N	Draft
1	18	330.0
2	18	341.3
3	18	339.6

Implement	Speed	N	Draft
1	1	9	264.9
1	2	9	276.5
1	3	9	277.9
2	1	9	383.8
2	2	9	400.7
2	3	9	417.9

Implement	Tillage depth	N	Draft
1	1	9	264.4
1	2	9	279.6
1	3	9	275.4
2	1	9	395.7
2	2	9	402.9
2	3	9	403.8

Speed	Tillage depth	N	Draft
1	1	6	314.7
1	2	6	329.7
1	3	6	328.7
2	1	6	341.2
2	2	6	338.9
2	3	6	335.6
3	1	6	334.2
3	2	6	355.1
3	3	6	354.5

Implement	Speed	Tillage depth	N	Draft
1	1	1	3	251.2
1	1	2	3	268.9
1	1	3	3	275.4
1	2	1	3	288.9
1	2	2	3	275.6
1	2	3	3	265.0
1	3	1	3	253.0
1	3	2	3	294.3
1	3	3	3	286.6
2	1	1	3	378.1
2	1	2	3	390.4
2	1	3	3	382.8
2	2	1	3	393.6
2	2	2	3	402.3
2	2	3	3	406.1
2	3	1	3	415.4
2	3	2	3	416.0
2	3	3	3	422.5

Appendix H: Maximum draft requirement means and safe sizes of the animal drawn tillage implements compared to the work bull's tractive effort

Variation	Period								
	2008			2009			2010		
	Maximum mean Draft (N)	% of utilization of tractive effort	Safe size of implement	Maximum mean Draft (N)	% of utilization of tractive effort	Safe size of implement	Maximum mean Draft (N)	% of utilization of tractive effort	Safe size of implement
Speed (S)	352.5	55.9	1	351.1	55.7	1	347.9	55.2	1
Tillage depth (d)	350.8	55.6	1	349.0	55.3	1	341.3	54.1	1
Implement (I)	400.8	63.5	1	405.9	64.3	1	400.8	63.5	1
I x S	412.7	65.4	1	424.0	67.2	1	417.9	66.3	1
I x d	410.0	65.0	1	414.2	65.7	1	403.8	64.0	1
S x d	373.5	59.2	1	364.3	57.8	1	355.1	56.3	1
I x S x d	426.4	67.6	1	432.1	68.5	1	422.5	67.0	1

Note: Work bull's combined estimated tractive effort = 630.78N (From Table 4.1)

Appendix I: The Emcot ridger draft Pi – terms data

$\pi_1 = \frac{D}{S^2 d^2 \rho}$		$\pi_2 = \frac{I_m}{\rho d^3}$		$\pi_3 = M$	
6.22×10^4	6.66×10^4	8.19×10^4	8.76×10^4	5.540	5.319
1.92×10^4	3.06×10^4	1.45×10^4	2.31×10^4	4.075	7.878
1.25×10^4	1.67×10^4	6.32×10^3	8.47×10^3	5.128	7.134
4.07×10^4	5.08×10^4	7.33×10^4	9.14×10^4	5.335	5.705
1.06×10^4	1.34×10^4	1.51×10^4	1.92×10^4	4.473	8.531
6.70×10^3	7.02×10^3	6.78×10^3	7.11×10^4	4.055	6.729
1.76×10^4	2.52×10^4	7.37×10^4	1.06×10^5	3.150	4.145
6.66×10^3	7.99×10^3	1.48×10^4	1.77×10^4	3.813	10.597
3.72×10^3	4.34×10^3	5.96×10^3	6.94×10^3	4.579	7.597
5.25×10^4	5.95×10^4	8.76×10^4	7.84×10^4	7.663	10.460
1.88×10^4	2.10×10^4	2.31×10^4	1.59×10^4	6.734	8.72
1.18×10^4	1.23×10^4	8.47×10^3	6.25×10^4	6.691	7.462
3.40×10^4	4.03×10^4	9.14×10^4	7.26×10^4	6.552	9.604
1.06×10^4	1.13×10^4	1.92×10^4	1.61×10^4	5.312	7.846
5.43×10^3	5.81×10^3	7.11×10^3	5.88×10^3	6.661	8.054
1.61×10^4	1.74×10^4	1.06×10^5	7.30×10^4	9.433	13.019
6.56×10^3	7.87×10^3	1.77×10^4	1.75×10^4	6.737	8.569
3.60×10^3	3.89×10^3	6.94×10^3	6.23×10^3	5.777	7.575

Appendix J: The mould board plough draft Pi – terms data

$\pi_1 = \frac{D}{S^2 d^2 \rho}$		$\pi_2 = \frac{I_m}{\rho d^3}$		$\pi_3 = M$	
8.14×10^4	1.01×10^5	6.53×10^4	6.53×10^4	9.495	3.540

2.69×10^4	3.37×10^4	1.20×10^4	1.20×10^4	6.082	5.075
1.69×10^4	1.79×10^4	5.94×10^3	5.94×10^3	6.944	5.128
3.59×10^4	5.28×10^4	5.60×10^4	5.60×10^4	8.507	3.335
1.38×10^4	1.64×10^4	1.20×10^4	1.20×10^4	4.473	5.473
8.71×10^3	9.81×10^3	5.85×10^3	5.85×10^3	6.184	5.055
2.57×10^4	3.22×10^4	6.45×10^4	6.45×10^4	7.832	5.150
7.81×10^3	1.02×10^4	1.10×10^4	1.10×10^4	5.090	4.183
5.51×10^3	6.03×10^3	5.89×10^3	5.89×10^3	7.171	6.579
8.06×10^4	8.68×10^4	6.47×10^4	6.97×10^4	9.566	8.430
2.52×10^4	3.06×10^4	1.12×10^4	1.36×10^4	6.495	6.882
1.58×10^4	1.60×10^4	5.55×10^3	5.63×10^3	8.056	9.631
3.85×10^4	4.66×10^4	6.02×10^4	7.28×10^4	7.594	10.525
1.32×10^4	1.64×10^4	1.14×10^4	1.42×10^4	5.902	7.618
8.40×10^3	9.06×10^3	5.64×10^3	6.08×10^3	7.357	9.387
2.37×10^4	2.76×10^4	5.94×10^4	6.92×10^4	7.181	9.209
7.92×10^3	9.20×10^3	1.11×10^4	1.29×10^4	7.294	9.280
4.88×10^3	5.40×10^3	5.22×10^3	5.77×10^3	6.194	10.995