# MODELLING OF ENERGY REQUIREMENT DEMAND FOR TILLAGE OPERATIONS IN MAIZE PRODUCTION

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**JANUARY 2015**

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BY

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PhD/Eng/00708/2006-2007

A DISSERTATION SUBMITTED TO THE SCHOOL OF POST GRADUATE STUDIES,

AHMADU BELLO UNIVERSITY, ZARIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OFA

DOCTOR OF PHILOSOPHY IN AGRICULTURAL ENGINEERING.

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JANUARY, 2015

# DECLARATION

I declare that the work in this dissertation entitled “Modelling of Energy Demand for Tillage Operations in Maize Production”has been carried out by mein the Department of Agricultural Engineering. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

| | | |
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# CERTIFICATION

This dissertation titled “**MODELLING OF ENERGY DEMAND FOR TILLAGE OPERATION IN MAIZE PRODUCTION”** by Abdussalam Omuya YUSUF meets the regulations governing the award of Doctor of philosophy (Agricultural Engineering) of Ahmadu Bello University Zaria, and is approved for its contribution to knowledge and literary presentation.

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# ACKNOWLEDGEMENT

I wish to acknowledge with gratitude the following persons: Prof D.D Yusuf, Prof Abdullahi El-Okene and Dr U.S. Muhammed who supervised this research work. Their guidance, criticism and understanding throughout the study were of tremendous value. My gratitude also goes to Dr M.Siaka and Prof. Zakari Abdussalam for their support and encouragement.

Iam grateful to all the academic staff of the department of Agricultural Engineering, Ahmadu Bello University, Zaria, whose criticism during my project seminars further improved the work.

Ialso wish to acknowledge the late Dr Muhammed Ali Olukade of blessed memory, who encouraged me to push on, when I almost chickened out from the programme due to work pressure at my office.

Finally I wish to thank my beloved wives and children for their understanding, care, love,prayers and support when the work was getting tough during this programme. They endured my frequent absence from home during the research work.

# DEDICATION

This work is hereby dedicated to my dear parents of blessed memory, the roots of my tree and the fruits of whose sacrifice I now enjoy. To my guides and models, the compass of my journey. To my dear wives, my companions in toils and treats. And to my beloved kids, the coolness of my eyes.

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# ABSTRACT

While mechanization is known to enhance production and reduce drudgery, powering agricultural machinery entails energy consumption withattendant financial and environmental costs. Financial costs in agricultural mechanization is exacerbated by the rising energy prices due to ongoing energy sector liberalization and this has negative impact on the profitability of agricultural business. An optimum path is needed which ensures efficient level of production and minimum energy consumption.This study was conducted with the objective of developing a mathematical model for predicting the energy input to tillage operations for maize production in southern guinea savanna belt of Nigeria in relation to the level of mechanization. A theoretical model relating energy demand with the soil and tillage operation parameters were evolved from dimensional analysis using Buckingham pie theorem.

Using a 3x5 factorial Randomized Complete Block Design experimental layout, field investigation was carried out on a sandy loam soil at Gui village, Abuja for three years (2010-2012) to determine the influence of degree of mechanization on the energy demand as well as provide data to validate the model. The study established thattheoptimum diesel consumption for ploughing , harrowing and ridging operations were found to be 20, 23 and 24 litres per hectare when working at the respective speed of 5.6, 7.8 and 4.8km/h and at depth of 10cm, 15cm and 20 cm respectively.

A mathematical model was developed for predicting tillage energy at different depth and speeds. The model was implemented using MS Excel visual basic macros and was applied for predicting energy demand for different field scenarios. The predicted values showed good correlation with the measured.Based on the study, 15% fuel saving is achievable through tillage depth and speed management.

# Chapter 1

# INTRODUCTION

## 1. Background of Study

Energy, the capacity to do work, is an important input to all farming operations. From soil tillage, through planting, weed control, fertiliser application to harvesting, energy is required in the form of human muscle power, solar, fossil fuel for internal combustion engine, or as components of the basic farm inputs (Umar 2003).

Given the rising global energy prices, the ongoing energy sector reforms and the imminent price deregulation, the obvious direction is towards removal of subsidies and payment of the true price of fuels. Energy is thus increasingly being recognized as an important cost component in agricultural business (CAEEDAC, 2000), which must be minimized to enhance profitability.

Underscoring the significance of energy component of agricultural production cost Randy (2004) reported a farm expenditure survey in the United States from 2000 to 2003, which indicated that energy expenses accounted for 14.84 % of their annual total production expenses. These costs resulted from fuel consumed in operating various farm equipment typical of highly mechanized agriculture.

The importance of energy cost in farm management is further indicated by Siemens and Bowers (1999) who stated that fuel and lubricant costs will usually represent at least 16 percent to over 45 percent of the total machine costs, depending on the type of fuel and the amount of time a tractor or machine is used.

It is noteworthy that, increased expenditure on farm energy translates into lower net farm income and lower profitability and competitiveness of farm produce. Thus while mechanization is desirable for the associated increased productivitythere is need to find the most appropriate level of mechanization that minimizes energy consumption and enhance profitability and reduce environmental damage from fossil fuel related emission. To achieve this, the total energy input to the cropping process must be estimated for different levels of mechanization, the energy determinanttillage parameters identified and their relationship established.

## 1.2 Energy and Agricultural Mechanization

Agricultural mechanization is the process of improving farm labour productivity through the use of agricultural machinery, implements and tools. It involves the provision and use of all forms of power sources and mechanical assistance to agriculture as well as maintenance of all types of tools, implements, machines and equipment for agricultural production (Yusuf, 2006). Esmay  and Hall (1972) defined agricultural mechanization as the scientific application of mechanical aids for increased production, processing and storage of food with less drudgery and increased efficiency.

The primary objectives of mechanizing crop production are to reduce human drudgery and to raise the farmer’s output by either increasing the yield per unit area or increasing the area under cultivation or both. While mechanization has eased much of the backbreaking toils of the farmers and enormously increased efficiency of farm operations, the required machine and equipment (farm tractors, planters, harvester, airplanes and helicopters in control agricultural pests, disease, fighting forest fires and transporting perishable products) all consume one energy form or the other.

Increased mechanization means increased energy consumption per unit value of crop output known as energy intensity. Efficient or profitable mechanization schemes must therefore identify and promote farming techniques that result in low energy intensity, since energy input constitutes a significant production cost item (Randy, 2004).

The relationship between energy and food production may be viewed from the fact that tractorization (aimed at achieving higher per capita hectare age) and increased use of fertilizer and pesticides (aimed at higher yield per hectare) all translate to increased energy input. In whatever form, whether mechanical (from machines, human labour, animal draught), chemical (natural gas as feedstock for fertiliser, pesticides and herbicides), electrical or heat, the amount of energy used is expected to grow with expanding population if the country wishes to attain the self-sufficiency in food production and attain the Millennium Development Goals(MDGs). According to Stout(1990) and Faidley (1992), increases in food production in the developed countries were as a result of commercial energy inputs, in addition to improved varieties.

### 1.3 Type of Energy Consumption in Agricultural Production

At the farm level, energy consumed in primary agricultural production is classified as either direct or indirect use. Direct energy use is the consumption of fossil fuels for various farm operations such as fuel for tractors or fuel for crop drying. Electricity is used largely for lighting, heating, and cooling in homes and barns. Dairies also require electricity for operating milking systems, cooling milk, and supplying hot water for sanitation.

Indirect energy use in agriculture refers to fossil fuel consumed as feedstock in producing agricultural input such as fertilizers and pesticides. Of particular importance in this respect is the use of natural gas (a fuel used in power generation, transportation and thermal application in the manufacturing industry) as feedstock for the manufacture of agricultural fertilizer and pesticides. As pointed out by McLaughlin *et al.,* (2000), the production of all inorganic agricultural fertilizers requires large amounts of energy ( i.e natural gas) as feed-stock. According to Bhat *et al*. (1994) the production of a kilogram of N requires from 51 to 68 MJ of energy depending on the type of nitrogen fertilizer produced and the efficiency of the process. Mudahar and Hignett (1987) estimated the primary energy input for urea production at 35 MJ/kg urea based on synthesis of ammonia from natural gas which is then reacted with carbon dioxide to produce urea. They also reported 1.7 MJ/kg fertiliser for the common phosphate fertilizer (the single superphosphate), 6.4 MJ/kg of $K_2O$. Dawson (1978) obtained values of 5.1 MJ/kg of KCl and 9.7 MJ/kg of K, and 5.3 MJ/kg sulphur. Based on these reports, the energy requirements for the production of fertilisers may be determined by multiplying the basic energy factors for N P K and S described above, by the percentage of these elements in the final fertiliser. Table 1 shows examples of energy input into various farming activities.

Table 1.1:Direct and Indirect Energy Uses in Agriculture

| Farming process | Energy input |
|---|---|
| Operating farm machinery<br>- field work (tractors, combines, mowers, balers) | Diesel fuel |
| - Delivery of farm inputs (large trucks and vans) | Premium Motor Spirit (PMS), Diesel |
| -Farm management activities (Operating cars and pickup trucks) | Premium Motor Spirit (PMS) |
| Operating small farm equipment:<br>- Irrigation equipment, Standby generators<br>- Drying of grains | Diesel<br>Natural Gas<br>Liquified Petroleum Gas (LPG) |

| | |
|---|---|
| - Heating/cooling of cattle barn, or poultry brooder, greenhouse | Electricity |
| General farm overhead<br>- Lighting for houses, sheds, and barns<br>- Power for farm household appliances | Electricity |
| **Indirect Use of Energy Fuel**<br>Fertilizer ( Nitrogen-based, Phosphate, Potash ) | Natural Gas |
| Pesticides (insecticides, herbicides, fungicides) | Petroleum or NG |

Source : Randy (2004)

### 1.4 Estimating Fuel Requirements for Crop Production

Numerous studies have been done to quantify energy consumption in agricultural production (Swanton et al., 1996). McLaughlin et al., (2000) reported three methods of estimating and analyzing agricultural energy consumption viz: (a) statistical analysis, (b) input-output analysis, and (c ) process analysis. Statistical analysis method uses global statistics such as fertilizer sales to arrive at an estimate of total energy use but does not achieve the accuracy which can be obtained with other methods. Input-output analysis utilizes a square matrix of energy inputs and is most valid for nationwide analysis.

Process analysis is considered to be the most suitable and accurate method of estimating farm energy consumption. In this method, the processes used to produce a crop are identified and analyzed to quantify their respective energy inputs (Fluck and Baird, 1980). The results can then be expressed as energy productivity in terms of joules of energy required per kilogram of crop yield (McKyes et al., 1986). This method will be adopted for this study.

## 1.5 Statement of Problem

While mechanization can increase agricultural productivity, reduce drudgery and improve the timeliness of farm operations, it results in commensurate increase in energy inputs. This translates to higher production cost and greater carbon emission with attendant environmental impacts. An understanding of the parameters driving energy consumption in tillage operations and opportunities for energy conservation will not only reduce production cost and increase profitability but also contribute to reducing green house gas emission. Such an understanding calls for a mathematical modeling of the various stages of crop production process which is the subject of this research.

Nigeria is currently a net importer of final energy in spite of her large oil and gas reserves. As the country moves towards energy market liberalization and removal of subsidies, the prices of petroleum products will become cost reflective. That means farmers would soon have to pay the full cost of the energy they use thus increasing their total production costs. An understanding of the energy component of the agricultural business will not only enhance productivity but also profitability.

Literature search indicates that most of the existing work on the subject matter consider energy consumption in crop production on aggregate basis without differentiating between the stages of production.( Downs and Hansen,1998; Ozkan *et al;* 2004). While such aggregate energy data may be good enough for country-wise energy system planning, it is not adequate for comparing cropping systems and it does not also allow for process optimization which requires that each stage be treated separately. An operation-by-operationdisaggregation of energy consumption is required to identify the stages of cropproduction with potentialsfor energy efficiency improvement and cost reduction. With increasing concern for fuel conservation and energy management either for economic or environmental reasons, farmers may like to estimate the amount of fuel required to perform specific farm operation based on which he can decide the least energy intensive path.

Researchers such as Hatirila *et al.*, (2006), Hamedan *et al*., (2011) and Ibrahim (2011), have estimated farm energy consumption in relation to crop yield with the assumption that crop yield responses were the aggregate of the response of the crop to energy input to individual farm operation. It may be noted that several non-energy factors contribute to crop yield. For instance crop variety, soil nutrient and cultural practices such as timeliness of farm operations affect yield but are often not considered in the equation linking energy consumption with yield. This study will relate energy consumption to operations and area cultivated rather than the final yield. Energy use in farm operation has both financial and environmental costs. We must take steps to optimize energy use in farm production.

Linear, semi-log, log-linear and polynomial models have been used to investigate the functional relationship between energy input and crop productivity. These models have not addressed agricultural energy consumption on operation by operation basis, the cost of the energy input and the possible levels of energy substitution for improved profitability.

## 1.6 Justification

The role of the agricultural engineer is not limited to the design and production of physical systems for mechanization but also include the strategies for efficient use of the equipment to achieve maximum output. In fact, energy optimization during tillage has been a driving force in farm machinery design improvement. Improvement in power unit and rubber tractor tyres for improved traction, were all aimed at reducing fuel consumption and operating costs(Shoemaker *et al*.,2006). It is therefore necessary to evaluate the pattern of energy consumption in tillage operations.

That energy is an important cost element in maize production has been demonstrated by Nautiyal *et al.,* (2007). With a growing population, the need for cost effective production strategies for the basic staple food crops such as maize cannot be overemphasized.  Vision 20:2020 strategy is hinged on increasingly liberalized energy sector including eventual removal of energy subsidies. The implication is that the energy costs for agricultural production will increase leading to increased production cost and negative impact on the competiveness of our agricultural outputs in the export market. Energy conservation is the most promising short-term solution to the rising energy costs of agricultural production. There a need for an effective energy efficiency strategy  built on an  understanding of the energy consumption patterns for the various production processes in order to determine the least energy intensive path for maize production. The outcome of the study  would provide baseline information for developing energy efficiency strategy for the agricultural sector as well as a tool for evaluating the energy implications of farm mechanization options.

The Nigerian population is growing at 3.2% annually according to NPC(2006). This implies a growing need for increased food production. As stated by Singh (2002), increased crop production depends on arable land expansion, higher cropping intensity and yield. Bringing larger area under cultivation means increased energy input  directly as fuel for tractorization and human muscles or indirectly through fertilizer and pesticide  application(Ozkhan *et al*., 2004).  This means that the current share of agriculture in the national energy consumption will increase. The study will bench mark the energy need for producing a major staple crop (maize) such that future energy need for a target level of agricultural production can be estimated.Umar (2003) note the lack of data on energy expenditure in the Nigerian agricultural sector and pointed out this as a barrier to energy conservation on the farm.

### 1.7Aims and Objectives

The general objective of this study is to determine the energy input requirement for the production of maize.

The specific objectives are:

i. To determine by field measurement, the energy demand for the production of maize in Gui village, Nigeria
ii. To develop a mathematical model for estimating energy demand for tillage operations in maize production and testing same within the middle belt region of Nigeria.
iii. To predict energy demand for tillage operation using the developed model

### 1.8 Limitation

The research is limited to maize production. Although both depletable and renewable energy sources are consumed in crop production activities, this work ignored renewable energy input such as solar absorbed for plant photosynthesis and preharvest crop drying. . This is because the renewable energy is not a threat to agricultural sustainability as they are naturally and freely available.

Since soil type, vegetation and climate often determine the prevalent crop type cultivated and the level of mechanization, the research is limited to the middle belt region. With appropriate factors to compensate for regional variation in vegetation and soil type, it is expected that the national energy demand for maize production can be estimated from this study. Energy used in post-harvest processing of crop will not be included as that actually belong to the appropriate industrial energy consumption. The energy consumed for producing the farm equipment was not considered because this study was not intended to consider life cycle energy input as such input is neither part of the national energy balance nor within the farmers’ control. For the purpose of the present work, modelling of energy demand focused on the mechanical soil tillage only while estimate for the remaining operations will be through alternative routes.

## Chapter 2

## LITERATURE REVIEW

### 2.1 Energy Demand in Agricultural Sector

Agriculture is a major user of energy directly in the forms of fossil fuel, electricity and human muscle and indirectly as feed stock in agrochemical inputs such as fertilizer and pesticides. According to an estimate made in respect of the US Agriculture, energy accounts for 15 percent of total farm cash production expenses(Randy, 2004). In addition, agriculture has the potential to become an increasingly important source of renewable energy and provide significant economic opportunities for farmers.Energy is also consumed in livestock production in such application as egg incubation, chick brooding, and cattle milking (Bowers, 1992; Coxworth, 1997).

Sambo *et al*., (2006) conducted a national energy demand study which showed that energy demand for agricultural sector will double its 2005 value by the year 2020 based on the projected growth in agricultural production. The implication is that energy management will become increasingly important to agricultural profitability in the coming decades.

### 2.2 Type of Energy Consumption in Agriculture

The energy consumed in agriculture consists of all direct and indirect energy used on the farm. Direct energy (refined petroleum products, natural gas, coal and electricity) are consumed during various farming operations from land preparation through seed planting, crop protection, irrigation to harvesting and processing.

Indirect energy associated with the manufacture of farm inputs also constitute a significant source of farm energy input. For instance in the production of urea from ammonia, natural gas is used as a feed stock. Mudahar and Hignett (1987) estimated the primary energy input for urea production as approximately 35 MJ/kg of urea based on synthesis of ammonia. According Smaling et al., (2006), Nigeria import of Urea fertiliser as at 2006 was 6,400 tonnes. This is equivalent to 224,000MJ or 212,322 scf of Natural gas consumption. Although energy consumed off the farm for manufacture and repair of farm machinery is sometimes included as indirect energy, such is not included in this study because of measurement difficulties. Some studies have also included the energy used in farm buildings (Coxworth, 1997) and machine repairs (Bowers, 1992).

Although direct use of natural gas by agriculture is the smallest of any major energy source, its importance is increased by an indirect linkage with fertilizers, particularly nitrogenous fertilizers. Natural gas is the major feedstock of nitrogenous fertilizers and represents as much as 90% of the cost of production of anhydrous ammonia. Chancellor (2002) showed that fertilizer input is a major source of total Energy input to crop production on marginal lands. Although, to a smaller extent, natural gas is an important cost component in the production of pesticides

### 2.3. Energy Used in Fertilizers and Agrochemicals

Substantial commercial energy is required to produce pesticides. The raw material for pesticides comes mostly from petrochemical industry, the manufacturing, packaging and distribution of pesticides also require energy input. According to Mudahar et al, (1987), energy used in the production of fertilizers accounts for 40% of total energy used in agricultural production in developed countries. Most of this energy was consumed in the production of nitrogen, phosphorous and potassium fertilizers.

CAEEDAC(2000) estimated the total energy consumed for fertilizer production in Canada from the total quantities of all fertilizer sold annually in Canada by assuming that the quantities of fertilizer used for purposes other than farming are negligible. Using the energy required per tonne of fertilizer production, the total quantity of each fertilizer nutrient was multiplied by the corresponding energy used per tonne of nutrient. For example since the production of ammonia required 57.62 Gigajoules (GJ) of energy per tonne of nutrient, the total quantity (in tonnes) of ammonia sold was multiplied by 57.62 GJ. Coxworth (1997) and Green (1987) reported estimates of energy used in fertilizer and pesticide production based on methods and effects described later by Bhat et al., (1994).

Sims *et al*., (1983) carried out a study of energy use in New Zealand agriculture to identify opportunities for energy conservation while Stanhill *et al*.,*(*1984) compared the intensity of energy outputs, fossil fuel energy and labour inputs from a number of New Zealand's agricultural systems during the 1970s. These studies were based on survey of randomly selected farms and looked at all energy forms and all activities in the cropping cycle for the selected crops. The typical maize production system in the study area was established during the preliminary study. Singh and Chancellor (1974) conducted a study of energy input in different farm categories in Northern India and came to the conclusion that power sources have little influence on crop yield.

## 2.4 Estimating Energy Demand in Crop Production

Researchers such as Mudahar and Hignett (1987), Hatirila et al., (2006), Hamedan, *et al*., (2011) and Ibrahim (2011) have evaluated energy consumption patterns in agriculture for the different situations, different crops and different cropping sequences all over the world and all of them show the importance of how energy resources are used. Davoodi and Houshyar (2009) investigated energy consumption in canola and sunflower farming in Iran. They concluded that canola production consumed 30,889MJ/ha while sunflower consumed a total 22,945.3MJ/ha

According to Moulik et al., (1990) earlier attempts on forecasting energy demand for agriculture have largely been based on aggregate macro-level data and overall national averages and trends. Useful as they are in indicating some broad trends, these forecasts are unable to capture variations between crops, operations and levels of technology used. In a study conducted in Morocco, Baali and Ouwerkerk(2005) attempted to determine energy balance in wheat production by summing up the average energy consumed along the production itinerary and considering several forms of energy including muscle energy. The results showed that the total energy used to produce wheat is approximately 14 GJ/ha, that is 558MJ/kg of wheat , consisting of 24% direct and 76% indirect energy. The result also showed that N-fertilizer accounts for more than 50% of the total input energy whereas seeds, pesticides and machines have only a marginal importance with 5, 3 and 5% of total energy input respectively. The share of human (animate) power is less than 1% of total energy input.

Singh *et al*., (1997) conducted a comparative study of energy requirement for the production of groundnut, sugar cane and cotton in India the results of which showed that energy consumption not only varied with the crop but also with the area of production. Groundnut gave the highest consumption of 17.56GJ/ha.

Pimental *et al*., (1973) showed energy requirement in the US agriculture tripled within a span of 30years corresponding to rise in the level of mechanization and suggested ways to reduce energy inputs in agricultural production. Singh and Singh (1976) concluded that tillage operations consumed the bulk of energy used in crop production activities.

Dipankar (2001) studied the energy consumption patterns of 275 rain-fed soybean farms in Madhya Pradesh (India). He applied a linear programming technique to determine optimal energy resource allocation for maximum yield obtainable under business-as-usual and improved cultivation practices. He concluded that adoption of the improved cultivation practice would improve energy productivity to 0.30 kg of soybean per mega joule of energy input as compared to 0.179 kg/MJ. Tsatsarelis (1991) conducted a survey of energy utilized in cotton production as practiced by farmers in central Greece, to examine means of reducing energy inputs and securing greater efficiency in energy use without yield losses. They recommended a less energy intensive system based on reduced irrigation and fertilizer inputs and on better machinery management.

Pimentel *et al*., (2003) made an assessment of the energy efficiency, yield performance, and labor requirements for the production of corn, wheat, potatoes, and apples using organic (without synthetic chemical fertilizers and pesticides) and conventional farming technologies. They concluded that organic corn and wheat production was 29–70% more energy efficient than conventional production. However, conventional potato and apple production was 7–93% more energy efficient than organic production. For all four crops, the labor input per unit of yield was higher for organic systems compared with conventional production.

Argiro *et al*., (2006) evaluated the energy inputs for apple production in 26 orchards in Central Greece. The study was undertaken to evaluate the energy inputs for apple production, to identify the highest energy consuming operations and propose ways to improve them. They showed that chemicals (pesticides, fertilizers), use of machinery and fuel were the most important inputs for apple production, while human labor, although intensively used, accounted for small energy inputs due to conversion factor used. The study also showed that energy savings could be obtained without significant yield reduction, mainly through reducing fertilizer inputs (especially N), diminishing pest control applications through proper techniques and improving the farm road network. Shahan *et al.*, (2008) conducted energy and economic analysis of wheat production in Iran. Results indicated that 31.19% of the energy consumption was from chemical fertilizers, 26.05% from diesel oil and machinery while 26.73% was direct (human labor, diesel). Following a comparative energy and economic analysis of cultivation of traditional and improved crops, Nautiyala, *et al.*,(2007) showed that the introduced crops required high energy and monetary input was associated with human labor, forest resources, chemical fertilizer and pesticides.

Mani *et al.*, (2007) studied energy consumption pattern, energy management and supply constraints, with respect to wheat–maize cropping system in selected hilly rural villages Western Himalayas. He surveyed 90 farmers drawn from nine villages, three each from three selected altitudes using two-stage random sampling. The average values of energy consumption for wheat crop in low and high hills were, respectively, 41.68 and 110.8 MJ/ha and those for maize crop were, respectively, 43.43 and 81.33 MJ/ha. This implies that topography affects energy demand in agriculture. Jekayinfa (2004) conducted an energy audit of selected mechanized farm in the South Western part of Nigeria on section by section basis. Abubakar and Ahmad (2010) evaluated the energy use patterns in millet production in Jigawa State, Nigeria. Based on a survey of 250 farmers covering energy input from land preparation up to harvesting/threshing, they concluded that the least amount of energy input was for land clearing while the highest intensities of energy used in was soil tillage and weeding. Bridges and Smith (1979) developed a method for determining the total energy input for agricultural practices. The categories of energy considered were those of manufacture, transport and repairs (MTR), fuel and labour.

Attempts at estimating the energy demand in the agricultural sub-sector in Nigeria has been limited to either arbitrarily allocating a share of the national overall energy demand to agriculture on the basis of its sub-sectoral contribution to the Gross Domestic Product (GDP), the so-called Top-down approach or by estimating the time used by an estimated number of tractors working on the Nigerian soil annually. Akinbami (1997) estimated the total number of tractors on Nigerian soil from record of tractor importation and then estimated annual hours of use. Based on these he estimated diesel consumption in the Agricultural sector. But it is known that not all tractors are used exclusively for agricultural operations hence the estimate may only be taken as indicative of how energy demand may change with increase in tractorization. For specific crop, it is necessary to estimate energy demand of each production stage. First the energy for tillage, the energy for planting, weed control up till harvest.

## 2.5 Energy Input to Agricultural Tillage Operations

The major determinants of energy consumed in tillage operation can be classified into three: soil, tool and operational parameters (Zadeh, 2006). Soil physical properties (soil cohesion, soil-soil friction, soil cone index and, shear strength ) influence the resistance to penetration, the weight of furrow slices and thus the amount of energy consumed in a tillage operation(Yusuf 2006). Moisture content relates to the plasticity, density, compressibility and swelling potential. Hence, as the soil wetness increases, the inter-particle bonds weakens, causing swelling and reducing internal friction making the soil more workable and compactable (Hillel, 1980). Hence the resistance to implement cutting edge and the draught force necessary to overcome such resistance depend on the soil moisture content among other factors. Soil bulk density and shear strength which depend on soil moisture and texture are candidate parameters for investigation.

Mouazen and Ramon (2002) reported that draught force of subsoiler was increased with wet and dry bulk densities where it decreased with soil moisture content. They showed that draught force varied linearly with soil moisture content , a quadratic function of wet bulk density up to a moisture content of 17%. Analyzing the effect of change in bulk density on the mechanical behavior of soil, Ayers (1987) showed that soil moisture content and density affect soil shear strength parameters of coarse grained soils during tillage operations.

## 2.6The Effect of Forward Speed on Energy Demand during Tillage Operations

The effect of travel speed on implement draught depend on soil type and type of implement. Collines et al., (1978), Al-Hashem et al., (1983) and Ashby et al., (1993) based on their study of mouldboard and chisel plows concluded that the response of draught to implement speed was parabolic for mould board and linear for chisel plough. Krishnan et al., (1988) reported that specific draught of a tandem disc harrow used as primary tillage implement can be expressed as a quadratic function of speed whereas in the secondary tillage operation it show a linear relationship. Summers et al., (1986) also reported that draught of disc harrow has linear relationship with speed in a silty loamy soil. The effect of working depth on the draught was reported linear, according to Collins *et al*.,(1978) for mouldboard and chisel ploughs.

In explaining the observed effect of forward speed on the performance of tillage tools Zadeh (2006) stated that as forward speed of a tillage tool increases, dynamic effects on the cutting force become more predominant due to continuous acceleration of new mass of soil as the tool travels. Speed and tillage depth are thus important candidate parameters for tillage energy modelling.

## 2.7 Measuring Human Energy Expenditure

Energy expended by human being is often measured by the indirect calorimetry, which is a method of estimating heat production based on the determination of gaseous exchange. It is based on the laws of thermodynamics, which state that, “when the chemical energy content of a system changes, the sum of all forms of energy given off or absorbed by the system must be equal to the magnitude of the changes” (Dubois 1954).In this method, Body surface area (BSA) is obtained from anthropometric details of the subject using equation 2.1 based on Dubois (1954).

$$BSA = 0.007184 * H^{0.725} * W^{0.425} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.1$$

where BSA= Body Surface Area ($m^2$)

H= Height (cm)

W= Body weight (kg)

The Basal Metabolic Rate (BMR) method uses the metabolic rate of the individuals in rest position as standard, which can then be compared with metabolic rate during physical exertion under similar environment. Rennie et al., (2001) stated that heart rate monitoring method for measuring energy expenditure of a free-living subject compared favourably with laboratory methods even without calibration.

Fahey et al., (2005) stated that resting metabolic rate varies with age, gender, and weight. They gave the following equations for calculating the approximate RMR of a subject based on the World Health Organization (WHO) publication.

$$RMR = A * Weight + B \quad \text{-------------------------------------------------------------} 2.2$$

where RMR= Rest metabolic Rate (MJ/ha)

Weight = weight of subject (Kg)

A , B= factors indicated in table

Levine(2005) reviewed indirect and direct calorimetric and non-calorimetric methods for measuring energy expenditure in humans and concluded that where high accuracy is required and sufficient resources are available, such laboratory method as open-circuit indirect calorimeter can be used. He recommended the use of basal metabolic rate and multiplying it by appropriate factors.

David *et al.*, (2003) conducted a validation of several established equations for determining basal metabolic rate and came to the conclusion that among the various standards tested, the Mifflin standard provided an accurate estimate of actual resting metabolic rate in humans. Freedson and Miller(2000) and Crouter *et al.*, (2004) showed that for moderate to strenuous activity a person's heart rate increases linearly with oxygen consumption. He recommended that for countries where agriculture is dominated by human energy, it is reasonable to adopt the value 0.75MJ/h for men and 0.69MJ/h for womenas proposed by Norman (1978). These values were also adopted by Abubakar et al (2010) in a study of energy use pattern in sugar production.

## 2.8 Energy Input from Agrochemicals

A number of different classes of herbicides, fertilizer, pesticides are commonly used in on-farm crop management. The manufacture of these agrochemicals consumed some forms of energy. Nitrogenous fertilisers are particularly important in this respect due to their high usage and their high energy cost to manufacture. The quantities of different chemicals used on each farm operations may be summed to compute total chemical energy in MJ/ha. Stout (1990) presented data on the energy requirement for manufacturing herbicides from a number of sources. Fluck and Baird (1980) summarized the energy equivalent of common agrochemicals as contained in table 2.1. For this study, Gramazone (Paraquat) with 276.4g/liter of active ingredient 459.6MJ/kg will be used.

Table 2.1 Energy indexes of some herbicides

| Herbicide | | **Fertilizer** | |
|---|---|---|---|
| Product | **Energy Coefficient** (MJ /kg )* | **Element** | **Energy Coefficient (MJ/kg )**** |
| Atrazine | 188.38 | Nitrogen (N) | 65 |
| Paraquat) | 459.60 | Phosphorous (P) | 15 |
| Dicamba | 295.13 | Potassium (K) | 10 |
| Glifosate | 454.20 | Sulphur (S) | 5 |
| Diquat | 400.18 | | |
| Captan | 115.05 | | |
| Carbofuran | 454.20 | | |

*Source: Fluck & Baird (1980), ** Source: Mudahar and Hignett, (1987)

## 2.9Modelling Tillage Energy Demand

A model is a representation containing the essential structure of an item or a concept.It is a scaled replica of a system and simplified representation of a complex system(Yusuf, 2001). While a model should be a close approximation to the real system and incorporate most of its salient features, it should not be so complex that it is impossible to understand and experiment with it. Good models connect each stage of the system lifecycle and share many of the essential characteristics of the object it models. Detailed models allow us to imagine how the modeled object itself might behave. However the model is never exactly the same as the real thing since, in the building of a model, certain compromises with reality have to be made. In other words, a good model is a judicious tradeoff between realism and simplicity (Maria, 1997).Modeling enables analysts to develop scientific understanding - through quantitative expression of current knowledge of a system, help researchers to test the effect of changes in a system; system managers to take tactical decisions; and planners to make strategic decisions. It will, therefore, be helpful to an understanding of the energy requirement of maize production by modeling the relationship between energy consumed and the soil, operation and implement parameters.

### 2.9.1 Types of Model

**Mathematical model:**A mathematical model describes the behavior of a real-life system in terms of mathematical equations. Such equations represent the relations between the relevant properties of the system under consideration. Eykhoff (1974) defined a mathematical model as a representation of the essential aspects of an existing system (or a system to be constructed) which presents knowledge of that system in a set of equations that establish relationships between the variables that represent some properties/parameters of the system to be controlled or optimized. A major merit of a model is that it allows the researcher to organize theoretical beliefs, axiom and empirical observation about a system and to deduce logical implication of such organization (Fishman, 1973). Kheiralla *et al*., (2004)developed a mathematical representation of tractor draft for moldboard and rotary tillage implement. Sharifat and Kushwaha(2000) developed mathematical model for the horizontal movement of soil particles in front of a tillage tool in which they assumed that there is a dynamic influence zone moving in front of the tillage tool. They concluded that tool geometry, operating speed and soil physical properties are important factors influencing the soil movement. In general, the complexity of a model depends on a trade-off between simplicity and accuracy of the model.

**Physical model:**A physical model is a smaller or larger but geometrically similar copy of an object. The object being modelled may be small (for example, an atom) in which case the model is intended to show an enlarged view that allows the researcher to see the structure of things that are normally too small to be seen properly. If the object being model is a large system,(for example a space craft), the physical model tends to scale it appropriately to mimic and study the system's physical behavior without actually constructing it.

The geometry of the model and the object it represents are often similar in the sense that one is a rescaling of the other. However, in many cases the similarity is only approximate or even intentionally distorted. Physical models allow visualization, from examining the model, of information about the thing the model represents. A common example of a physical model is an architectural model of a building, constructed to allow visualization of internal relationships within the structure or external relationships of the structure to the environment. A physical model is a three dimensional alternative for a two dimensional representation such as a drawing or photograph.

**Dynamic model:** Dynamic model is used in applied mathematics to describe the behavior of complex dynamical systems, on a time scale, usually by employing differential equations for continuous dynamical system or differential equations for discrete dynamical systems . Juziuczuk and Kamiński(2006) developed a model of the dynamic forces on a moving tractor with three-hitch implement in which they simplified the system by assuming that the tractor moves rectilinearly on the road with the same road roughness under both left and right wheels of the tractor. In general, models are produced to show the relationships between two or more factors, and their effect on the system or process being modeled but since all models are usually simplified and idealized, they give only a general guide to what may happen.

### 2.9.2 Modelling Process

The process of modeling involves four broad stages, viz: Model construction, calibration, verification and validation. The process of constructing models involve making simplifying assumptions; identifying the boundary conditions or initial conditions; defining the range of applicability of the model, defining the variables, formulating the mathematical function linking the decision variables, calibrating the model and validation of the model.

During the development of a model, each sub-model as well as the complete model is continually compared to the other sub-models and to the real system and the feedback is used to adjust appropriately the assumptions. Defects found at the studying and testing stages are corrected by returning to the building stage. Changes made to the model during these stages may necessitate repeating the other stages iteratively. This process of repeated iteration is typical of modelling projects, and is one of the most useful aspects of modelling in terms of improving our understanding about how the system works. A pictorial representation of iterative process involved in modelling is shown in fig 2.1:

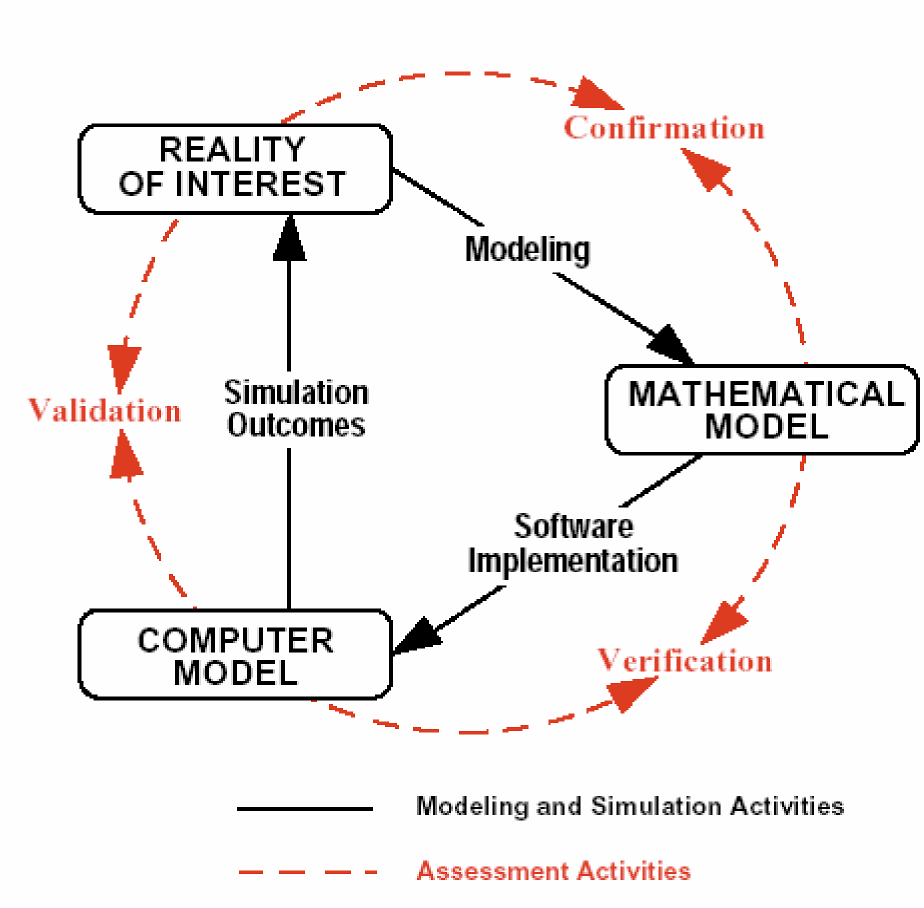


Fig. 2.1: Simplified view of the model verification and validation process
(Source: Schlesinger, 1979)

### 2.9.3 Model Verification and Validation

Verification is the process of checking that the model meets specifications and that it fulfills its intended purpose. These processes are essential parts of the model development process if models to be accepted and used to support decision making. It is an attempt to show the validity of the model and the underlying assumptions by performing its intended function adequately.

Verification is done to ensure that the model is programmed correctly, the algorithms have been implemented properly, the model does not contain errors, oversights, or bugs.

For instance, in this study, the accuracy of the model will be statistically tested by computing energy demand using known tillage operation parameters and the result statistically compared with the energy demand computed from field measurement under the same tillage parameters. The Chi-square test of significant difference between the results at confidence levels of 95% and 99% will reveal the level of accuracy and reliability of the model.

Validation is the process of determining the degree to which the model or simulation, and their associated data are accurate representations of the real world from the perspective of the intended use(s). Model Validation attempts to show that the model represent and correctly reproduce the behaviors of the real world system. The ultimate goal of model validation is to make the model useful in the sense that the model addresses the right problem, provides accurate information about the system being modeled, and that the model is actually useful.

While verification is an internal quality control process that is used to evaluate whether or not the model complies with the developer's conceptual description and specifications, or conditions imposed at the start of a development phase. Validation,on the other hand, is a quality assurance process of establishing evidence, to end users and other product stakeholders, that the model accomplishes its intended purpose.

A number of statistical methods are available to determine the degree to which the model accurately represent the real system being modeled. Imam (1994) provided a summary of statistical descriptors that may be used to evaluate a model's predictive capacity by matching the observational dataset with those predicted using the model, the so called goodness of fit test.The root mean square error (RMSE) is often used to measure the difference betweenvalues predicted by a model and the values observed in the actual situation beingmodelled. The difference between each pair of Observed and modelled output (Oi-Pi)areknown as errors or residuals, while the RMSE is used to aggregate them into a singlemeasure of predictive power. Sorooshian *et al*.,(1983) and Imam *et al*., (1999) describedRMSE as residual based goodness -of-fit indicators which is defined as the square root ofthe mean squared error.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N} (P_i - O_i)^2}{N}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. 2.3$$

where P and O are a set of N predicted and measured data pairs.

Another commonly used indicator is the Pearson's correlation coefficient (r) which is based statistical association(Box *et al*., 1978.). It is defined as

$$r = \frac{\sum_{i=1}^{n} (P_i - \overline{P})(O_i - \overline{O})}{\sqrt{\sum_{i=1}^{n} (P_i - \overline{P})^2 \sum_{i=1}^{n} (O_i - \overline{O})^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.4$$

Correlation – often measured as a correlation coefficient – indicates the strength anddirection of a linear relationship between two variables (for example model output andobserved values). The Pearson product-moment correlation coefficient is obtained bydividing the covariance of the two variables by the product of their standard deviations. Ifwe have a series n observations and n model values, then the Pearson product-momentcorrelation coefficient can be used to estimate the correlation between model andobservations.

The correlation is +1 in the case of a perfect increasing linear relationship, and -1 in caseof a decreasing linear relationship, and the values in between indicates the degree oflinear relationship between for example model and observations. A correlation coefficientof 0 means the there is no linear relationship between the variables. The square of thePearson correlation coefficient ($r^2$), known as the coefficient of determination, describes how much of the variance between the two variables is described by the linear fit.

Wilmott (1982) described the inadequacy of Pearson’s correlation coefficient (r), its square and tests for their statistical significance in evaluating the predictive ability of models and proposed that the observed and predicted variates, respective means (O, P) and standard deviations ($S_o$ $S_p$); the intercept (a) and slope (b) of a least-squares linear regression between the variates and the root mean squared error (RMSE), all be examined.

Willmott and Wicks (1980) recommended the use of root mean squared error as validation statistic because it is easy to interpret since it has the same metric as Observed and Predicted variates. Furthermore, RMSE informs the modeler and reader about the actual size of the error produced by the model-unlike r or $r^2$ in which a large error may be masked by high values of standard deviations $S_o$ and $S_p$ or a small error may appear significant owing to low magnitudes of $S_o$ or $S_p$.

Another model performance indicator, the Dent and Blackie regression test is based on the theory that if there is perfect agreement between two data sets(e.g observed and predicted data), the linear regression of the two sets of data represented by equation 2.5 will give a slope, b= 1 and intercept, a= 0. The linear regression model is

$$Y_i = a + bX_i \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 2.5$$

where $X_i$ are the model's predicted (expected) data and $Y_i$ the actual (observed) data.

### 2.9.1 Student's t-test: Comparison of two means

Student's t-test is commonly applied to small data sets for the comparison of two means. The outcome of these tests is the acceptance or rejection of the null hypothesis ($H_0$) which generally states that there is no significant difference between the means of the data set. The treatments have no real effect or the data set are essentially the same and any differences, discrepancies, or suspiciously outlying values are purely due to random and not systematic errors. The alternative hypothesis ($H_a$) states exactly the opposite.

All significance tests provide results within a predefined confidence level (90%,95% and 99%). Using a confident level of 95%, the researcher is 95% or more certain that in case of rejecting $H_o$ the probability of erroneous rejection is no more than 0.05. A confidence levels of 95% is commonly used in field trials where high level of precision is not practicable.

## 2.10Predicting Diesel Fuel Consumption in Farm Operations

Ahmad and Amran(2004) developed a mathematical model to predict the energy requirement for the combined effect of a disk plow and a rotary blade in clay soil suitable for wet rice cultivation in Malaysia. Various researchers have investigated the interaction between disc and soil and concluded that the physical size and shape of a disc, its setting relative to the direction of motion through the soil and the properties of the soil itself determine its performance characteristics.

Abo-El-Ees and Wills (1994) studied the geometrical interaction between a vertical disc and the soil in terms of disc geometry, disc setting and working depth. They concluded that the radius of curvature of the disc sphere and the diameter of the circle formed by the disc edge relate directly to the geometry of the disc, whereas the disc angle and the depth of penetration define the attitude and position of the disc within the soil mass.

As stated by Onwualu (2011), draught prediction models have been based on theory of soil failure. Stafford, (1984) pointed out that various researchers have assumed different approximation of the cutting edge of tillage tools in their models, while Mckyes and Ali (1977) assumed a straight line bottom or chisel like tool to determine soil failure zone by minimizing the dimensionless term of gravity.

Sahu and Raheman(2005) proposed that the draught requirement of any passive tillage implement, D, in Newton, is a function of working depth d in metres, travel speed v in km/h, width of the implement W in metre, tool geometry characterised by angle $\sigma$ in degree and length l in metres, and soil properties such as bulk density $\rho$ in kg/m$^3$ and cone penetrationresistance R in kPa . They proposed a relationship between the above parameters which is as follows:

$$D = f_1(d,v)\,f_2(w,l,\sigma)\,f_3(\rho,R) \ldots\ldots\ldots\ldots\ldots\ldots 2.6$$

Where:

D= Specific draught (N)

d= depth of implement(m)

v= Travel speed (m/s)

w= width of implement(m)

l= length of implement(m)

$\sigma$ = tool geometry characteristic (degrees)

$\rho$ = Bulk density (kg/m$^3$)

R= cone index (kPa)

Researchers such as Oni et al., (1992); Kushwaha and Linke, (1996); McKyes and Maswaure, (1997);Onwualu (2011); Al-Suhaibani and Al-Janobi,(1997); Mamman and Oni, (2005) and Sule *et al*.,( 2007) have investigated draught in various ways.

Manuwa and Ademosun (2007) pointed out that the specific draught of agricultural tools and implements depend on such factors as the soil type and condition, forward speed, tool type and shape, friction characteristics of the soil-engaging surfaces, share sharpness, and shape, depth of ploughing, width of furrow slice, type of attachments, and adjustment of the tool and attachments.

Reporting the effect of soil type and condition on specific draught, Ademosun (1990) stated that draught decreased linearly with increasing soil moisture content within the range of 12 to 16% (wb) in a sandy loam soil. James *et al*., (1996) wrote a general expression for the draught of any implement as

$$\frac{D}{\tau\sigma w^2} = f^2\left(\frac{d}{w}, \frac{\tau_1 s}{\tau\sigma}, \frac{\rho s^2}{\tau_0}, \frac{Gj}{w}, \alpha K, \mu\right). \text{-------------------------------}2.7$$

Where

D = implement draught, F;

d = depth of cut, L;

s= forward speed,LT-1

w =implement width, L;

Gj= set of characteristic length describing implement geometry; L;

μ = soil-metal friction coefficient

$\tau_0$ = static component of soil shear stress, FTL$^{-2}$;

Wang and Liang (1970) indicated that that the draught of tillage tool of any chosen soil at any velocity can be described by the following dimensionless equation

$$\frac{R}{\rho L^3} = F\left(\frac{V^2}{gL}, \frac{C}{gL}, \phi, \mu\right) \text{-------------------------------------------------------2.8}$$

Where:

R= draught force, F

L= Characteristic length, L

P= bulk density of soil; FL$^{-3}$

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

g= gravitational constant

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

μ = apparent soil-metal friction angle

ɸ =apparent soil-metal friction

## 2.11 Use of Dimensional Analysis

Dimensional analysis works on the basis of the principle that absolute numerical equality of quantities may exist only in systems that are qualitatively similar and that the ratio of magnitudes of two quantities is independent of the units in which they were measured.

Dimensional analysis may be used to develop prediction equation using the relationship that exists among variables. The main advantage of the dimensional analysis is that it helps to reduce the number of variables to be experimentally investigated by eliminating the less important ones .

The basic step in dimensional analysis is to identify a complete set of independent quantities on which the dependent variable depends. The dimensions of the dependent and independent viable are listed. The quantities are grouped into dimensionally independent subsets. The product of these subsets are reassembled in the form of dimensionless terms that can be tested experimentally for verification and validation.

### 2.11.1 Decision Variables

To perform dimensional analysis, all the variables defining a problem are listed. These decision variables are then expressed in terms of the fundamental quantities (mass, length, time and temperature). These may be conveniently summarized in a dimension matrix thus reducing the problem to that of linear algebra. In the dimension matrix, the variables are represented by the columns of the matrix and the fundamental dimensions are represented by the rows of the matrix (Table 2.2). The numbers within the matrix represent the exponent on the fundamental dimensions in the units of the corresponding variable, as demonstrated here.

Table 2.2: Dimension matrix

|  | $\Delta P$ | $V$ | $D$ | $e$ | $\nu$ | $\rho$ |
|---|---|---|---|---|---|---|
| $m$ | $-2$ | $1$ | $1$ | $1$ | $2$ | $-3$ |
| $kg$ | $1$ | $0$ | $0$ | $0$ | $0$ | $1$ |
| $s$ | $-2$ | $-1$ | $0$ | $0$ | $-1$ | $0$ |

The dimension matrix can then be row reduced to find the number of pivot columns which is equal to the rank of the matrix. The number of variables minus the rank of the matrix gives the number of independent dimensionless combinations that must be formed.

### 2.11.2 Buckingham pi Theorem

The Buckingham pi theorem states that when a complete relationship between dimensional physical quantities is expressed in dimensionless form, the number of independent quantities (Buckingham's pi terms) that appear in it is the number of quantities involved minus the number dimensions or the number of the fundamental units involved.

Similarly , if an equation involving k variables is dimensionally homogeneous, it can be reduced to a relationship among k - r independent dimensionless products, where r is the minimum number of reference dimensions required to describe the variables. The combinations formed by the variables are dimensionless products, often called pi terms. The minimum number of reference dimensions needed to describe the original list of variables is represented by r. The number of pi terms required to describe the system is r fewer terms than the original list of variables. Thus

$$s = k - r \qquad \text{2.9}$$

where

s = the number of pi terms,

k = total number of quantities involved

r = the number of basic dimension involved.

In determining the pi terms, the only restriction is that they should be independent and dimensionless. The procedure involves writing auxiliary dimension equation, assigning arbitrary numerical values to the unknown exponents, solving the resulting simultaneous equation and combining the results.

# Chapter 3

# THEORETICAL DEVELOPMENT

## 3.0 Modelling Tillage Energy Demand for Crop Cultivation

Cultivation of maize involves five major stages. They are land clearing and seedbed preparation, planting, fertilizer application, crop protection and harvesting.

Land clearing may involve removal of vegetation cover, tree stumping and trash disposal. This may be done mechanically or manually. In areas with light vegetation such as the guinea savannah, land clearing operation is often substituted with land plowing or the farm is manually cleared and the trash burnt.

Tillage implement whether powered by man, animal or machine, works on the following principle. The power source generates a straight and steady movement of the implement frame and the tools connected to it. Draught is the horizontal component of pull and work is done when the force produces motion.The volume of soil cut per unit travel distance ( the area swept by a tillage tool is the width of soil cut multiplied by the depth of cut).The work done by a power source carrying a tillage implement is a function of the draught developed by the power source at the given operational condition.The intensity of soil engagement with the tool depends mainly on depth of soil cut, type of tillage tool, soil condition and on the forward speed (Yusuf, 2001). For the purpose of developing the theoretical modeling framework, a number of assumptions were made

## 3.1 Modelling Assumptions

The following assumptions were made in the modelling process:

i. The soil is homogeneous through the experimental area before imposition of tillage treatments

ii. It is assumed that soil conditions at the different dates of the same season are alike throughout the field work.

For manual cultivation, only physical ergonomic parameters such as height, weight and age were assumed to affect work output of the subject.

### 3.2 Modelling Approach

The draught required to pull a tillage implement is basically a function of width and geometry of the tillage implement (tillage tool parameters), operating depth and the speed at which it is pulled (operational parameters) soil conditions(soil parameters)( Al-Hamed and Aljanobi (2001). The effect of speed on implement draught depends on the soil type and the type of implement. It varies with the density of soil, soil-metal friction, shear strength of soil, speed of tractor, angle of inclination of the implement, depth of implement, width of cut of implement, number of bottom of implement, according to Sheikh (1972). Hence energy demand in land tillage depends on such soil parameters as soil moisture, soil texture and resistance to cone penetrometer. It also depends on tillage tool parameters such as implement weight, tool edge width as well as operational parameters such as forward speed and depth of tillage. Soil moisture affects soil properties such as plasticity and bulk density. Thus the relationship between the pertinent parameters may be summarized in the following form

$$E_{lc} = f(d, \rho, v, w, s, r) \text{ ------------------------------------------------------3.1}$$

Where

E = energy , $ML^2T^{-2}$;

d= depth of tillage, L;

$\rho$= soil bulk density $ML^{-3}$

w= width of cut , L

s= resistance to cone penetrometer, $ML^{-1}T^{-2}$

v= forward speed, $LT^{-1}$ ;

r= soil shear strength, $ML^{-1}T^{-1}$ ;

Table 3.1:Dimensions of Basic Draught Parameters

| Quantity | Symbol | Unit | Dimension |
|---|---|---|---|
| Energy | E | MJ | $ML^2T^{-2}$ |
| Width of cut | W | M | L |
| Depth of tillage | D | M | L |
| Speed of Operation | V | m/s | $LT^{-1}$ |
| Soil bulk density | P | Kg/m$^3$ | $ML^{-3}$ |
| Cone Index | S | kPa | $ML^{-1}T^{-2}$ |
| Moisture content, | Φ | % | |
| Soil Shear resistance | R | kg/m/s | $ML^{-1}T^{-1}$ |

Expressed as a dimensionless quantity, equation 3.1 becomes:

$$C_a E^{c1} d^{c2} \rho^{c3} v^{c4} w^{c5} r^{c6} s^{c7} = 1 \text{------------------------------------------------} 3.2$$

Suppose component terms are raised to the power of $c_1$, $c_2$------- $c_7$, then

$$f_a \left(ML^2T^{-2}\right)^{c1} \left(L\right)^{c2} \left(ML^{-3}\right)^{c3} \left(LT^{-1}\right)^{c4} \left(L\right)^{c5} \left(ML^{-1}T^{-1}\right)^{c6} \left(ML^{-1}T^{-2}\right)^{c7} = 1$$

$$M : c_1 + c_3 + c_6 + c_7 = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

$$L : 2c_1 + c_2 - 3c_3 + c_4 + c_5 - c_6 - c_7 = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4$$

$$T : -2c_1 - c_4 - c_6 - 2c_7 = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.5$$

The dimension matrix may be written as follows:

$$\begin{array}{c|ccccccc}
 & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 \\
\hline
M & 1 & 0 & 1 & 0 & 0 & 1 & 1 \\
L & 2 & 1 & -3 & 1 & 1 & -1 & -1 \\
T & -2 & 0 & 0 & -1 & 0 & -1 & -2
\end{array}$$

Since there are three equations with seven unknowns, arbitrary values are assigned to the four of the unknowns. Many combinations are possible

If we select $c_1$, $c_5$, $c_6$ and $c_7$, then the coefficients of the remaining terms ($c_2$,$c_3$ & $c_4$) can be put in a matrix form asfollows:

$$\begin{vmatrix} 0 & 1 & 0 \\ 1 & -3 & 1 \\ 0 & 0 & -1 \end{vmatrix}$$

The determinant of this matrix is 0*(-3*-1-1*0)-1*(1*-1-1*0)+0*(1*0-0*-3) =1.

Since the determinant is not zero, the resulting equations are independent and valid. Values are arbitrarily assigned as follows:

Let $C_1$=1 and let $C_5$=$c_6$=$c_7$=0, then

Equation 3.3 becomes

$$M: 1 + c_3 + 0 + 0 = 0$$

$$c_3 = -1$$

Equation 3.4 becomes

$$L: 2 + c_2 + 3 + c_4 + 0 - 0 - 0 = 0$$

$$c_2 + c_4 = -5$$

Equation 3.5 becomes

$$T: -2 - c_4 + 0 - 0 = 0$$

$c_4 = -2$ thus $c_2 = -3$

Therefore , with c1=1, c2=-3, c3=-1, c4=-2, c5=c6=c7=0,

Then $\pi_1 = \dfrac{E}{d^3 \rho v^2} = \dfrac{ML^2T^{-2}}{\left[L^3\right]\left[ML^{-3}\right]\left[LT^{-1}\right]^2}$ which is dimensionless.

Similarly, let $C_5$=1 and let $C_1$=$c_6$=$c_7$=0, then

Equation 3.3 becomes

$$0+c_3+0+0=0$$

$$c_3=0$$

$$0+c_2-0+c_4+1+0-0=0$$

$$c_2+c_4=-1$$

$$-0-c_4+0-0=0$$

$c_4=0$ thus $c_2=-1$

Therefore , with c2=-1, c1=c3=c6=c7=0,$c_5$=1,c4=0

Then $\pi_2=\frac{w}{d}\ \ ==\frac{L}{L}$which is dimensionless.

Similarly, by letting $C_6$=1, c1=c5=c7=0, and solving the equations

$$M:0+c_3+1+0=0$$

$C_3$=-1

$$L:0+c_2+3+c_4+0-1-0=0$$

$$c_2+c_4=-2$$

$$T:-0-c_4-1+0=0$$

$c_4=-1$ thus $c_2=-1$

$C_1$=0,$C_2$=-1,$c_3$= -1, $c_4$= -1,$C_5$=0,$c_6$=1

$\pi_3 = \frac{r}{d\rho v} = \frac{ML^{-1}T^{-1}}{[L][ML^{-3}][LT^{-1}]}$ which is dimensionless

By substituting c7=1, c1=$c_5$=$c_6$=0 into the equation and solving them will give

$M: 0 + c_3 + 0 + 1 = 0$

$c_3 = -1$

$T: -0 - c_4 - 0 - 2 = 0$

$c_4 = -2$

$L: 0 + c_2 - 3c_3 + c_4 + 0 - 0 - 1 = 0$

$c_2 + 3 + c_4 - 1 = 0$

$c_2 + 3 - 2 - 1 = 0$

$c_2 = 0$

$C_1=0, C_2=0, c_3= -1, c_4= -2, C_5=0, c_6=0, C_7=1$

$\pi_4 = \frac{s}{\rho v^2} = \frac{ML^{-1}T^{-2}}{[ML^{-3}][LT^{-1}]^2}$ which is dimensionless

The problem can thus be described by the following function of the three dimensionless pi groups

$$\Phi(\pi_1, \pi_2, \pi_3, \pi_4) = 0$$

$$\Phi\left(\frac{E}{v^2 d^3 \rho}, \frac{w}{d}, \frac{r}{vd\rho}, \frac{s}{v^2\rho}\right) = 0$$

This may be written as: $\frac{E}{v^2 d^3 \rho} = f\left(\frac{w}{d}, \frac{r}{vd\rho}, \frac{s}{v^2\rho}\right)$

These pie terms contains the requirement for similarity and therefore contains the ratios defining the geometric and dynamic similarities for the variable relevant to the determination of tillage energy.

### 3.3Method of Solution

By plotting $\pi_1$ against $\pi_{2,}$ $\pi_{3,}$ $\pi_4$,respectively using the data collected in the first two years (2010 and 20011), the most important decision variables can be identified. The model obtained is then verified using the data collected in the third year 2012.

For the purpose of the present work modelling of energy demand was focused on the mechanical soil tillage only and estimate for the remaining operation by alternative routes.

## Chapter 4

## MATERIALS AND METHODS

### 4.1 Introduction

This chapter describes the approach and methodology adopted in carrying out the field measurements which was used to validate the above theoretical equations as well as provide data for testing the scenarios to be developed. The chapter presents a description of the study area, the field layout, the treatments imposed, measurement of fuel consumed in tractor operation and the measurement of energy demand for manual operations.

### 4.2 Description of Study Area

The study area is located at Gui, a farming community in Abuja (longitude 007°10'E and Latitude 09°10'N), the area hosts a number of commercial and small farms and has a wet season withmonthly average rainfall peaking at 342mm in August. Monthly maximum and minimum temperatures are 44 $^{0}$C and 16$^{0}$C, respectively. The average humidity ranges from 30% to 85% and is highest in the rainy months and lowest in the dry season (Abubakar and Mundi, 2000). The vegetation in the study area as in most part of FCT is dominated by herbaceous plants which were occasionally interspersed with shrubs. (Balogun, 2001).

A preliminary survey of the area showed that the seedbed for cultivation of maize in the study area is usually prepared manually by making ridgesafter clearing and trash burning. The commercial farmers practices thorough ploughing and harrowing followed by ridging or in some cases, direct planting after ploughing without ridging. The tillage is done using tractor implement system. Animal power is not used on the farms in the study area.

Fertilizer and agro-chemicals are generally applied manually on all the farms. The energy demand for fertilizer application wascomputed from the time spent per hectare by the subject applying the fertilizer. As commonly practice in the study area chemical weed control on maize farms was done with Paraquat, a non-selective herbicide. The energy demand for herbicide application was calculated from the time taken to spray one hectare.

### 4.3 Anthropometric Measurements

For the purpose of estimating energy demand for manual operation, anthropometric dimensions were recorded for all subjects. All measurements (body mass and height) were made by a single trained research assistant as follows: Height was recorded to the nearest millimeters by using a 5-meter tape rule. With the subject standing by a vertical wall, his height was marked against the wall and the measurement taken with the tape rule.

Body mass was measured with the use of a simple weighing scale. The subjects were weighed while wearing light clothing, and a correction of 0.5 kg was made to account for clothing weight. Their heights were measured using a tape rule and a vertically standing plank. Based on the body weight and height the Body Surface Area (BSA) of each farmer was computed from DuBois and Dubois (1954) as:

$$BSA(m^2) = 0.007184 \mathrm{x} \mathrm{Height(cm)}^{0.725} \ \mathrm{x} \ \mathrm{Weight(kg)}^{0.425}$$ -------------------------------

4.1

Body mass ratio (BMR) was computed for each subject using Mifflin standard equation and the Harris Benedict Equations.

### 4.4 Materials and Devices used in the Field Experiment

The materials used in the field experiment were:A local handheld hoe, a72HP Massey Ferguson Diesel Tractor, a three bottom disc plough (56cm diameter per disc), two gangs Disc harrow, Disc ridger, ranging poles, surveyor tape, stop watch, a sphygmomanometer, calibrated wooden bar, weighing scale, measuring tape and stethoscope.

**4.4.1 Tractor used in the Field Experiment**: For the tillage operations a MasseyFergusson farm tractor belonging to Kuje Area Council was used. The detail specifications of the tractor are in Table 4.1.

Table 4.1: Tractor Information

| | |
|---|---|
| Model | MF 435 |
| Type of engine | 4-Cylinder |
| Type of fuel | Diesel |
| Type of steering system | Power-assisted |
| Transmission | 8X2 4WD |
| Type of injector pump | In-line Injector |
| Rated Power output(hp) | 72 |
| Fuel tank capacity(litre) | 75 |
| Rated engine speed(rpm) | 2200 |
| Type of cooling system | Water-cooled |
| Front inflation pressure(psi) | 32 |
| Rear inflation pressure/psi | 28 |

**4.4.2Local Handheld Hoe Used for Manual Tillage**: Figure 4.1 show the hand-held hoe which is the traditional tillage tool that is commonly used by farmers in the locality for weeding, ridging and harvesting operations. It consist of wooden handle and a heart-shape concave metal blade made from mild steel by a combination of forging and annealing process in the blacksmith shop. The hoe weighs1.5 to 2 kg, , the handle is 70 to 75 cm long and 3 to 4 cm in diameter, blade is 25 to 30 cm long with width ranging from 22 to 24 cm. Angle between blade and handle is $65^o$. The blade size diminishes with age due to wear. While new blades are normally used for ridging and heap making, the older and smaller blades are used for weeding.

Fig. 4.1: Local Hand held hoe used in the study area

### 4.5 Experimental Design

The treatments were randomly assigned in a 5 x 3 factorial experiment arranged in a randomized complete block design with five tillage treatments (P1, P2, P3, P4 and P5) representing Land preparation(removal of vegetation,/ploughing and harrowing), Ridge making, Planting, Fertilizer Application andWeeding; and three mechanization levels (T1, T2 and T3), representing manual, and two varying level of mechanized cultivations as described in table 4.2. The treatments were replicated thrice over three years. Each plot measured 10 m x 15 m or 0.015 hectare, making a total area of 0.225 hectare each year. The clearing of vegetation from the experimental plot was repeated each year.

**4.5.1 Tillage treatments:** The field trial design consists of 2 factors(level of mechanization T and Operation P. Three levels of mechanization were considered (tagged technology levels T1, T2, T3) with five operations (tagged as P1, P2, P3, P4, P5). Where P1= Land preparation (land clearing, ploughing and harrowing), P2= Ridge making, P3= Planting, P4= Fertilizer Application, P5= Weeding. T1= Mechanized , T2= semi-manual, T3= manual. The treatment description are as given in table 4.2 below:

**Table 4.1: Treatment Description**

| Treatment | Description |
|---|---|
| P1T1 | Ploughing + harrowing |
| P1T2 | Ploughing only |
| P1T3 | Clearing with hoe/cutlass |
| P2T1 | Ridging with tractor after harrowing |
| P2T2 | Ridging with tractor without harrow |
| P2T3 | Ridging with hoe |
| P3T1 | Planting with Tractor Drawn planter |
| P3T2 | Manual Planting(dibbling) on tractor made ridges |
| P3T3 | Manual Planting(dibbling) on manual ridges |
| P4T1 | Manual fertilizer application |
| P4T2 | Manual fertilizer application |
| P4T3 | Manual fertilizer application |
| P5T1 | Weeding using Knapsack herbicide applicator |
| P5T2 | Manual weeding with hoe |
| P5T3 | Manual weeding with hoe |

**4.5.2Experimental Procedure:** With the aid of two field assistants, a surveyor tape, ranging poles, twine line and pegs, the plot was marked out into 15 plots of 10m x 15m size. The treatment were then randomly allocated. The procedure was repeated for three years (2010, 2011 and 2012).

**4.5.3Land preparation:** With a three- bottom disc plough mounted on a 72 hp Massey Ferguson tractor, ploughing was carried on all the plots except those for manual land clearing. To determine the quantity of fuel used in each operation, the method used by Umar (2003) was adopted. At the start of each plot, the fuel tank of the tractor was filled to capacity and the fuel tank was refilled at the end of the operation on that plot. The quantity of diesel consumed in each ploughing operation is the amount of fuel required to refill the fuel tank to capacity from a measuring cylinder. This method was used to measure fuel consumed for all tractorized operations (plates 4.1 to 4.6).

Plate. 4.1:Mechanized Ploughing

Plate. 4.2:Mechanized Land preparation ( Harrowing)

Plate. 4.3:**Mechanized Ridging**

Plate. 4.4:Manual Ridging

**Plate. 4.5:Manual Weeding**

**Plate 4.6: Dibbling of Maize**

Three tillage depths were maintained 115, 150 and 200 mm corresponding to the low, medium and high positions of the tractor depth control lever. The resulting actual depths were measured using steel measuring tape with the undisturbed soil as reference. The plough time was determined by using a stop watch to note the interval between the start and end of ploughing for each subplot. Plough speed was computed from the average time it took to plough through the length of each plot.

The energy input was then computed from Umar (2003) as :

$Ef=V_d*F_d$ ------------------------------------------------------------------------4.2

where :$V_d$ = volume of diesel consumed in Litre

$F_d$= unit energy value of diesel, MJ/l, (A value of 36.4 MJ/l as reported by Pimentel (1992).)

Harrowing and ridging operations were conducted on the second and third weeks respectively. For each operation the fuel consumed and the time taken to complete each subplot were measured as described above.

**4.5.4 Measurement of manual energy input**: The remaining third of the land was manually cleared and ridged after two weeks. All operations were carried out by a group of five workers. The records of the number of people in the group working weretaken at the end of each minute. In this way, individual worker could work and rest at his own pace and not influenced bythe fact that they are being watched (supervisory pressure). The energy expenditure was computed using the mean values of measurements taken for each activity. From that record, the total man-hours worked by the group was then computed. Manual energy was estimated based on the value recommended by Norman

(1978), i.e. 0.75 MJ/h for an adult male worker. Thus for each subject, the manual energy expended, $E_m$, was determined as:

$$E_m = \frac{0.75 * Ta}{60} \text{-----------------------------------------------------------} 4.3$$

where

$E_m$= Manual Energy (MJ)

Ta = useful time spent by a worker on a farm activity (minutes)

**4.5.6 Seed planting:** The planting manual methods used in the research was foot dibbling which involves dropping seeds directly into holes made with the farmer's heels, covering the seeds and slightly compacting the soil also with the heels.

For the purpose of this study White DMR – LSRW variety was obtained from the FCT ADP office. Seed planting was carried out two days after ridging using the foot dibbling method as described above. Plant spacing and seed rate were based on Ikan and Amusa (2004). The actual time spent in planting as measured using stop watch was used to compute the human energy input.

**4.5.7 Fertilizer Treatment:** As noted by Egharevba (1979) and Yusuf (2001), the most important fertilizer required by maize is nitrogen followed by phosphorus. Based on the recommendations of the extension leaflets of the Ministry of Agriculture for the area under investigation, NPK fertilizer was applied at the rate of 300kg/ha.

The actual time spent in planting as measured using stop watch was used to compute the human energy input. As applied by Umar (2003), the indirect energy input from fertilizer application may be computed based on Mudahar and Hignett(1987) . However since this study was intended to assess only farm-level energy consumption and not life cycle energy consumption, the energy use in manufacturing and transporting the various farm inputs were not included.

**4.5.8 Application of herbicide:** A pre-emergent herbicide ‘paraquat’ was applied three days after planting and following a light shower of rain. The sprayer was first calibrated according to Smith (1990). Using the knapsack filled with water and a pegged-out area, A $m^2$ of the farm was sprayed with water. The volume, V litres of water applied was determined by measuring the amount of water required to refill the spray tank completely.

The volume application rate (VAR) in lit/ha was computed from

$$VAR = \frac{10000 * V}{A} \qquad \text{------------------------------------} \; 4.4$$

Where v= liters of water ($m^3$)

A= pegged out area ($m^2$)

The quantity of chemical mixed in the sprayer tank was computed from

$$Dose(ml) = \frac{1000 * V_{product} * V_{Tansk}}{VAR}$$

where

$V_{tank}$= Volume of knapsack tank (l)

$V_{product}$ = Recommended product application rate (l/ha)

VAR= calibrated Volume application rate

For Treatment T1 plots, paraquat was applied as post-emergence on a clean seed bed at the recommended rate of 2.5 L /ha and volume application rate of 250 litre of solution per hectare. This means putting 150ml of the chemical in 15 litre capacity knapsack sprayer (CP3) . Each plot therefore received 37.5 ml of paraquat or approximately 10.375g of active ingredient (since paraquat contains 276.4g of active ingredients/litres as indicated in the product labels )

### 4.6 Input Energy for Herbicide Application

Two sources of energy input may be computed for the herbicide spraying operation. The input energy from the operator of the sprayer and the indirect energy content of the herbicide being applied. However, the indirect energy for the manufacture of herbicide and their transportation were not considered as they are outside the farmer's control . The energy expended for herbicide application is computed from:

$$E_{sp} = \frac{0.75 * Ta}{60} \text{ -------------------------------------------------------------------------- } 4.5$$

where $E_{sp}$= Manual Energy for Spraying (MJ)

Ta = useful time spent by a worker operating the sprayer (minutes)

Equation 4.5 was used to evaluate manual energy inputs for all subsequent field operations.

### 4.7 Input Energy for Fertilizer Application

The energy input for fertilizer application is computed in the same manner as herbicide application using equation 4.5 above.

### 4.8 Input Energy for Weeding

Manual weeding was used to control weed in the plots under manual and semi-mechanized cultivation. The first weeding was carried out 20 days after planting while the second weeding was done 58 days after planting. The energy for manual weeding was computed using equation 4.5.

## 4.9 Tillage Energy at different Speeds and Depths

In order to provide data for testing the model under different scenarios, the time and fuel required to plough, harrow and ridge a strip of land at three depths (115, 120, 150mm) and six operating speeds were measured using the Umar(2003) procedure as described above.

## 4.10 Developing Computer Algorithm to run the Model

Having derived the predictive equation based on Buckingham pi theorem the equation was then coded in Excel Macro to provide a user friendly interface for data entry. With such user interface the farmer can rapidly compute the estimated energy demand for tillage operation under different soil and operation conditions and decide on conservation techniques. The flowchart for the Excel Macro is as shown in fig. 4.2.

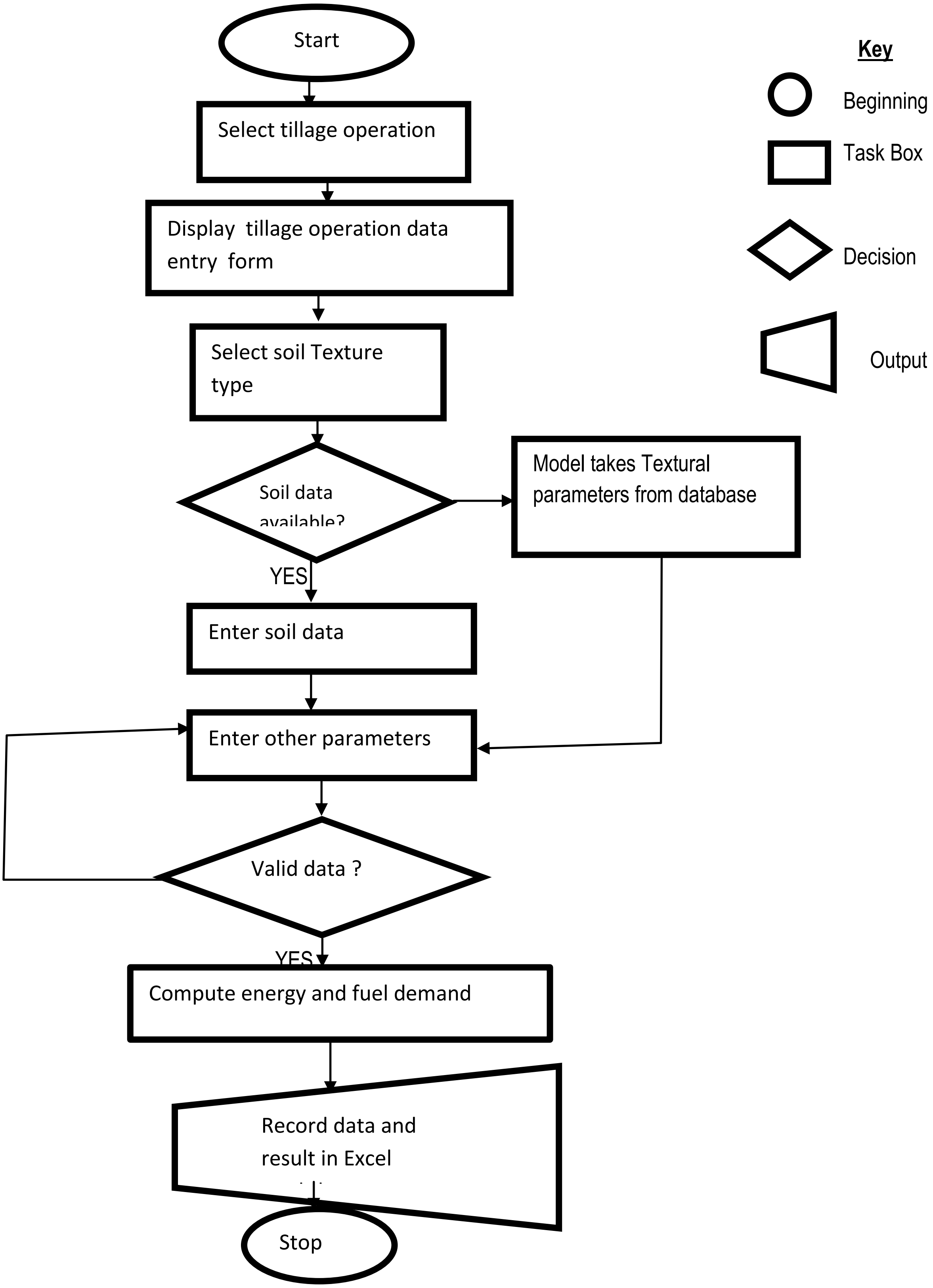


Fig. 4.2: Flow Chart for the Tillage Energy Calculator

# Chapter 5

# RESULTS AND DISCUSSION

Introduction

This chapter presents the results of the field measurement of various parameters, mathematical modeling and scenarios developed during the study as described in chapter 4. The objective was to develop a simple energy prediction model for tillage operations carried out in the cultivation of maize with a view to determining optimal operation parameters. Time and fuel input were measured for each of the cropping operation and the final yield of each treatment was also recorded. Based on the results of the first two years, a tillage energy demand model was developed for predicting fuel consumption at different speeds and depths of tillage. The time(h/ha), fuel consumed(l/ha), the model equations for the ploughing harrowing and ridging, the proportion of energy consume for each operation and average yield (kg/ha) are presented as follows:

## 5.1 Time

Table 5.1 shows the time required per hectare to plough, ridge and harrow for different speeds. The average ploughing time of 2.5 h/ha and ridging time of2.3 h/ha are higher than those recorded by Oyelade and Aduba (2012) whoreported 1.85h/ha and 1.98h/ha for ploughing and ridging respectively. Ahaneku *et al.*,(2010) also reported 1.35 and 1.18h/ha for ploughing and ridging respectively while working atdepths less than 20 cm.The difference may be due to the small size of the experimental plot and relatively largeturning time such that any error or overestimation get multiplied when expressed on perhectare basis.It is noteworthy that ploughing takes more time than harrowing and ridging since the operator has to move at slow speed in stumpy plots and cut the roots of shrubs. Inridging much care is required to ensure straight ridges and avoid half rows. Ridgestherefore take more time than harrowing where the operator simply moves through theplot ensuring overlap of harrow width of cut to avoid unharrowed spots.

Table 5.1: Average Time (h) Taken to Plough, Harrow and Ridge a Hectare

| Tillage Operations | Mechanization Levels | | |
|---|---|---|---|
| | T1* | T2 | T3 |
| Ploughing | 2.5 | 2.2 | 10.0 |
| Harrowing | 1.6 | 1.6 | |
| Ridging | 2.3 | 2.3 | 11 |
| Total average time(h) | 6.4 | 6.1 | 21 |

* T1= Mechanized, T2= Semi-manual, T3= Manual

Table 5.2: Average Time Taken to Weed (h/ha)

| Year | Mechanization Levels | | |
|---|---|---|---|
| | T1* | T2 | T3 |
| 2010 | 5.5 | 10.5 | 12 |
| 2011 | 5.6 | 10.8 | 11.5 |
| 2012 | 5.6 | 12 | 10.8 |
| Average time(h) | 5.6 | 11.1 | 11.4 |

* T1= Mechanized, T2= Semi-manual, T3= Manual

## 5.2 Energy Consumption

. Table 5.3 shows the average energy consumption by operation and treatment over the three years of field trials. The details are shown in Appendix D.

Table 5.3: Average Energy Consumption (MJ/ha) by Operations

| Year | Operation* | Mechanization Levels | | |
|---|---|---|---|---|
| | | T1 | T2 | T3 |
| 2010 | Land preparation | 1309.59 | 1159.14 | 26.39 |
| | Ridge making | 659.24 | 620.01 | 28.61 |
| | Planting | 211.12 | 21.67 | 21.67 |
| | Fertilizer | 10.00 | 23.89 | 25.00 |
| | Weeding | 26.94 | 46.11 | 46.94 |
| 2011 | Land preparation | 1339.52 | 1286.13 | 25.56 |
| | Ridge making | 710.20 | 677.04 | 28.33 |
| | Planting | 201.41 | 21.67 | 22.50 |
| | Fertilizer | 23.06 | 24.44 | 23.61 |
| | Weeding | 26.94 | 47.50 | 40.83 |
| 2012 | Land preparation | 1303.12 | 1290.99 | 26.11 |
| | Ridge making | 686.75 | 752.27 | 26.11 |
| | Planting | 207.08 | 20.56 | 21.67 |
| | Fertilizer | 23.89 | 23.61 | 25.56 |
| | Weeding | 27.22 | 42.22 | 40.83 |

*Parameter values are average of three replicates

## 5.3 Energy Consumption by Operation

### 5.3.1 Land Preparation

Table 5.2 shows the energy consumed during land preparation and ridge making by mechanical and manual methods over the three years of the field study.

Table 5.4:Energy Consumption during Land Preparation (MJ/ha)

| Year | Mechanization Levels | | |
|---|---|---|---|
| | T1 | T2 | T3 |
| 2010 | 1309.59 | 1159.14 | 26.39 |
| 2011 | 1339.52 | 1286.13 | 25.56 |
| 2012 | 1303.12 | 1290.99 | 26.11 |
| Average | 1317.41 | 1245.42 | 26.02 |

* T1= Mechanized, T2= Semi-manual, T3= Manual

Table 5.5:Energy Consumption during Ridge Making (MJ/ha

| Year | Mechanization Levels* | | |
|---|---|---|---|
| | T1 | T2 | T3 |
| 2010 | 659.24 | 620.01 | 28.61 |
| 2011 | 710.20 | 677.04 | 28.33 |
| 2012 | 686.75 | 752.27 | 26.11 |
| Average | 685.40 | 683.11 | 27.69 |

* T1= Mechanized, T2= Semi-manual, T3= Manual

It will be noticed that the total energy used during land preparation is highest in treatment T1 with an average of 1093.46MJ/ha and lowest in fully manual plots (T3) with an average of 23.51MJ/ha(less than 10% of the mechanical energy input). This was expected since treatments T1 and T2 involved three energy intensive operations (ploughing, harrowing and ridging) while the manual system involved only two operations (clearing and ridging) and the energy required to move the tractor and the implements cannot be expected to be equal to that required to move the hand held hoe. Meanwhile the work rate or field capacity of manual tillage was much less than that of tractor.

Although, manual tillage has the merit of low energy input, the amount of time required, the drudgery suffered by farmers are disproportionately high. As shown in table 5.1 above, a total time of 6.4 hour is required to prepare (plough, harrow and ridge) one hectare while manual operation took a total of 21 man-hours or three times higher for land clearing and ridging of one hectare. Timeliness of operation due to high field capacity (accomplishing larger hectare age per hour) with reduced human drudgery are the main selling points for mechanization. Also, in terms of cost, manual land preparation was about 70% more expensive per hectare than mechanized operation.

### 5.3.2 Energy Demand for Planting

Table 5.4 shows the energy consumed in mechanical and manual planting as measured in MJ/ha. For treatment T1, Planting was done with tractor drawn planter while in the treatments T2 and T3 , planting were done by manual drilling. As expected, manual planting recorded low field capacity compared to the mechanized planting. Manually planted plots had fewer plant stands which are irregularly spaced.

Table 5.6:Energy Consumption during Planting (MJ/ha)

| Tillage Operations | Mechanization Levels* | | |
|---|---|---|---|
| | T1 | T2 | T3 |
| 2010 | 211.12 | 21.67 | 21.67 |
| 2011 | 201.41 | 21.67 | 22.50 |
| 2012 | 207.08 | 20.56 | 21.67 |
| Average | 206.54 | 21.30 | 21.94 |

* T1= Mechanized, T2= Semi-manual, T3= Manual

Planting appear to less energy intensive compared to ploughing and ridging, looking at the energy consumed by tractor drawn planter in T1 above tractor mounted plough or harrow in table 5.2 above. It is therefore reasonable to conduct planting operation with manual method where possible. This will not only reduce fuel consumption but also the number of tractor passes on the land and the consequent soil compaction.

### 5.3.3 Weed control

Table 5.7 shows the energy consumed in manual and mechanized weeding. T1 which used chemical weed control consumed the lowest amount of total energy , 37.05 MJ/ha compared to 43.17,MJ/ha and 41.17MJ/ha in treatments T2 and T3,respectively, which were manual weed control using hand held hoe.

Table 5.7: Energy Consumption during Weed Control (MJ/ha)

| Tillage Operations | Mechanization Levels* | | |
|---|---|---|---|
| | T1 | T2 | T3 |
| 2010 | 26.94 | 46.11 | 46.94 |
| 2011 | 26.94 | 47.50 | 40.83 |
| 2012 | 27.22 | 42.22 | 40.83 |
| Average | 27.04 | 43.17 | 41.00 |

* T1= Mechanized, T2= Semi-manual, T3= Manual

It is noticeable that in comparison with manual planting, manual weed control required more energy input. The import of this observation is that weed control is energy intensive and should as much as possible be mechanized. From table 5.2 it is evident that manual weeding operation requires more than twice the time required to spray herbicide on one

hectare of farm. While 11 man-hour is required to manually weed an hectare , only 5.5 man-hours are required to spray a hectare with herbicide using knapsack sprayer. Manual weeding should be used only as a last resort as it is both energy intensive and time consuming.

### 5.3.4 Fertilizer application

For all treatments, fertilizer application was done manually as there was nomechanical fertilizer spreader available in the study area.

Table 5.8: Energy Consumed for fertilizer application (MJ/ha)

| Tillage Operations | Mechanization Levels* | | |
|---|---|---|---|
| | T1 | T2 | T3 |
| 2010 | 10.00 | 23.89 | 25.00 |
| 2011 | 23.06 | 24.44 | 23.61 |
| 2012 | 23.89 | 23.61 | 25.56 |
| Average | 18.98 | 23.98 | 24.72 |

* T1= Mechanized, T2= Semi-manual, T3= Manual

### 5.4 Total EnergyConsumption by Operation

Figure 5.1 shows the proportion of the total energy consumed per hectare by the operations. Land preparation and ridging accounted for 86% of the total energy demand for maize production. It is noteworthy that some researchers have included indirect energy sources in their estimate of energy demand and thus obtained energy demand shares that aregrossly influenced by the indirect energy source. For instance Umar (2003) assessed energy consumption in the cultivation of groundnut and showed that weeding hadthe largest  energy demand. This was due to the large contribution of indirect energy in the form natural gas used as feedstock in producing herbicides employed in the weed control. While inclusion of indirect energy is important in life cycle energy analysis and in estimating the implication of agricultural energy consumption in the national energy balance, the individual farmer is often oblivious of the energy used in producing the fertilizer and other agrochemicals used in the farm and such energy type is not reflected in his farm record as energy item. For the purpose of this study, which focuses on farm level energy conservation opportunities , only direct mechanical and human energy inputs wereconsidered.

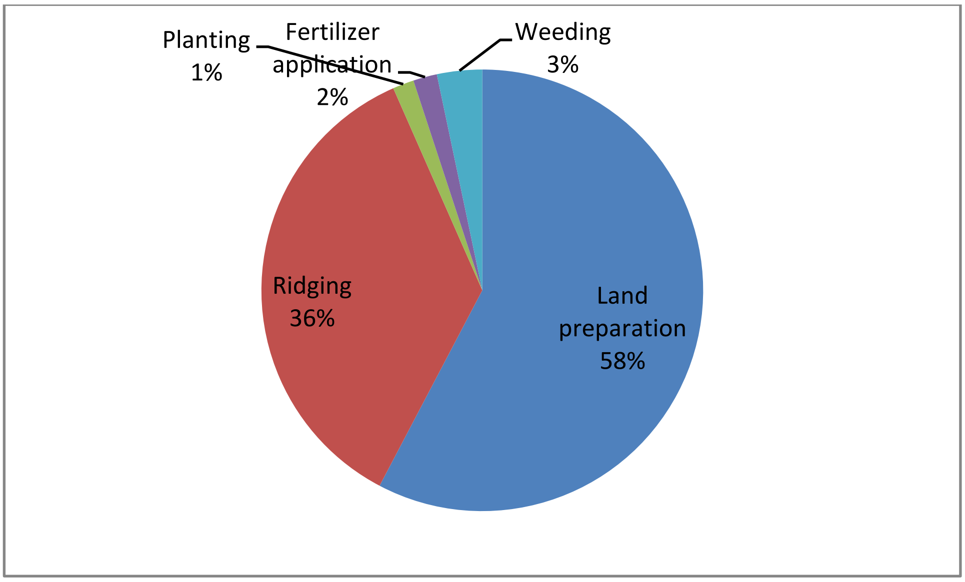


Fig.5.1: Composition of Energy Consumption by Operation in Mechanized Tillage

The above figure indicates that land preparation and ridging constitute the greatest share of the energy demand. Hence efforts at energy conservation should be directed at tillage operations.

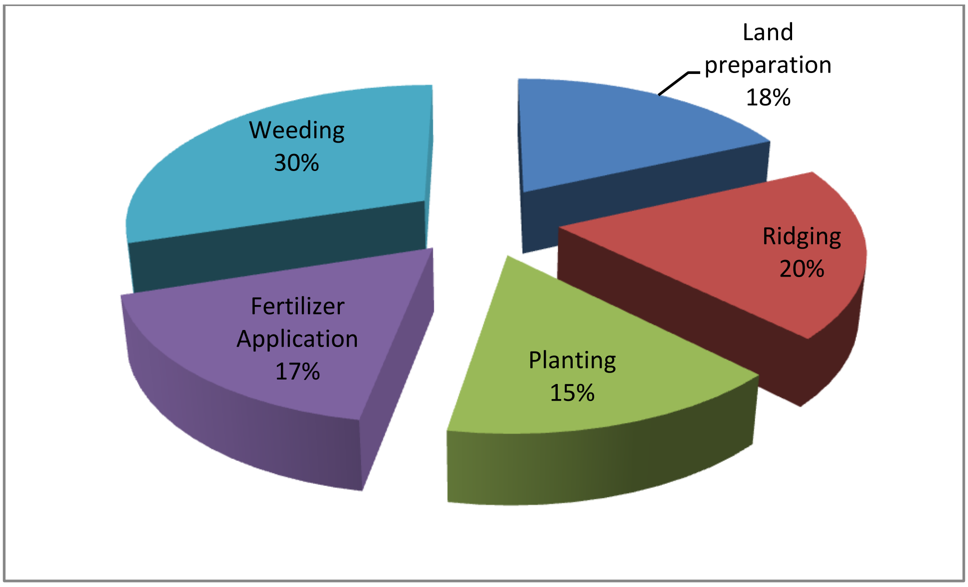


Fig.5.2: Composition of Energy Consumption by Operation in Manual Tillage

It could be seen from the two charts that the proportion of the total energy consumed attributed to each operation differs in the manual and mechanized systems. In manual system, weeding and ridge-making had the highest energy intensity; contributing 50% of the total energy consumed. However the weeding data is the sum of the energy demand for the two weeding operations. This is because maize production requires a minimum of two weeding operation. The implication is that reduction of farmers' manual energy input should target these two operations.

## 5.5 Time and Energy Demand in Mechanized Tillage

Table 5.8 shows tillage time (h/ha) for mechanized tillage operation (ploughing, harrowing and ridging) at different speeds. Time taken to complete the tillage of a parcel of land can determine the timeliness of other farm operations . It was therefore interesting to compare the time required for the tillage operations under the treatments. For ploughing, harrowing and ridging, the duration taken to complete the operations were found to depend on the operation speed and depth of tillage. Using the tractor depth control system to vary the tillage depth, the fuel consumption was measured for the above speeds. From the tables, it is evident that deeper till requires longer completion time.

From the table it can be seen that ploughing required an average of 20.57, 23.21 and 24.04 l/h for the tillage depths of 11.5cm, 15 cm and 20cm respectively. The average time required to ploughing, harrowing and ridging one hectare of land were 2.3, 2 and 2.8 hours respectively.

Table 5.9: Fuel Consumed vs speed of plough in three ploughing depths (l/ha)

| Operation Speed (m/s) | D115 | D150 | D200 |
|---|---|---|---|
| 1.8 | 19.9 | 19.4 | 23 |
| 2 | 21.9 | 20.9 | 26.4 |
| 2.3 | 20.75 | 24.75 | 23.62 |
| 2.5 | 20.07 | 22.07 | 20.53 |
| 2.7 | 23.11 | 27.31 | 27.37 |
| 2.8 | 23.72 | 25.88 | 23.35 |
| Average | 20.57 | 23.21 | 24.04 |

Table 5.10: Variation of Fuel consumption with Speed of Plough at three Ploughing Depths (l/ha)h

| Operation Speed (m/s) | D115 | D150 | D200 |
|---|---|---|---|
| 1.8 | 20 | 19 | 25 |
| 2 | 19 | 20 | 24 |
| 2.3 | 18 | 22 | 23 |
| 2.5 | 18 | 23 | 23 |
| 2.7 | 19 | 23 | 26 |
| Average | 19 | 21 | 24 |

Table 5.9 show the total energy consumed through the three years of field trials. It can be seen that ploughing, harrowing and ridging (P1 and P2) were the main sources of direct energy consumption. The high values of P4 and P5 (fertilizer application and weed control respectively) were due to large indirect energy input like fertilizer and agrochemicals. The implication is that energy conservation efforts in these operation can have very significant impact on the total farm energy consumption.

Tables 5.11 , 5.12 and 5.13 show the results of the statistical analysis of the energy demand computed from 2010, 2011 and 2012 field trials. The tables indicated statistically significant difference between the treatments in terms of operations and mechanization levels

Table 5.111: Analysis of Variance for 3x5 factorial experiment examining energy consumption for different level of mechanization in 2010

| | ANOVA for 3x5 factorial experiment in RCBD | | | | |
|---|---|---|---|---|---|
| Source of variation | Deg. of F | Sum of squares | Mean square | Computed F | Tabular F 5% |
| Between Replication | 2 | 1387.45 | 693.7 | 1.53 | 3.34 |
| Between Treatment | 14 | 5471796.55 | 390842.6 | 860.52** | 2.12 |
| Between Operation (P) | 4 | 2923078.69 | 730769.7 | 1608.94** | 2.27 |
| Technology (T) | 2 | 1005964.17 | 502982.1 | 1107.42** | 3.34 |
| P x T | 8 | 1542753.70 | 192844.2 | 424.58** | 2.29 |
| Residual | 28 | 12717.42 | 454.2 | 1.00 | |
| Total | 44 | 10957697.97 | | | |

** significant

Table 5.12: Analysis of Variance for 3x5 factorial experiment examining energy consumption for different level of mechanization in 2011

| | ANOVA for 3x5 factorial experiment in RCBD | | | | |
|---|---|---|---|---|---|
| Source of variation | Degrees of freedom | Sum of squares | Mean square | Computed F | Tabular F 5% |
| Between Replication | 2 | 1062.05 | 531.0 | 2.791 | 3.34 |
| Between Treatment | 14 | 4767855.65 | 340561.1 | 1789.97** | 2.12 |
| Between Operation (P) | 4 | 2467893.30 | 616973.3 | 3242.781** | 2.27 |
| Technology (T) | 2 | 914349.08 | 457174.5 | 2402.887** | 3.34 |
| P x T | 8 | 1385613.28 | 173201.7 | 910.339** | 2.29 |
| Residual | 28 | 5327.30 | 190.3 | 1.00 | |
| Total | 44 | 9542100.66 | | | |

** significant

Table 5.13: Analysis of Variance for 3x5 factorial experiment examining energy consumption for different level of mechanization in 2012

| | ANOVA for 3x5 factorial experiment in RCBD | | | | |
|---|---|---|---|---|---|
| Source of variation | Degrees of freedom | Sum of squares | Mean square | Computed F | Tabular F 5% |
| Between Replication | 2 | 167.18 | 83.6 | 0.390 | 3.34 |
| Between Treatment | 14 | 4439932.09 | 317138.0 | 1479.25** | 2.12 |
| Between Operation (P) | 4 | 2194675.74 | 548668.9 | 2559.20** | 2.27 |
| Technology (T) | 2 | 894293.56 | 447146.8 | 2085.66** | 3.34 |
| P x T | 8 | 1350962.78 | 168870.3 | 787.67** | 2.29 |
| Residual | 28 | 6002.94 | 214.4 | 1.00 | |
| Total | 44 | 8886034.29 | | | |

** significant at 95% confidence

The above ANOVA tables show that treatments and operations as well as their interactions have significant effects on energy demand in maize production, at 95% confidence level. That is, the differences in average energy demand for the three levels of mechanization and between the different operations are statistically significant. Thus , by changing the level of mechanization, the farmer can influence his energy expenditure. He may decide to mechanize the most tedious operations such as land preparation, ridging and weeding while planting and fertilizer application may be done manually to save energy and contribute to reducing fossil fuel related carbon emissions. Where he decides to use tractor drawn planter, it will be better to omit the ridge making operation and such planters work better on flat than on ridges since the operator is free to set the furrow spacing without being constrained by the existing ridge profile.

A Student's t-Test of significance showed that the variation due to speed was insignificant but the variation due to depth was significant. This was probably because at higher speeds the tractor operator had to repeat some ploughed swath to ensure proper coverage, thus wasting the time saved in speedy travel across the plot. A change from a tillage depth of 115mm to 200mm resulted in an increase of average fuel consumption from 20.6litre to 24.0 litre (16% increase in fuel consumption)

## 5.6: The Buckingham Pi theorem

Using the Buckingham pie theorem, the Pi terms for the land tillage parameters are as follows:

$$\Phi\left(\frac{E}{v^2 d^3 \rho}, \frac{w}{d}, \frac{s}{vd\rho}, \frac{r}{v^2 \rho}\right) = 0$$

$$\pi_1 = \frac{E}{d^3 \rho v^2} \tag{5.1}$$

$$\pi_2 = \frac{w}{d} \tag{5.2}$$

$$\pi_3 = \frac{r}{\rho d v} \tag{5.3}$$

$$\pi_4 = \frac{s}{v^2 \rho} \tag{5.4}$$

Where

E= Energy(MJ/ha)

D= Depth of tillage (m)

ρ= Soil bulk density(kg/m$^3$)

v= Speed of Operation(m/s)

w=Width of cut(m)

s= cone index(kN/m$^2$)

r= shear strength(kg/ms$^2$)

Using the values of site and tool parameters presented in table 5.14 below, the pie terms were plotted and the resulting equation used to compute theoretical values.

Table 5.12: Site and Tool Parameters Used During Field Trials

| Parameter | Values |
|---|---|
| Depth of tillage (m) | 0.115 |
| Soil bulk density(kg/m$^3$) | 1220 |
| Speed of Operation(m/s) | 1.8 |
| Width of cut(m) | 1.1 |
| Cone index (kg/ms$^2$) | 16560 |
| Shear strength(kg/ms) | 30.18 |

### 5.6.1 Formulation of prediction equation

According to Benmayor (2011), several correct solutions or possible combinations of the pi terms exist but only a few will be relatively simple and reflect the physical phenomena modeled by the terms. That is, the parameters may be combined as:Sum, Products or Quotient; to produce simpler pi terms that are independent and dimensionless. Any of the dimensionless groups may be raised to any power, multiplied by a constant or expressed as a function of the other groups.

The forms of component equation always give an insight on the likely mode of combination. A combination by summation is usually indicated by linear plots of the form $y = a + bx$.

While a product combination is usually indicated by a quadratic or logarithmic curve

$y = ab^x$.

The general prediction equation is obtained by product combination of the component equation.

### 5.6.2 **Product Function of Pi Terms**

Under certain conditions the component equations may be combined to form the general prediction equation by multiplication. The constant of multiplication in such a case may be determined by the following procedures.

The four pi-terms, $\pi_1, \pi_2$ $\pi_3$ and $\pi_4$ ,used in the model formulation were related as follows:

$\pi_1 = (\pi_2\ \pi_3\ \pi_4)$ ……………………………………………………………..5.5

Three component equations were established by plotting $\pi_1$ against $\pi_2$ , $\pi_3$ and $\pi_4$ while holding the others constant. These are expressed as:

$(\pi_1)_{\bar{3},\bar{4}} = f_1(\pi_2, \bar{\pi}_3, \bar{\pi}_4)$………………………………………………………… 5.6

$(\pi_1)_{\bar{2},\bar{4}} = f_2(\bar{\pi}_2, \pi_3, \bar{\pi}_4)$…………………………………………………….. 5.7

$(\pi_1)_{\bar{2},\bar{3}} = f_3(\bar{\pi}_2, \bar{\pi}_3, \pi_4)$ ……………………………………………………..5.8

Where the bar denotes the constant values.

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

$$\pi_1 = C(\pi_2)_{\bar{3},\bar{4}},\ (\pi_3)_{\bar{2},\bar{4}}\ (\pi_4)_{\bar{2},\bar{3}} \qquad \text{……………………………………….. 5.9}$$

Where:

C = constant of multiplication

In order to determine the necessary and sufficient condition for valid combination by multiplication of the component equations, the constant C has to be determined. This may done by assuming that the component equations are simply multiplied to form the general equation as:

$$F(\pi_2,\pi_3,\pi_4) = f_1(\pi_2,\bar{\pi}_3,\bar{\pi}_4)\, f_2(\bar{\pi}_2,\pi_3,\bar{\pi}_4)\, f_3(\bar{\pi}_2,\bar{\pi}_3,\pi_4) \text{.................... } 5.10$$

If this is true the set of pi obtained by holding $\pi_3$ and $\pi_4$ constant will give the second set of pi terms with $\pi_2$ and $\pi_4$ constant.

$$F(\pi_2,\bar{\pi}_3,\bar{\pi}_4) = f_1(\pi_2,\bar{\pi}_3,\bar{\pi}_4)\, f_2(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4)\, f_3(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4) \text{ ......................... } 5.11$$

From which

$$f_1(\pi_2,\bar{\pi}_3,\bar{\pi}_4) = \frac{F(\pi_2,\bar{\pi}_3,\bar{\pi}_4)}{f_2(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4)\, f_3(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4)} \text{.............................. } 5.12$$

Proceeding in similar way for the second pi term while we keep $\pi_2$ and $\pi_4$ constant,

$$F(\bar{\pi}_2,\pi_3,\bar{\pi}_4) = f_1(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4)\, f_2(\bar{\pi}_2,\pi_3,\bar{\pi}_4)\, f_3(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4) \text{ ............}5.13$$

From which

$$f_2(\bar{\pi}_2,\pi_3,\bar{\pi}_4) = \frac{F(\bar{\pi}_2,\pi_3,\bar{\pi}_4)}{f_1(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4)\, f_3(\bar{\pi}_2,\bar{\pi}_3,\pi_4)} \text{.............................. } 5.14$$

Proceeding in similar way for the third pi term

$$F\left(\bar{\pi}_2,\bar{\pi}_3,\pi_4\right)=f_1\left(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4\right)f_2\left(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4\right)f_3\left(\bar{\pi}_2,\bar{\pi}_3,\pi_4\right) \text{ .......... } 5.15$$

From which

$$f_3\left(\bar{\pi}_2,\bar{\pi}_3,\pi_4\right)=\frac{F\left(\bar{\pi}_2,\bar{\pi}_3,\pi_4\right)}{f_1\left(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4\right)f_2\left(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4\right)} \text{ .......................... } 5.16$$

Substituting the values of $f_1\left(\pi_2,\bar{\pi}_3,\bar{\pi}_4\right)$, $f_2\left(\bar{\pi}_2,\pi_3,\bar{\pi}_4\right)$ and $f_3\left(\bar{\pi}_2,\bar{\pi}_3,\pi_4\right)$ into eq. 5.6 gives:

$$F\left(\pi_2,\pi_3,\pi_4\right)=\frac{F\left(\pi_2,\bar{\pi}_3,\bar{\pi}_4\right)F\left(\bar{\pi}_2,\pi_3,\bar{\pi}_4\right)F\left(\bar{\pi}_2,\bar{\pi}_3,\pi_4\right)}{\left[f_1\left(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4\right)f_2\left(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4\right)f_3\left(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4\right)\right]^2} \text{ ........................ } 5.17$$

But the denominator is found from eq. 5.6 with $\pi_2$, $\pi_3$ and $\pi_4$ held constant.

Therefore

$$F\left(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4\right)=f_1\left(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4\right)f_2\left(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4\right)f_3\left(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4\right) \text{ ........................ } 5.18$$

Hence,

$$F\left(\pi_2,\pi_3,\pi_4\right)=\frac{F\left(\pi_2,\bar{\pi}_3,\bar{\pi}_4\right)F\left(\bar{\pi}_2,\pi_3,\bar{\pi}_4\right)F\left(\bar{\pi}_2,\bar{\pi}_3,\pi_4\right)}{F\left(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4\right)^2} \text{ ................ } 5.19$$

Equation 5.19 is in agreement with Benmayor(2000) who stated that if the general prediction equation for a system involving n pi-terms is formed by multiplication of component equations, then the equation is given by:

$$\pi_1 = \frac{F(\pi_2, \bar{\pi}_3, .......\bar{\pi}_n)\, F(\bar{\pi}_2, \pi_3, ....\bar{\pi}_n) .......F(\bar{\pi}_2, \bar{\pi}_3, ....\pi_n)}{[F(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4)]^{n-2}}$$

From equation 5.19, it can be seen that the value of C is :

$$C = \frac{1}{[F(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4)]^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \; 5.20$$

and that the component equation of the same form. As quoted by Yusuf (2001), Glenn, (1950) suggested that a test of validity may be done by assuming that a fourth component equation is determined from a fourth set of data in which two of the pi terms are held constant at a different value. That is, if the supplementary sets of data satisfy the equations, then the general equation may be formed by multiplication.

To test the validity of the product combination, a fresh set of data is from the experimental data is used ,in which the other pi terms are held constant at levels other than the above.

Eq.5.19 was obtained by serially holding $\pi_2 = \bar{\pi}_2$ , $\pi_3 = \bar{\pi}_3$ and $\pi_4 = \bar{\pi}_4$. If the equation is valid, then the same could be determined by letting $\pi_2 = \bar{\bar{\pi}}_2$, $\pi_3 = \bar{\bar{\pi}}_3$ and $\pi_4 = \bar{\bar{\pi}}_4$ one after the other.

$$F(\pi_2, \pi_3, \pi_4) = \frac{F(\pi_2, \bar{\bar{\pi}}_3, \bar{\pi}_4)\, F(\bar{\pi}_2, \pi_3, \bar{\bar{\pi}}_4)\, F(\bar{\bar{\pi}}_2, \bar{\pi}_3, \pi_4)}{[F(\bar{\pi}_2, \bar{\pi}_3, \bar{\bar{\pi}}_4)]^2} \quad \ldots\ldots\ldots\ldots\ldots \; 5.21$$

The right hand sides of eq. 5.19 and 5.21 must be equal. Hence,

$$\frac{F(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4)}{F(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4)} = \frac{F(\bar{\pi}_2, \bar{\pi}_3, \bar{\bar{\pi}}_4)}{F(\bar{\pi}_2, \bar{\pi}_3, \bar{\bar{\pi}}_4)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 5.22$$

In a similar way, if the value of $\pi_2$ were held constant at $\bar{\bar{\pi}}_2$

$$\frac{F(\bar{\pi}_2, \pi_3, \bar{\pi}_4)}{F(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4)} = \frac{F(\bar{\bar{\pi}}_2, \pi_3, \bar{\pi}_4)}{F(\bar{\bar{\pi}}_2, \bar{\pi}_3, \bar{\pi}_4)} \ldots\ldots 5.23$$

In a similar way, if the value of $\pi_3$ were held constant at $\bar{\bar{\pi}}_3$

$$\frac{F(\bar{\pi}_2, \bar{\pi}_3, \pi_4)}{F(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4)} = \frac{F(\bar{\pi}_2, \bar{\bar{\pi}}_3, \pi_4)}{F(\bar{\pi}_2, \bar{\bar{\pi}}_3, \bar{\pi}_4)} \ldots\ldots$$

5.24

Using the standard linear equation form

$$(\pi_1)_{\bar{3},\bar{4}} = a + b\pi_2 \ldots\ldots 5.25$$

$$(\pi_1)_{\bar{2},\bar{4}} = c + d\pi_3 \ldots\ldots 5.26$$

$$(\pi_1)_{\bar{2},\bar{3}} = e + f\pi_4 \ldots\ldots 5.27$$

$$\frac{a + b\pi}{a + b\bar{\pi}} = \frac{e + b\pi}{a + b\bar{\pi}} \ldots\ldots 5.28$$

$a^2 + ab\bar{\pi}_2 = ae + eb\bar{\pi}_2$ which is valid only when a=e, i.e when $\pi_1$ is independent of $\pi_2$

### 5.6.3 The Sum Function of Pi Terms

The prediction equation may also be formed by simple summation of the component equations. The validity of combining the component equation by summation may be tested by assuming that the general prediction equation is obtained by simple summation of the pi terms in the form :

$$F(\pi_2,\pi_3,\pi_4) = f(\pi_2) + g(\pi_3) + h(\pi_4) \text{ ……………………………………………….. } 5.29$$

If $\pi_3$ and $\pi_4$ are held constant at $\bar{\pi}_3$ and $\bar{\pi}_4$ respectively, and rearranging the terms we get

$$f(\pi_2) = F(\pi_2,\bar{\pi}_3,\bar{\pi}_4) - g(\bar{\pi}_3) - h(\bar{\pi}_4) \text{ ……………………………………………… } 5.30$$

Similarly,

$$g(\pi_3) = F(\bar{\pi}_2,\pi_3,\bar{\pi}_4) - f(\bar{\pi}_2) - h(\bar{\pi}_4) \text{ ………………………………………………. } 5.31$$

Similarly,

$$h(\pi_4) = F(\bar{\pi}_2,\bar{\pi}_3,\pi_4) - f(\bar{\pi}_2) - g(\bar{\pi}_3) \text{ …………………………………………… } 5.32$$

Equations 5.30, 5.31 and 5.32 may be substituted into 5.29 to give

$$F(\pi_2,\pi_3,\pi_4) = F(\pi_2,\bar{\pi}_3,\bar{\pi}_4) - g(\bar{\pi}_3) - h(\bar{\pi}_4) + F(\bar{\pi}_2,\pi_3,\bar{\pi}_4) - f(\bar{\pi}_2) - h(\bar{\pi}_4) + F(\bar{\pi}_2,\bar{\pi}_3,\pi_4) - f(\bar{\pi}_2) - g(\bar{\pi}_3) \text{ ……………………………………………….. } 5.33$$

$$F(\pi_2,\pi_3,\pi_4) = F(\pi_2,\bar{\pi}_3,\bar{\pi}_4) + F(\bar{\pi}_2,\pi_3,\bar{\pi}_4) + F(\bar{\pi}_2,\bar{\pi}_3,\pi_4) - 2(f(\bar{\pi}_2) + h(\bar{\pi}_4) + g(\bar{\pi}_3))$$

$$\pi_1 = F(\pi_2,\bar{\pi}_3,\bar{\pi}_4) + F(\bar{\pi}_2,\pi_3,\bar{\pi}_4) + F(\bar{\pi}_2,\bar{\pi}_3,\pi_4) - 2F(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4) \text{ ………………… } 5.34$$

Where $F(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4)$ = constant of summation

$$\pi_1 = F(\pi_2,\bar{\pi}_3,....\bar{\pi}_n) + F(\bar{\pi}_2,\pi_3,...\bar{\pi}_n) + ....F(\bar{\pi}_2,\bar{\pi}_3,...\pi_n) - (n-2)F(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4) \text{ ..........................................................5.35}$$

Equation 5.30 is in agreement with Benmayor(2000) who stated that if the general prediction equation for a system involving n pi-terms is formed by summation of component equations, a constant of summation must be subtracted. Supplementary experimental data may be obtained at which two of the pi-terms may be held constant to test the validity of eq. 5.31. Hence when $\pi_2$ is held constant at $\bar{\bar{\pi}}_2$ and $\pi_4$ is held constant $\bar{\bar{\pi}}_4$, eq. 5.30 becomes

$$\pi_1 = F(\pi_2, \bar{\pi}_3, \bar{\pi}_4) + F(\bar{\bar{\pi}}_2, \pi_3, \bar{\bar{\pi}}_4) + F(\bar{\bar{\pi}}_2, \bar{\bar{\pi}}_3, \pi_4) - 2F(\bar{\bar{\pi}}_2, \bar{\bar{\pi}}_3, \bar{\bar{\pi}}_4) \text{ ……………. } 5.36$$

Equating the right hand sides of equations 5.30 and 5.32 yields:

$$F(\pi_2, \bar{\pi}_3, \bar{\pi}_4) + F(\bar{\pi}_2, \pi_3, \bar{\pi}_4) + F(\bar{\pi}_2, \bar{\pi}_3, \pi_4) - 2F(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4) = F(\pi_2, \bar{\pi}_3, \bar{\pi}_4) + F(\bar{\bar{\pi}}_2, \pi_3, \bar{\pi}_4) + F(\bar{\bar{\pi}}_2, \bar{\pi}_3, \pi_4) - 2F(\bar{\bar{\pi}}_2, \bar{\pi}_3, \bar{\pi}_4)$$

--------------------- 5.37

A test of validity of combining the component equation by summation is done term by term. We test first for $\pi_2$ by isolating the terms containing $\pi_2$

$$\pi_1 = F(\pi_2, \bar{\pi}_3, \bar{\pi}_4) + F(\bar{\pi}_2, \pi_3, \bar{\pi}_4) + F(\bar{\pi}_2, \bar{\pi}_3, \pi_4) - F(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4) \text{…………. } 5.38$$

Additional set of data in which one of the variables, say $\pi_3$, is given a different value should result in the same value of $\pi_1$. Hence

The equation is a validity test for combination of the component equation containing $\pi_2$ with the component equation containing other variables by summation.

### 5.7 Test for summation combination method for ploughing operation

Figures 5.3 to Fig 5.20 shows the plots of pi-terms. The equations associated with graphs will be used to derive the component equation and the final model. The charts in fig. 5.3 to fig. 5.8are represented by the regression equations 5.39 to 5.44.

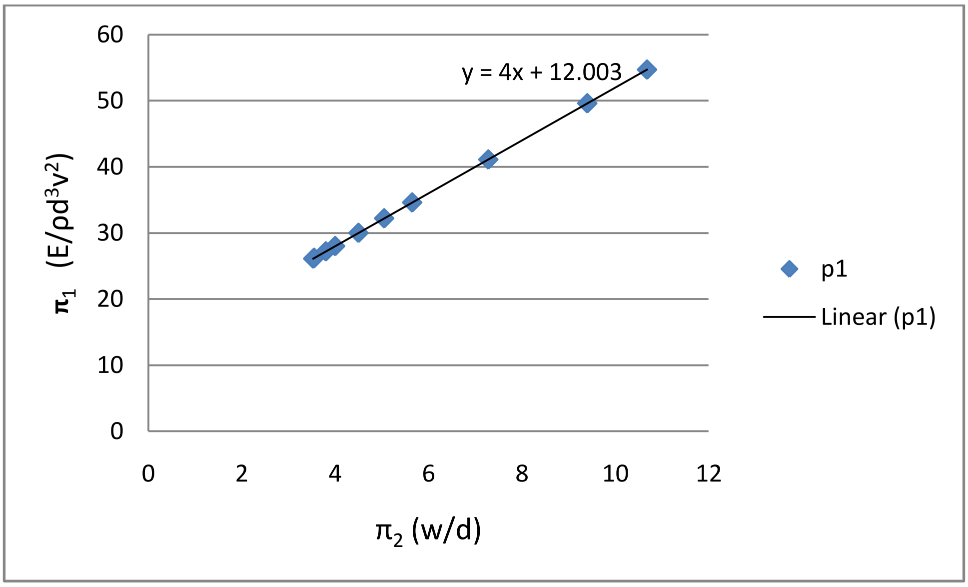


Fig.5.3: $\pi_1$ against $\pi_2$ for Ploughing Operation (2010)

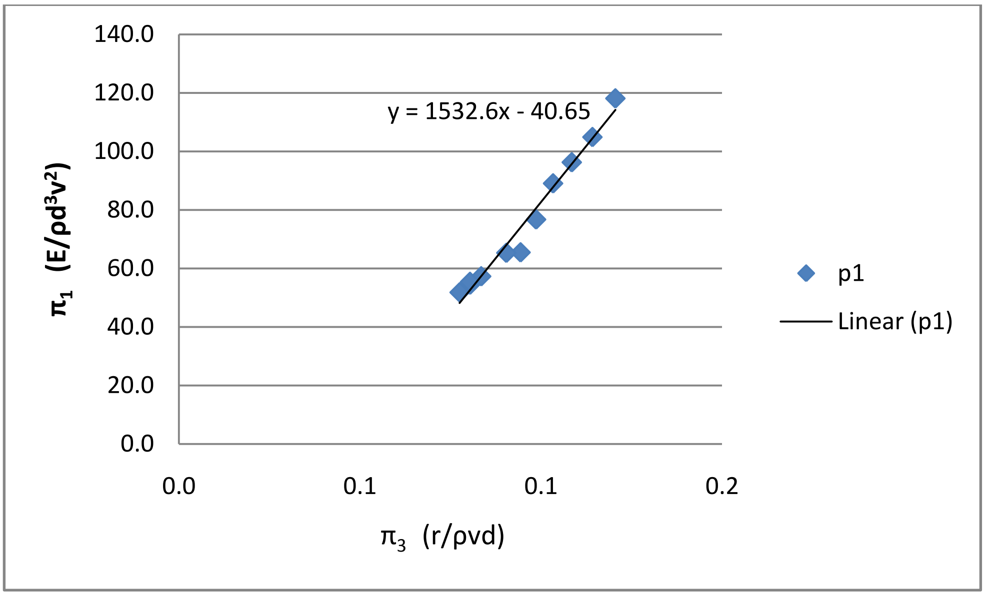


Fig.5.4: π1 against π3 for ploughing Operation (2010)

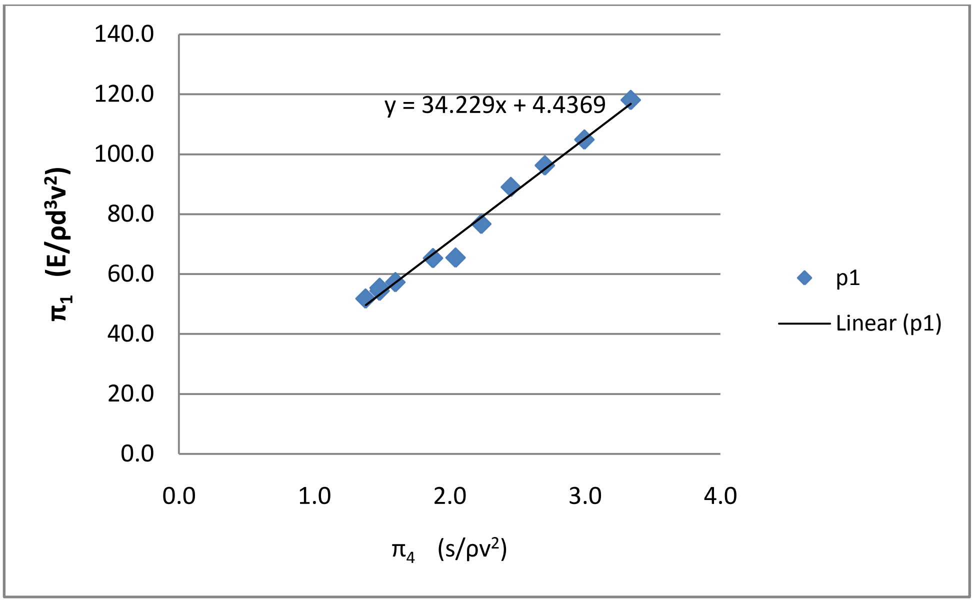


Fig.5.5: $\pi 1$ against $\pi 4$ for Ploughing Operation (2010)

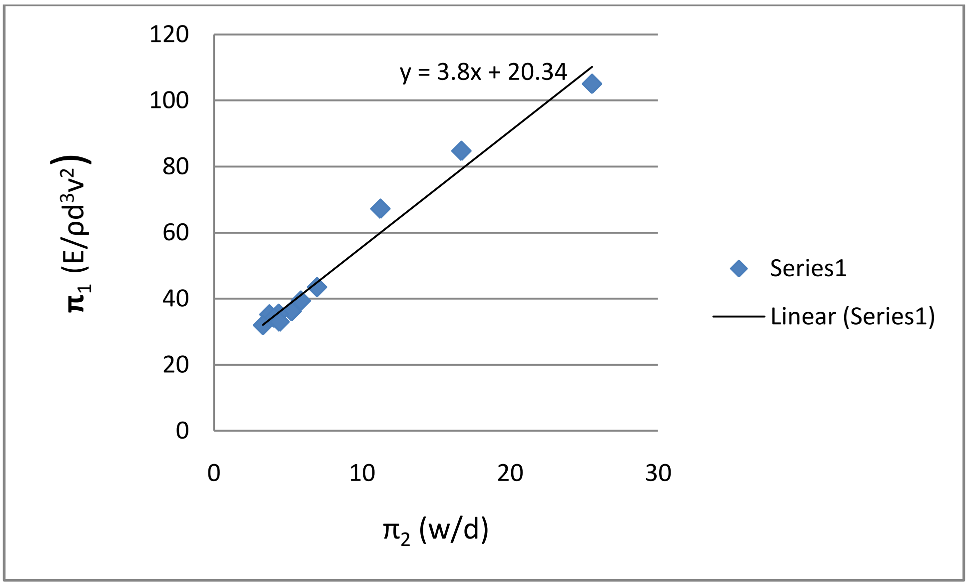


Fig.5.6: $\pi 1$ against $\pi 2$ for Ploughing Operation (2011)

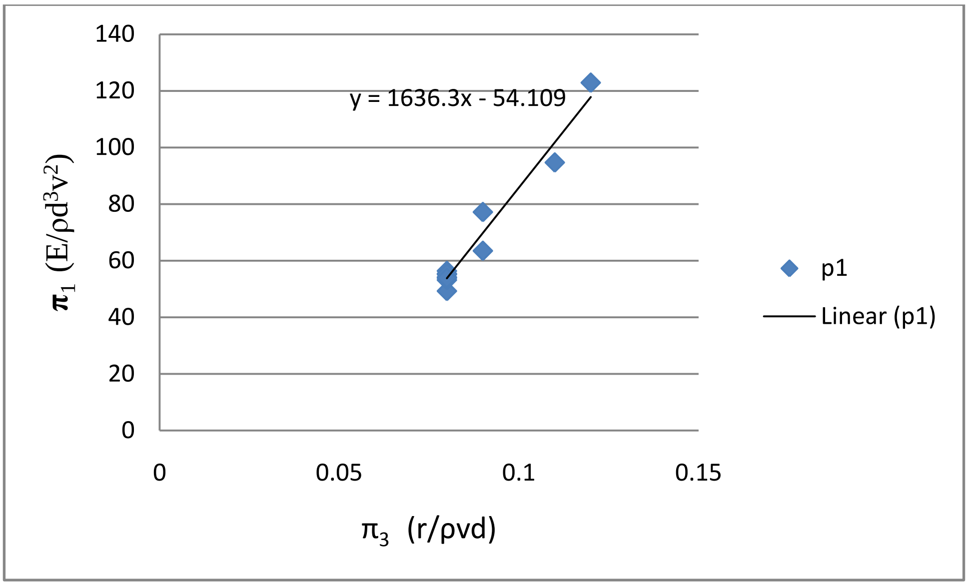


Fig.5.7: π1 against π3 for Ploughing Operation (2011)

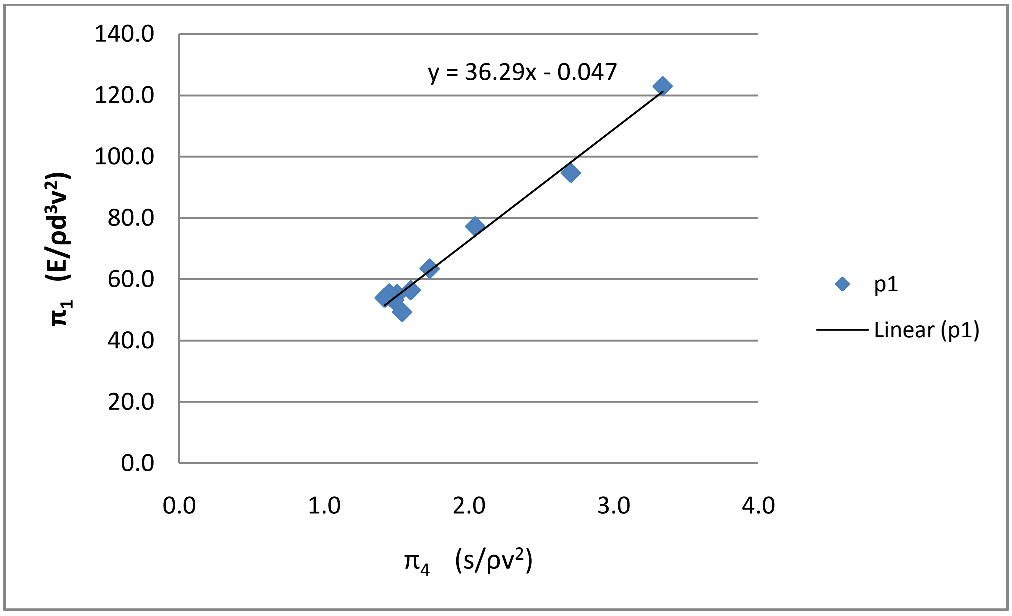


Fig.5.8: π1 against π4 for Ploughing Operation (2011)

Considering the charts in fig. 5.3 to fig. 5.8 representing the regression equation

$\left(\pi_{1p}\right)_{\bar{3},\bar{4}} = 4\pi_{2p} + 12.00$ ………………………………………………………….. 5.39

$\left(\pi_{1p}\right)_{\bar{2},\bar{4}} = 1532.6\pi_{3p}$ -40.65……………………………………………………..5.40

$\left(\pi_{1p}\right)_{\bar{2},\bar{3}} = 34.22\pi_{4p} + 4.43$ ………………..………………………………….5.41

$\left(\pi_{1p}\right)_{\bar{3},\bar{4}} = 3.8\pi_{2p} + 20.34$ …………………………………………………..5.42

$\left(\pi_{1p}\right)_{\bar{2},\bar{4}} = 1636.3\pi_{3p}$ - 54.109 ……………………………………………..5.43

$\left(\pi_{1p}\right)_{\bar{2},\bar{3}} = 36.2\pi_{4p}$ - 0.0476 ………………………………………………….. 5.44

$\pi_{1p}$=4$\pi_{2p}$ + 12.00

Taking $\bar{\pi}_{2p}$=6.9

$\pi_{1p}$=4x6.9 +12.0= 39.6

For a supplementary equation using data for 2011

$f_1\left(\pi_2, \pi_3, \bar{\pi}_4\right)$

$\pi_{1p}$=3.8$\pi_{2p}$ +20.34

Taking $\bar{\pi}_{2p}$=6.5

$\pi_{1p}$=3.8x6.5 +20.34= 45.04

Substituting the component and supplementary equations and their constant values in equation 5.39

$4\pi_{2p}$ + 12-39.6=3.8$\pi_{2p}$ +20.34 -45.04

$4\pi_{2p}$ - 27.6= 3.8$\pi_{2p}$ - 24.7 …………………………………….. 5.45

Since the R.H.S of eq. 5.45 is approximately equal to the L.H.S, it can be concluded that combination of the tillage energy component equations by summation is valid.

### 5.8 Determination of constant of summation

The constant of summation for the four pi-terms is given in equation

$C=F(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4)$

The constant term can be any of

$C=f_1(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4)$ or $C=f_2(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4)$ or $C=f_3(\bar{\pi}_2,\bar{\pi}_3,\bar{\pi}_4)$

The constant may be evaluated from any of the component equations and should result in practically the same values.

### 5.9 Determination of the Component Equations

The component equations may be formed from the experimental data plugged into the pi-terms. They represent the regression equations of the pi-terms data which are presented in Appendices E, F and G for the ploughing, harrowing and ridging respectively. Each of the tables consists of data of the three pi-terms required for the determination of the prediction equations.

From the component equations of ploughing given in eq. 5.39, 5.40 and 5.41

$C_p = f_1(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4) = 4\pi_{2p} + 12$

Let $\pi_{2p}$ =6.9 based on field data, and the equation 5.39 yields 39.6.

Similarly from equation 5.40,

$C_p = f_1(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4) = 1532.6\pi_{3p} - 40.649$

Let $\pi_{3p}$ =0.05 based on field data, and the equation 5.40 yields,

1532.6x0.05-40.65=35.98

Or

$C_p = f_2(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4)$

Similarly , substituting 1.1 for $\pi_{4p}$ in equations eq. 5.41 yield $\pi_{1p}$ =36.36.

Similarly if we substitute 6.5, 0.06 and 1.2 for $\pi_{2p}$ $\pi_{3p}$ $\pi_{4p}$ in the equations 5.42. 5.43 and 5.44 we get 45.04, 44.07 and 43.39

Substituting the component equations and their constants into equation 5.38

$$\pi_1 = 4\pi_2 + 12 + 1532.6\pi_3 - 40.6 + 34.2\pi_4 + 4.43 - 2(35.98) \text{........ } 5.46$$

$$\pi_1 = 4\pi_2 + 1532.6\pi_3 + 34.2\pi_4 - 96.13$$

$$\frac{E}{v^2 d^3 \rho} = 4\frac{\mathrm{w}}{\mathrm{d}} + 1532.6\frac{\mathrm{r}}{vdp} + 34.2\frac{s}{v^2 \rho} - 96.13$$

$$E_p = 4\mathrm{v}^2\mathrm{d}^2\rho\mathrm{w} + 1532.6\mathrm{rvd}^2 + 34.2sd^3 - 96.13v^2d^3\rho \text{ ............... } 5.47$$

Where

E= Energy(MJ/ha)

D= Depth of tillage (m)

ρ= Soil bulk density(kg/m$^3$)

v= Speed of operation(m/s)

w=Width of cut(m)

s= cone Index(kg/ms$^2$)

r= shear strength(kg/ms)

Fig. 5.9 to 5.14 show the plots of pi terms used for deriving equations for harrowing operation.

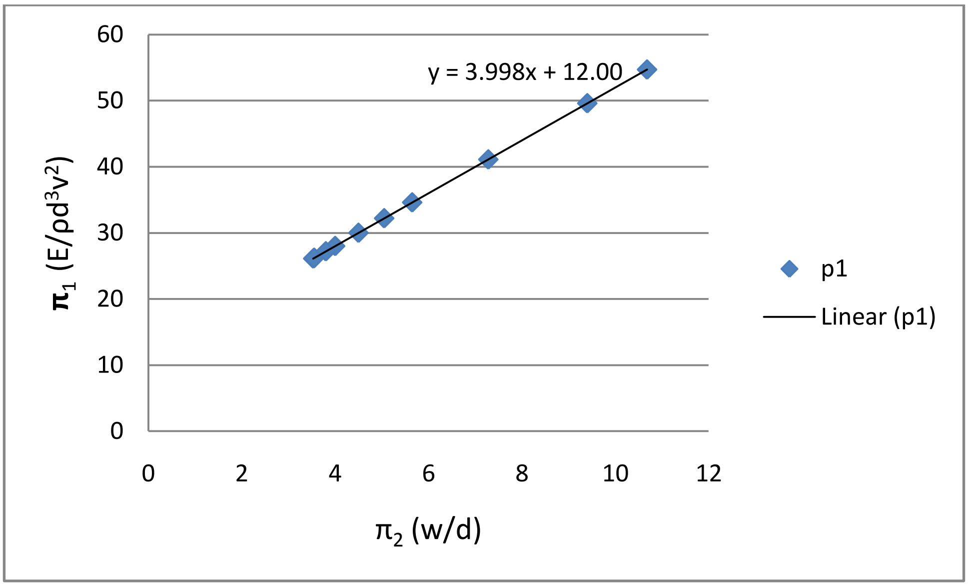


Fig.5.9: π1 against π2 for Harrowing Operation (2010)

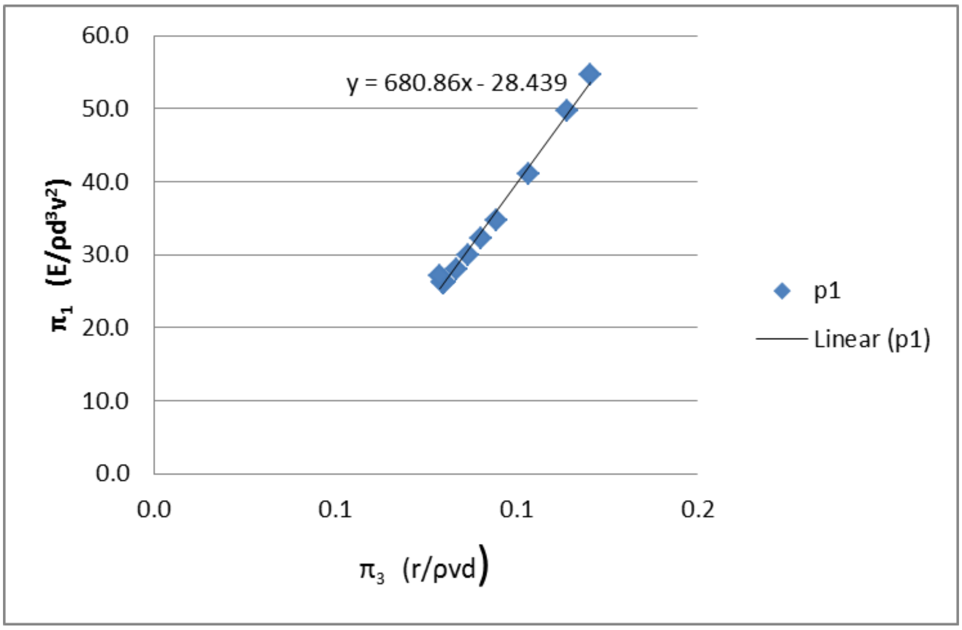


Fig.5.10: π1 against π3 for Harrowing Operation (2010)

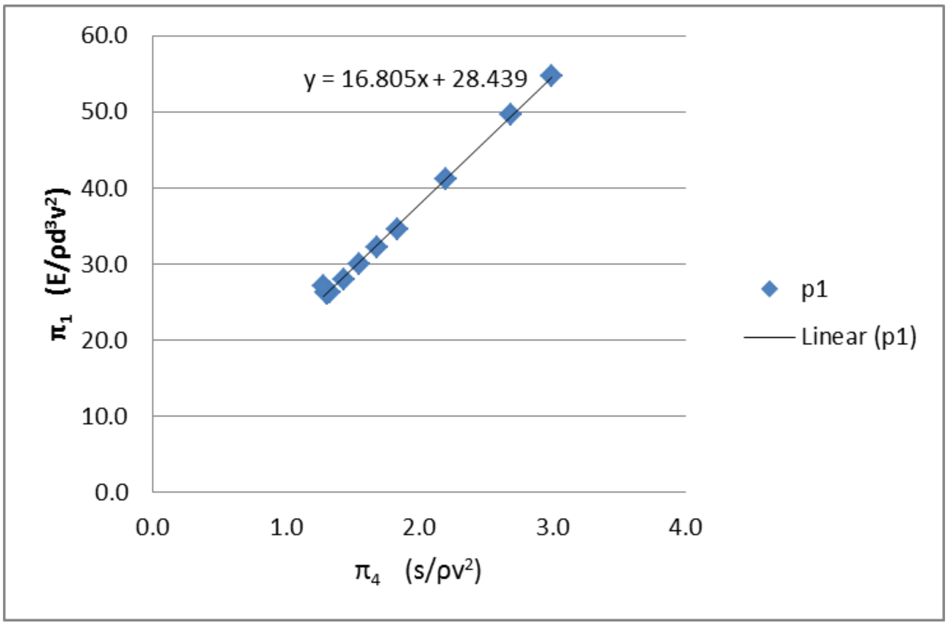


Fig.5.11: $\pi 1$ against $\pi 4$ for Harrowing Operation (2010)

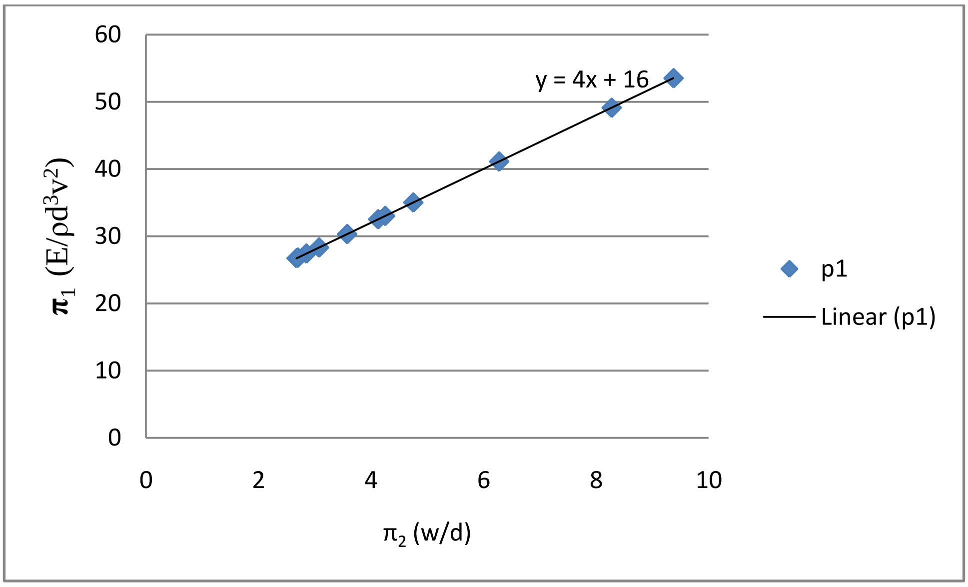


Fig.5.12: $\pi 1$ against $\pi 2$ for Harrowing Operation (2011)

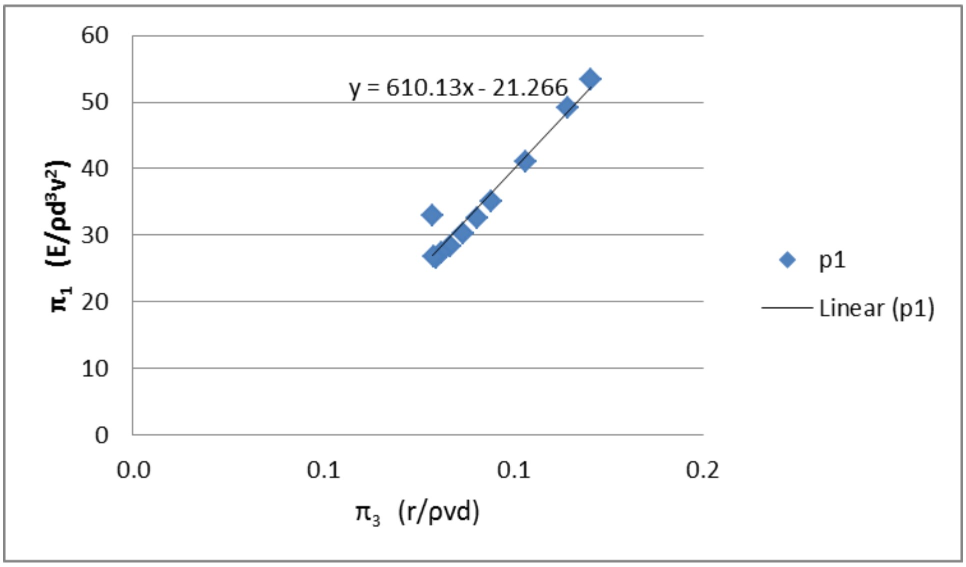


Fig.5.13: $\pi 1$ against $\pi 3$ for Harrowing Operation (2011)

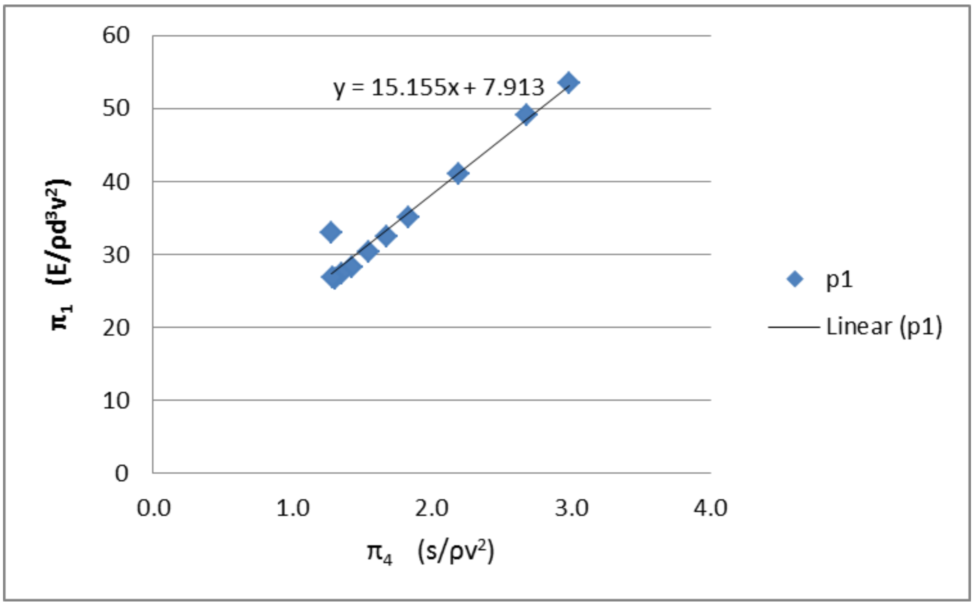


Fig.5.14: $\pi 1$ against $\pi 4$ for Harrowing Operation (2011)

Fig. 5.15 to 5.20 show the plots of pi terms used for deriving equations for ridging operation.

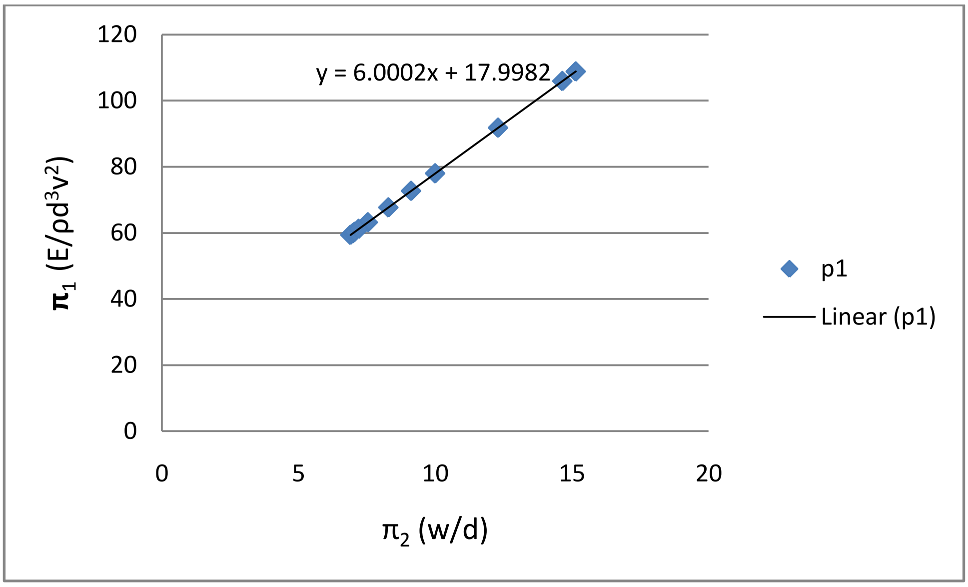


Fig.5.15: π1 against π2 for Ridging Operation (2010)

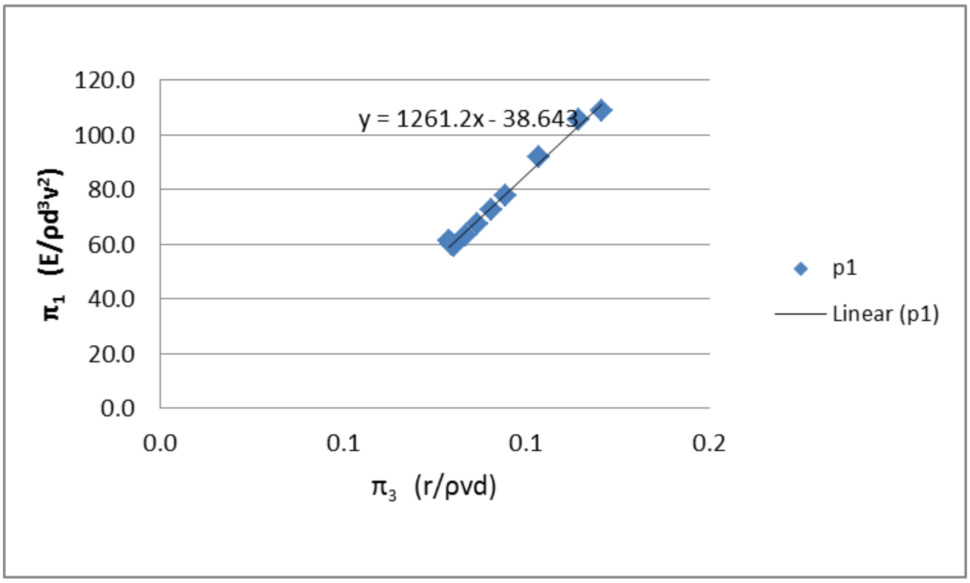


Fig.5.16: π1 against π3 for Ridging Operation (2010)

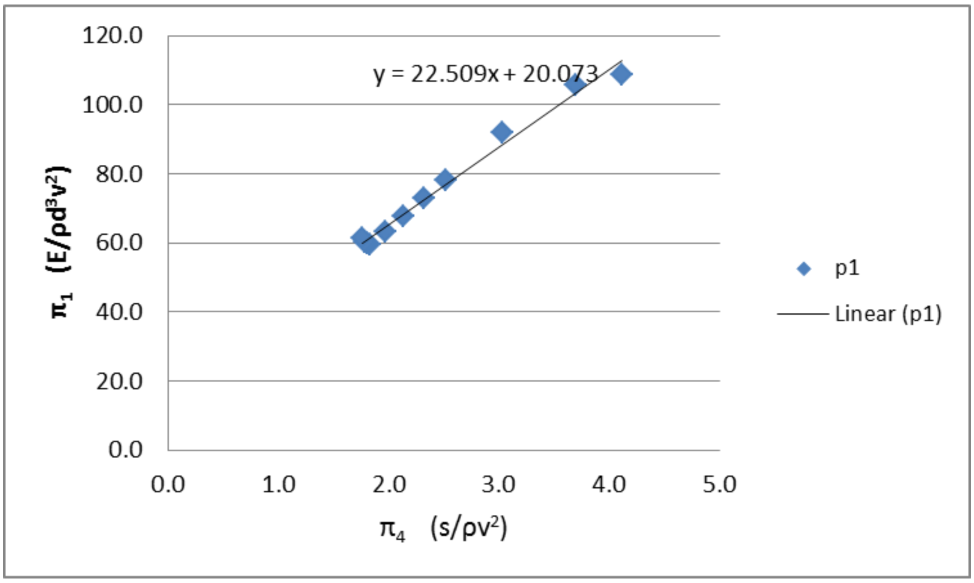


Fig.5.17: π1 against π4 for Ridging Operation (2010)

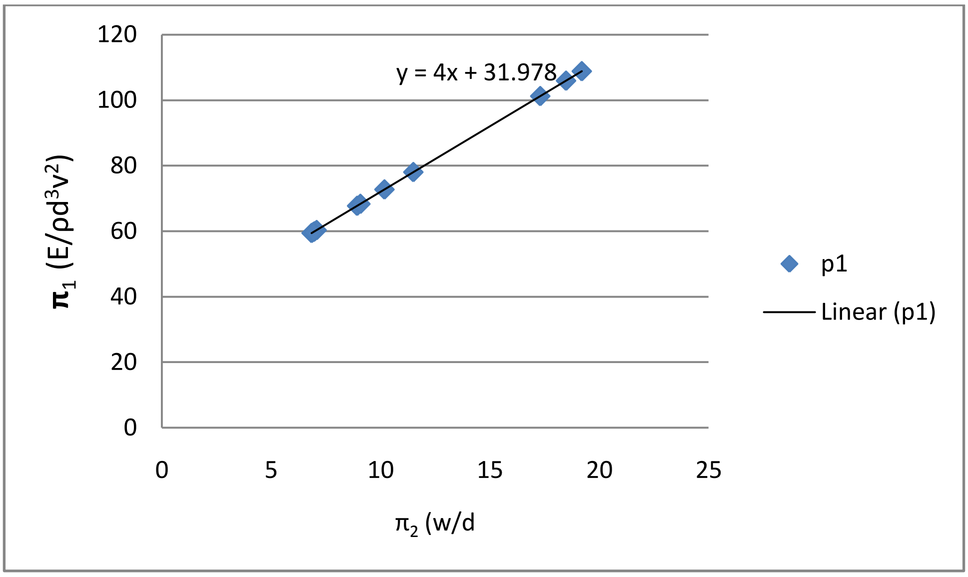


Fig.5.18: π1 against π2 for Ridging Operation (2011)

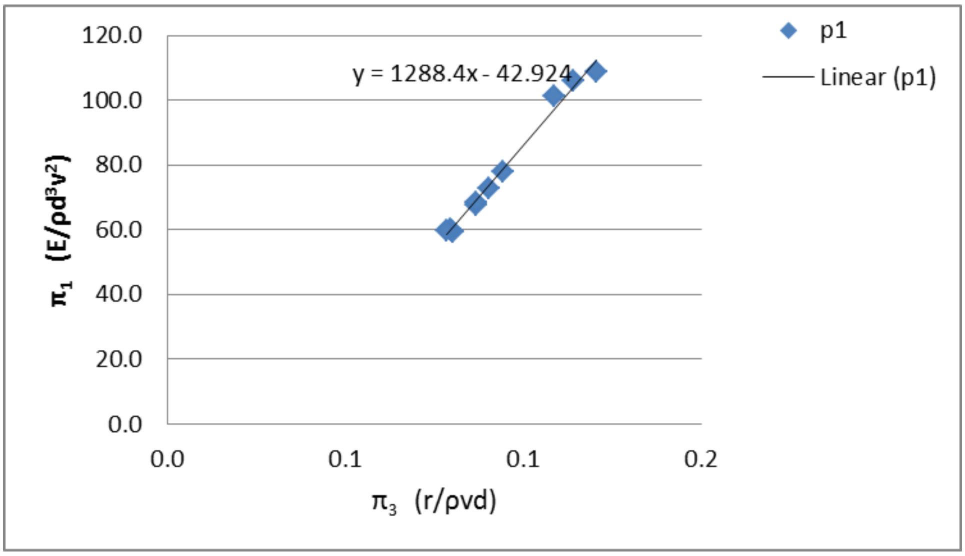


Fig.5.19: $\pi 1$ against $\pi 3$ for Ridging Operation (2011)

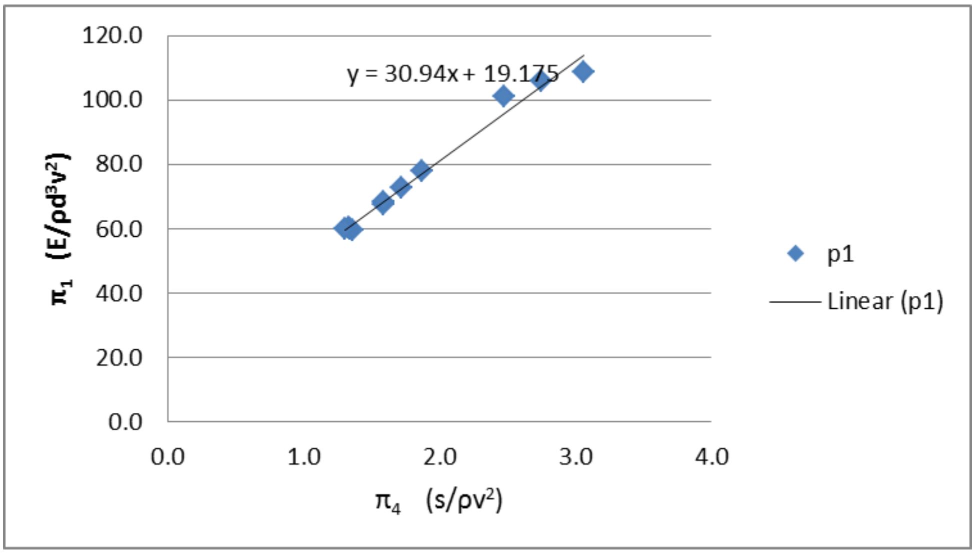


Fig.5.20: $\pi 1$ against $\pi 4$ for Ridging Operation (2011)

## 5.6 Test of Summation Combination Method for Harrowing Operation

Harrowing

$\left(\pi_{1h}\right)_{\bar{3},\bar{4}} = 4\pi_{2h} + 12.0$ ………………………………………………………….. 5.48

$\left(\pi_{1h}\right)_{\bar{2},\bar{4}} = 680.86\pi_{3h} - 28.439$ ……………………………………………………… 5.49

$\left(\pi_{1h}\right)_{\bar{2},\bar{3}} = 16.8\pi_{4h} + 28.439$ ……………………………………………………..

5.50

$\left(\pi_{1h}\right)_{\bar{3},\bar{4}} = 4\ \pi_{2h} + 16$ ……………………………………………………… 5.51

$\left(\pi_{1h}\right)_{\bar{2},\bar{4}} = 610.13\pi_{3h} - 21.266$ ………………………………………………… 5.52

$\left(\pi_{1h}\right)_{\bar{3},\bar{4}} = 15.155\pi_{4h} + 7.913$ ……………………………………………….. 5.53

Taking $\bar{\pi}_{2h}$ =6.7 based on field data

$\pi_{1h}$ =4x6.7 +12= 38.8

For a supplementary equation using data for 2011

$f_1\left(\pi_2,\pi_3,\bar{\pi}_4\right)$

$\pi_{1h}$ =4$\pi_{2h}$ + 16

Taking $\bar{\pi}_{2h}$ =6

$\pi_{1h}$ =4x6 +16= 40.2

Substituting the component and supplementary equations and their constant values in equation 5.39

$4\pi_{2h}$ +12-38.2= $4\pi_{2h}$ + 16-40

$4\pi_{2h}$ -28= $4\pi_{2h}$ -27.2………………………………………………………….. 5.54

Since the R.H.S of eq. 5.54 is approximately equal to the L.H.S, it can be concluded that combination of the tillage energy component equations by summation is valid.

### 5.10.1 Determination of constant of summation

The constant of summation for the four pi-terms is given in equation

$C = F(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4)$

The constant term can be any of

$C = f_1(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4)$ or $C = f_2(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4)$ or $C = f_3(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4)$

The constant may be evaluated from any of the component equations and should result in practically the same values.

From the component equations of harrowing given in eq. 5.48, 5.49 and 5.50

$C_p = f_1(\bar{\pi}_2, \bar{\pi}_3, \bar{\pi}_4) = 4\pi_{2h} + 12.0$

Let $\pi_{2p}$ =6.7 based on field data, and the equation 5.48 yields38.8.

Similarly from equation 5.49,

if $\pi_{3h}$ =0.09 based on field data, and the equation 5.49 yields, 680.86x0.09 -28.44= 37.6

Similarly , substituting 0.39 for $\pi_{4h}$ in equations 5.50 yields $\pi_{1p}$ = 16x0.4 + 4.18=38.48

Similarly if we substitute 6,0.08 and 1.55 for $\pi_{2p}$ $\pi_{3p}$ $\pi_{4p}$ in equations 5.51, 5.52 and 5.53 above we get 40, 37.26 and 37.17 respectively.

Substituting the component equations and their constants into equation 5.38

$$\pi_1 = 4\pi_2 + 12 + 680.86\pi_3 - 28.44 + 16.86\pi_4 + 28.43 - 2(39) \ldots\ldots\ldots\ldots.. \ 5.55$$

$$\pi_1 = 4\pi_2 + 680.86\pi_3 + 16.86\pi_4 - 66$$

$$\frac{E}{v^2 d^3 \rho} = 4\frac{\mathrm{w}}{\mathrm{d}} + 680.86\frac{\mathrm{r}}{vdp} + 16.86\frac{s}{v^2\rho} - 66 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ 5.56$$

$$E_h = 4\mathrm{v}^2\mathrm{d}^2\rho\mathrm{w} + 680.86\mathrm{rvd}^2 + 16.86sd^3 - 66v^2d^3\rho \ \ldots\ldots\ldots\ldots\ldots..5.57$$

## 5.11 Test of Summation Combination Method for Ridging Operation

From the charts pi-term for ridging operation (fig 5.15 to fig 5.20)

$$(\pi_{1r})_{\bar{3},\bar{4}} = 6\pi_{2r} + 18 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \ 5.58$$

$$(\pi_{1r})_{\bar{2},\bar{4}} = 1261.2\pi_{3r} - 38.643 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ 5.59$$

$$(\pi_{1r})_{\bar{2},\bar{3}} = 22.51\pi_{4r} + 20.07 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ 5.60$$

$\left(\pi_{1r}\right)_{\bar{3},\bar{4}} = 4\pi_{2r} + 24.6$ ………………………………………………………….. 5.61

$\left(\pi_{1r}\right)_{\bar{2},\bar{4}} = 1288.4\pi_{3r} - 42.92$ ……………………………………………… 5.62

$\left(\pi_{1r}\right)_{\bar{2},\bar{3}} = 30.94\pi_{4r} + 19.175$ ………………………………………………. 5.63

Taking $\bar{\pi}_{2r}$ =7.2 based on 2010 field data, equation 5.52 yields 6x7.2 + 19.175 =59.98

For a supplementary equation using data for 2011

Taking $\bar{\pi}_{2r}$ = 7.2

Equation 5.55 yields 6x7.2 + 18 =61.2

6x7.2 + 18 =61.2

$\pi_{1r}$ =1261.18 $\pi_{3r}$ -38.643

Taking $\bar{\pi}_{3r}$ =0.08

$\pi_{1r}$ =1261.181x0.08-38.643 = 60.25

$\pi_{1r}$ =22.5 $\pi_{4r}$ +20.07

Taking $\bar{\pi}_{4r}$ =1.87

$\pi_{1r}$ =22.5x 1.87+20.07 = 62.1

Considering the supplementary equation 5.61 using data for 2011 and taking $\bar{\pi}_{2r}$ =8.9

$\pi_{1r}$ = 4x8.9 + 24.6 = 60.2

Taking $\overline{\pi}_{3r}$ =0.081 based on field data in 2011, equation 5.62 is evaluated as

$\pi_{1r}$ = 1288.4 $\overline{\pi}_{3r}$ -42.924 to yield 61.4.

### 5.12 Determination of constant of summation

The constant of summation for the four pi-terms is given in equation

C= $F(\pi_2, \overline{\pi}_3, \overline{\pi}_4)$

The constant term can be any of

C= $f_1(\pi_2, \overline{\pi}_3, \overline{\pi}_4)$ or C= $f_2(\pi_2, \overline{\pi}_3, \overline{\pi}_4)$ or C= $f_3(\pi_2, \overline{\pi}_3, \overline{\pi}_4)$

The constant may be evaluated from any of the component equations and should result in practically the same values. This may be evaluated from the component equations of ridging given in eq. 5.58, 5.59 and 5.60

$C_r$= $f_1(\pi_2, \overline{\pi}_3, \overline{\pi}_4)$= 1288.4 $\overline{\pi}_{3r}$ - 42.924.

Let $\pi_{3r}$ =0.08 based on field data, and the equation 5.59 yields 60.25

Similarly , substituting 1.87 for $\pi_{4r}$ in equations 5.60 yield $\pi_{1r}$ =62.1

Similarly, from 2011 field data, if we substitute 8.9,0.81 and 1.34 for $\pi_{2r}$ $\pi_{3r}$ $\pi_{4r}$ in equations 5.61, 5.62 and 5.63 above , we get 60.2, 61.4 and 60.63 respectively which are practically the same.

Substituting the component equations and their constants into equation 5.38

$$\pi_1 = 6\pi_2 + 12 + 1261.2\pi_3 - 38.64 + 30.93\pi_4 + 19.709 - 2(60) \quad \ldots\ldots\ldots\ldots 5.65$$

$$\pi_1 = 6\pi_2 + 1261.2\pi_3 + 30.93\pi_4 - 120.57$$

$$E_r = 6\mathrm{v}^2\mathrm{d}^2\rho\mathrm{w} + 1261.2\mathrm{svd}^2 + 30.93rd - 120.57v^2d^3\rho \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5.66$$

Equations 5.47, 5.57 and 5.66 showed that the energy demand for tillage operations are quadratic functions of the operating speed. This is in agreement with Zadeh (2006) who showed that both linear and quadratic relationships exist between energy and speed. Following field trials with narrow tools, he stated that energy -speed relationship is linear at lower speed and quadratic at higher speed.

The relationship between energy consumption and depth of tillage may be explained in terms of energy required to overcome shear resistance and cut through larger soil cross section, lift, turn and pulverize larger mass of soil (width of cut x depth of tillage x density of soil). At greater tillage depth the mass of soil moved increases and so the tillage energy required. Moving this mass of soil at higher speed require greater energy to impart the required momentum.

## 5.8 The Tillage Energy Computation Programming

A simple visual basic programme was developed based on model Equations 5.42, 5.51 and 5.61 above to compute the energy required for tractor powered ploughing, harrowing and ridging operations. The Flow chart for the programme is shown in fig 4.1 while the excel macros are shown in appendix L.

**5.13.1 Description of the Computer Programme :**The model was designed as an interactive and user friendly tool that provides a simple estimate of fuel requirement for tillage under diverse soil and operational conditions. Built on Microsoft Excel platform using simple Visual Basic macros, the programme allows the user to enter data directly from the user interface form or takes from its database of soil and implement characteristics according to the soil type. Soil is categorized as sandy and clay loam with their typical soil bulk density and shear strength. Machine-specific parameters and soil texture adjustment parameters were taken from typical values given in the ASAE Standards (2000). These speed are adopted as default data to validate speed data entry from the user form. The programme uses international system (SI) units only.

**5.13.2 How the Programme works:** The programme starts by initializing all properties, limits and constants and input variables. On selecting the type of operation, the user is requested to indicate the availability or otherwise, of soil data for the specific site. If the data is not available, the programme with take from its data base of typical soil parameters corresponding to the selected soil type. If the user has soil data , he may enter them along the implement parameters.

While entering the data, the programme checks and validates the data for:

(i) Type((accepts numeric type and reject alphanumeric data type)

(ii) Range (rejects values outside typical ranges)

The user may be prompted to reenter the data if the data fails the validation tests. This is to prevent entering the wrong data type that may crash to VB macros.

The parameters to be entered are:

Depth of tillage(m)

Speeds of operation(m/s)

With of cut(m)

Implement weight(kg)

Soil bulk density (kg/m3)

Soil shear strength (kg/m/s$^2$)

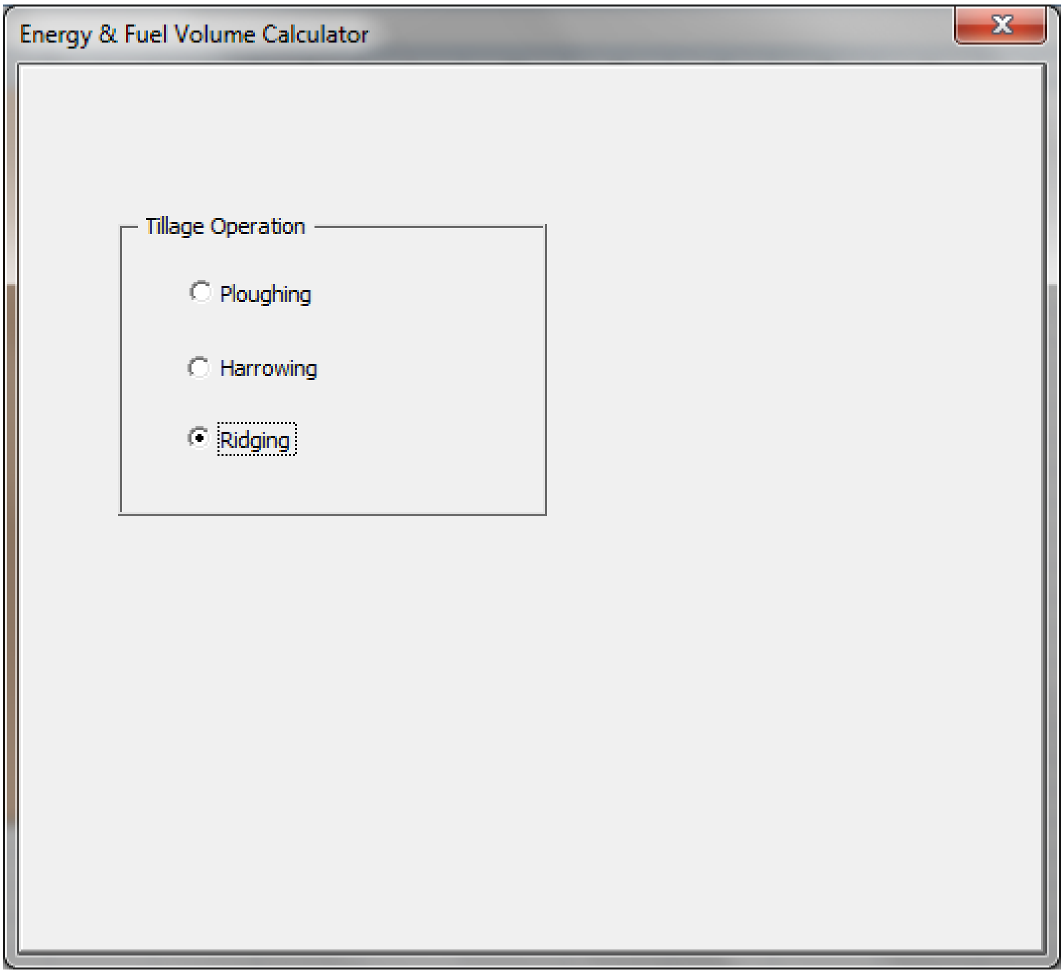
On clicking the compute button, the programmme compute the energy required in MJ and in equivalent liters of diesel per hectare.

The user may click “record data” button to transfer the input data to the Excel worksheet titled “Record sheet” from which hard copies may be printed. To exit the programme the user simply click Exit button located at the extreme lower right corner of the form.

### 5.13.3 User Interface

On the Excel sheet is placed a user form with ‘radio button’ for selecting the desired operation from the three option buttons representing ploughing, harrowing and ridging operations. On selecting the operation(e.g. ploughing), thePlough user interface is displayed. The user selects the soil texture type.

Fig. 5.21, Fig. 5.22 and Fig.5.23 show the user interface forms.


Energy & Fuel Volume Calculator

Tillage Operation

○ Ploughing

○ Harrowing

● Ridging

Figure5. 21 Data Entry  Interface for Selecting Operation

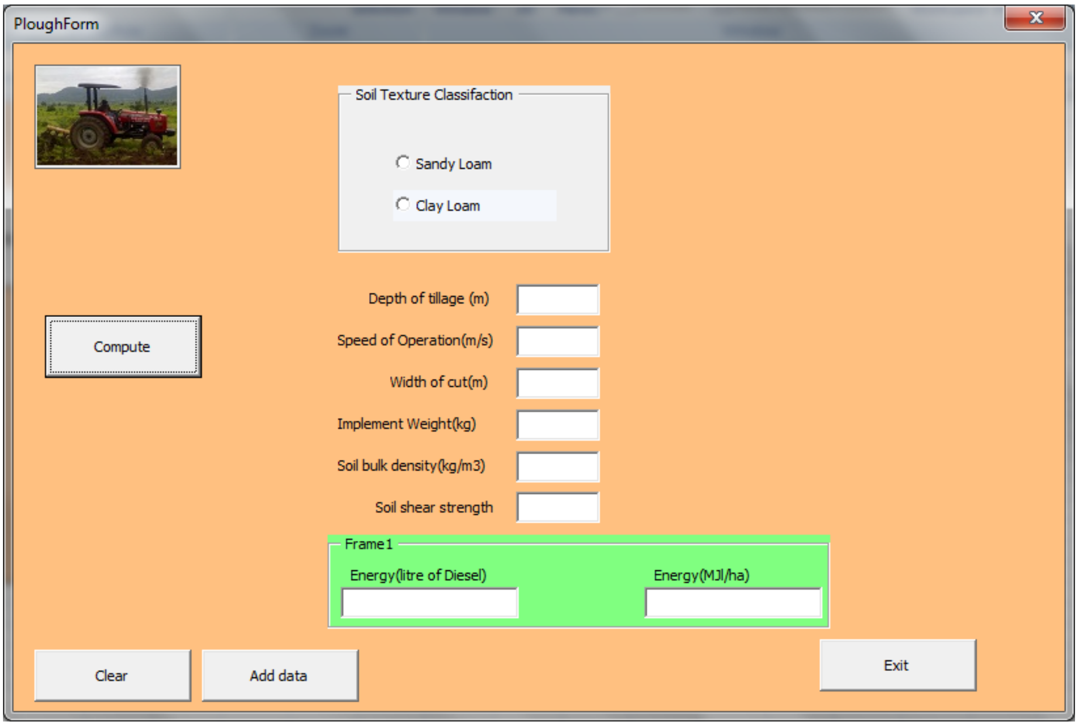


Figure 5. 22 Data Entry Interface for Computing Energy Demand for Ploughing Operation

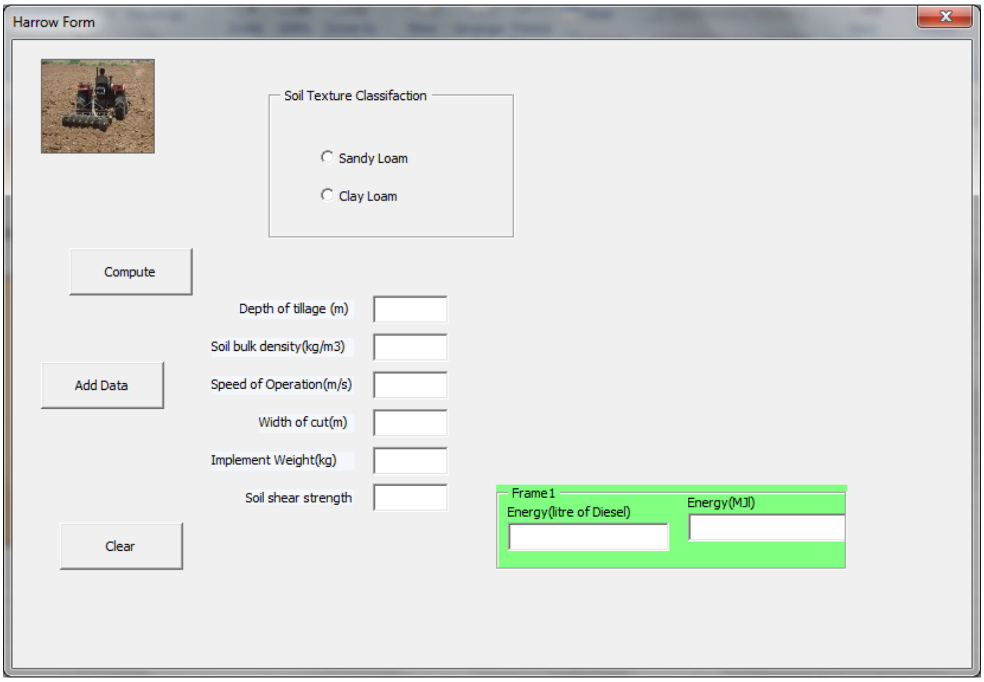


Fig. 5. 23: Data Entry Interface for Computing Energy Demand for Harrowing Operation

The model was tested for predicting tillage energy demand at depths of 115, 150 and 200 mm for speeds of 1.8 to 2.75. Fig 5.24 shows the variation of tillage energy with ploughing speed at depths E100 (100mm), E115 (115mm) and E120 (120mm) respectively over the speed range 1.8 to 2.7m/s. Fig. 5.25 shows the predicted ridging pattern at two depths. This shows that greater tillage depth results in higher energy consumption for the same tillage speed.

## 5.14 Validation of the Prediction Model

In order to determine the degree to which the model accurately represent the real system being predicted , the model was used to predict tillage energy demand for ploughing at selected speeds for three depths of plough. The result were plotted against actual field data for the same speeds and depths as shown in Figures 5.24, 5.25 and.26.

The predicted values correlated well with the observed values with correlation coefficient between 0.5 and 0.9. The results showed close agreement between the model result and the measured values . The maximum percentage error of estimates was 4.6, 3.0 and 3.0 % for ploughing, Harrowing and ridging respectively. The use of student t test reveals no significant difference ($P < 0.05$) and ($P < 0.01$) between the measured and computed values.

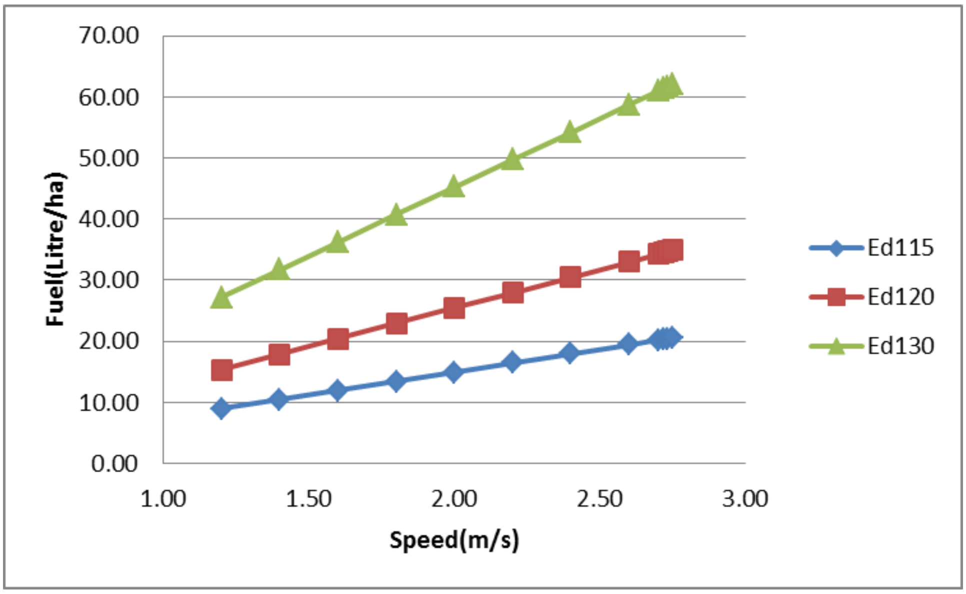


Fig. 5. 24 variation of plouging Energy with speed at 3 Depths of tillage

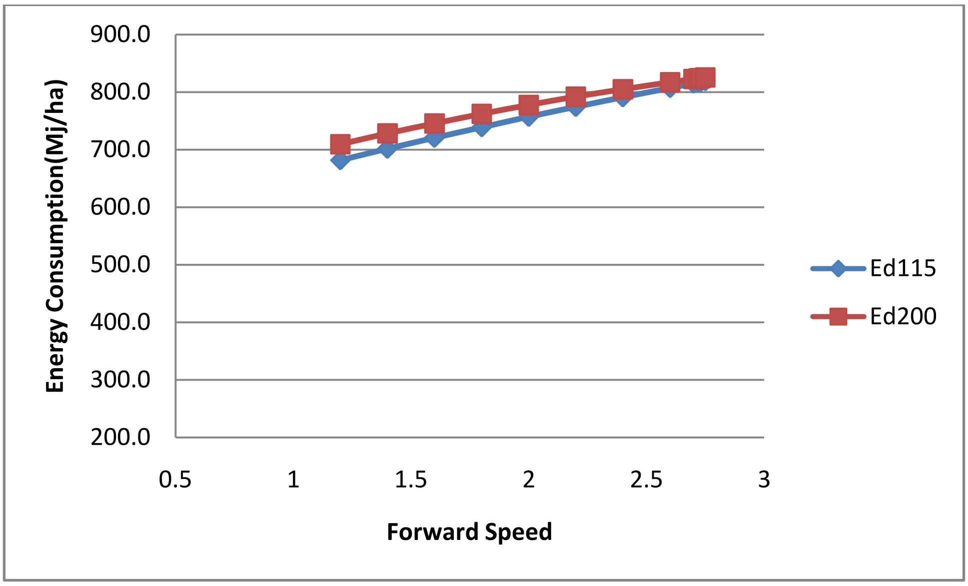


Figure 5. 25: Variation of Ridging Energy Demand with Speed & Depth of Tillage

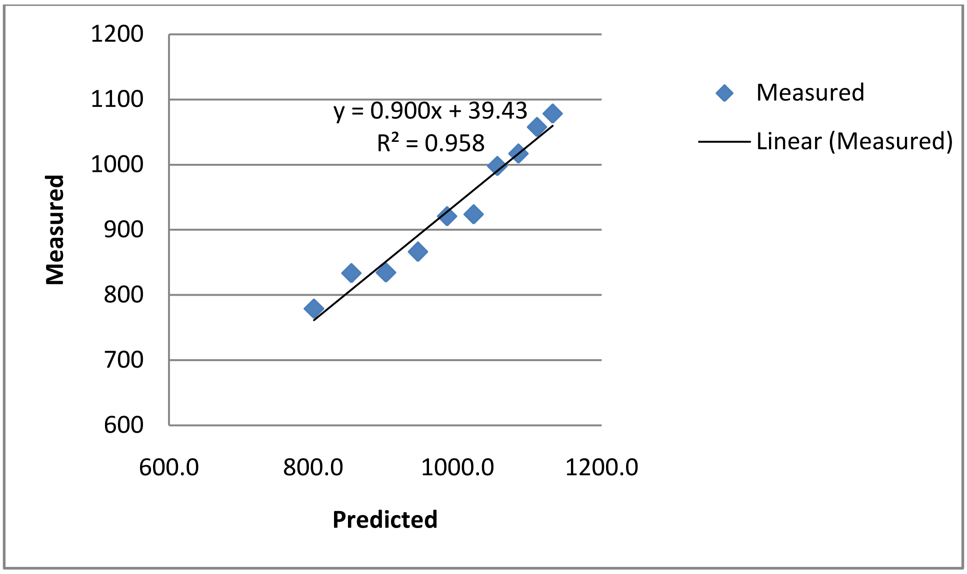


Fig. 5.26: Predicted vs measured energy demand for ploughing at 115mm depth.

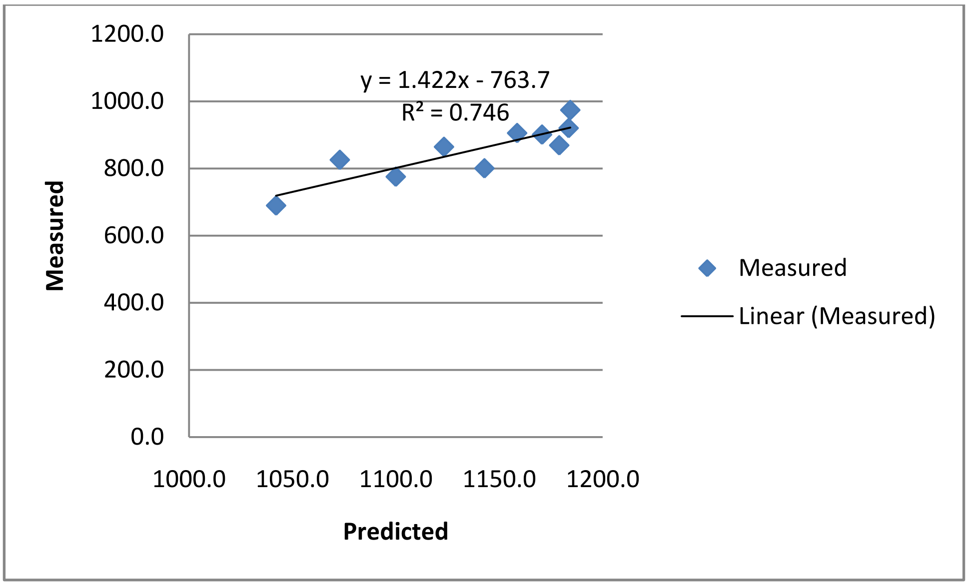


Fig. 5.27: Predicted vs measured energy demand for ploughing at 150mm depth.

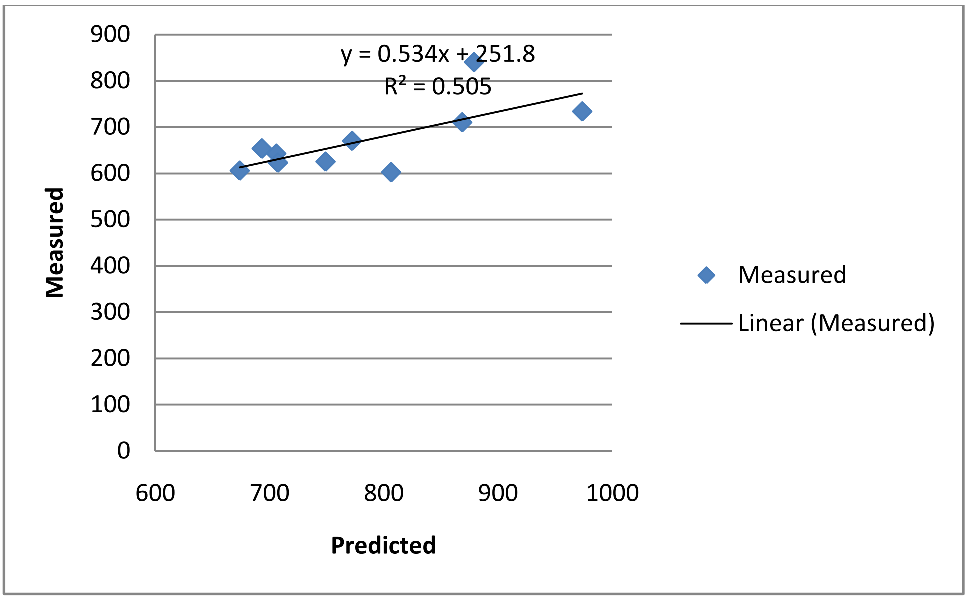


Fig. 5.28: Predicted vs measured energy demand for ploughing at 200mm depth.

### 5.14.1 Student's t-test: Comparison of two means

Student's t-test is commonly applied to small data sets for the comparison of two means. The outcome of these tests is the acceptance or rejection of the null hypothesis ($H_0$) which generally states that there is no significant difference between the means of the data set.

The computed P-value of0.925 was obtained, which is greater than 0.05. Hence, we cannot reject the null hypothesis and conclude that the variations of the two samples are the same.

### 5.14.2 Testing of the Model and programme

The model was tested with selected tractors and implements parameters taken from literature, soil parameters from soil test report and actual operational speed measured during the field trials. Energy demand for ploughing using speeds of 1.8, 2.2, 2.4 and 2.7 m/s at a depth of 115mm,150mm and 200mm were computed using the model.

The predicted values were in close correlation with the observed values with coefficient of determination ($R^2$)of 0.9581, 0.7466 and 0.5057 (correlation coefficients of 0.9788, 0.8640 and 0.7111) for ploughing at depths of 115 mm,150 mm and 200 mm respectively. This shows that the model closely fits the field situation. It could be noted that correlation coefficient is lowest at 200 mm. This means that the model performs best at shallower plough depths. The explanation is that since the fuel consumption has a cubic relation with de parameter depth, measurement errors in this parameter will lead to significant error in the resulting model computation.

### 5.14.3 Sensitivity Analysis.

Sensitivity of a model to a given parameter is the rate of change in the output of the model with respect to the change in tile value of the parameter while keeping other parameters constant. The model was used to examine the sensitivity of tillage energy demand to change in depth of tillage.A sensitivity test was done on the model in terms of the effect of varying the input data on the output results with respect to both depth of tillage and speed of operation. This was done for ploughing, harrowing and ridging operations.

Although most of the predicted and observed values show reasonable concordance, for several points the observed values significantly deviate from the expected values at greater depths of tillage. It appears that the model accuracy weakens at depths below 200mm. This may be due to difficulties in accurately measuring other parameters such as cone index beyond this depth

## 5.15 Tillage Energy Demand Scenarios

With the model developed in this study, a farmer can have first hand feeling of his farm energy budget depending on the available data. By varying one of the pertinent parameters and holding the others constant, the model may be used to predict the energy demand under different conditions. Fig 5.15 to 5.18 show energy demand as influenced by soil and operation parameters.

### 5.15.1 Soil Cone Index

Figure 5.17 shows that the energy demand for ploughing varies directly with typical cone index for sandy loam soil based on Ayers and Perumpra(19982). Given that in situ field measurement of moisture content is difficult, unlike cone index which can be rapidly assessed with cone penetrometer, soil cone index was used as proxy for soil moisture content because of the established relationship between them. Kumar et al., (2012) reported that values of CI tended to increase with increase in bulk density and decrease in moisture content. Similar relationship has been reported by Ayers and Perumpra(1982) and Mapfumo and Chansyk(1998).

Using the developed model, volume of fuel required to plough an hectare of farm land was computed and plotted for varying cone index values at three depths(115, 150 and 200mm). As shown in figure 5.29 the volume of fuel demand per hectare increase with increase in cone index. This means that harder soils with higher shear strength demand more fuel. The rate of variation is higher at greater tillage depth as indicated by the slope of the D200 line compared to D115 line in the above chart.

The relationship between energy consumption and cone index or soil resistance to penetration, stems from the fact that tillage process requires energy for cutting through the soil by overcoming its shear strength , lifting the soil clod and accelerating the clod in the direction of the implement's motion. Higher cone index indicates harder soil which means that greater energy is required to cut through the soil hard pan, shear through the soil profile. It is therefore not surprising that tillage energy demand increases with soil cone index. As noted by Yasin *et al*., (1993), soil cone resistance increases with depth. Hence the variation of energy consumption with cone index became more obvious at greater depths of tillage. This is shown by the steeper slope noticeable in fig 5.29 at depth D200. The practical implication of this result to the farmer is that harder and tougher soils whether due to low moisture content of high clay and gravel contents will require more fuel per hectare, and to a commercial tractor hiring outfit, it means charging higher tariff per hectare for such soil. Minimizing the depth of tillage can save some energy in this regard since energy consumption increases with depth.

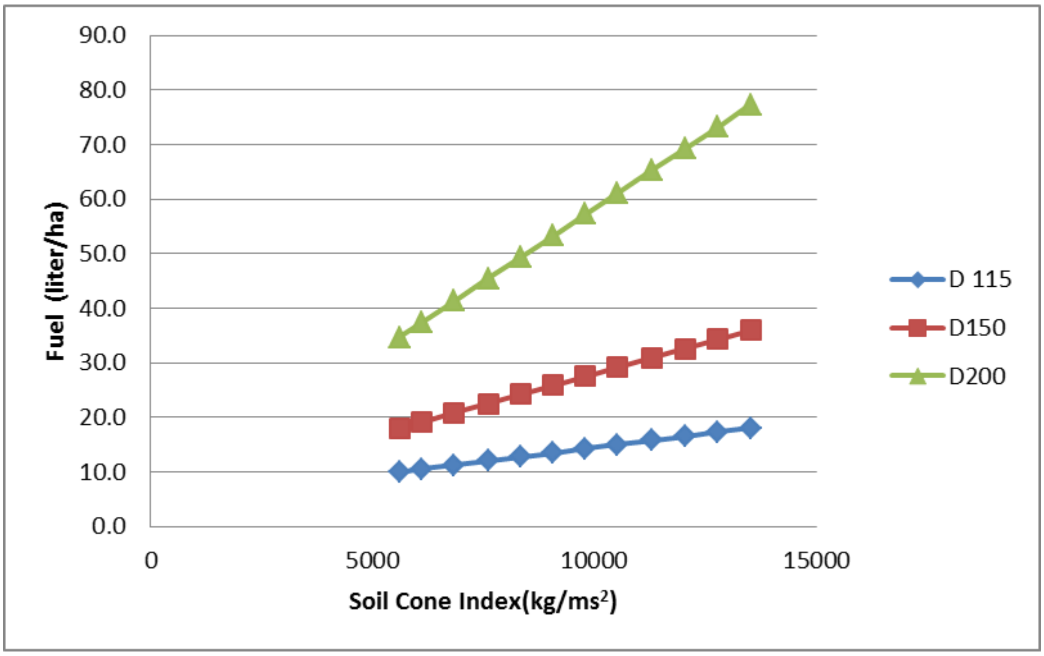


Fig 5.29: Tillage Energy demand under varying Cone index.

### 5.15.2 Bulk Density

Figure 5.30 shows the variation of fuel demand (l/ha) with soil bulk density. The gentle slope of the lines indicates that soil bulk density , compared to cone index, is not a very critical determinant of fuel consumption in tillage.

Bulk density has been shown to be influenced by soil porosity and gravel contents (Lampurlanes and Cantero-Martinez( 2006), compaction dues previous tillage and traction and traffic (Hao and Yang , 2013). As noted by Jones (1983), the optimum bulk density for most soils ranges from 900 to 1200 kg/m$^3$ as root growth becomes severely impede in loam and clay loam soils when bulk density exceeds 1300kg/m$^3$ or bulk density above 1600 in sandy soils. Onwualu and Anazodo (1989) reported an optimum bulk density of 1200kg/m$^3$ for maize production. It was therefore thought interesting to see how the tillage energy demand changes with soil bulk density in this range at different tillage depth. Mamman and Oni (2005) also found a direct positive correlation between draft developed by tillage tools and tool speed and depth of tillage.

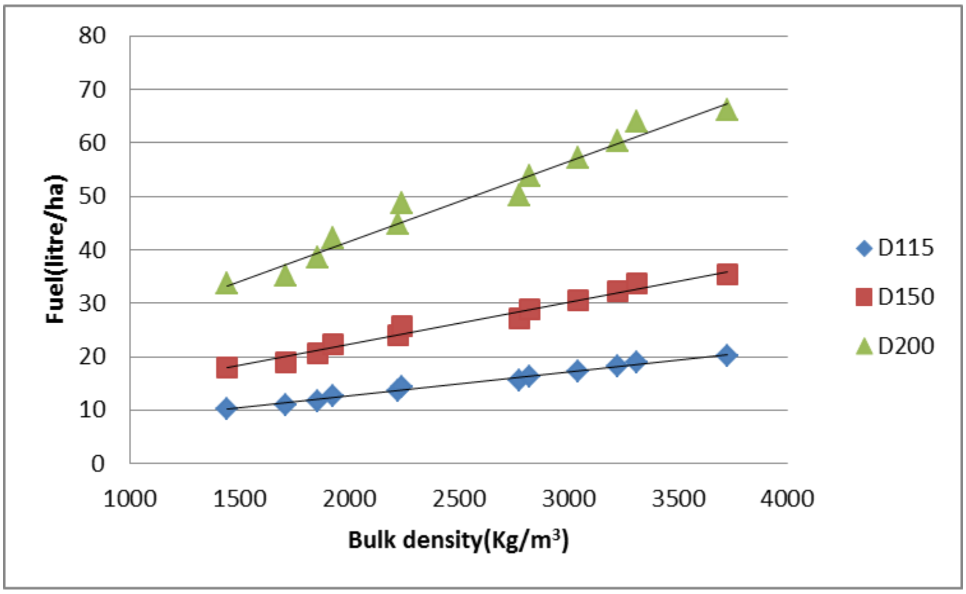


Fig 5.30: Variation of Tillage Energy Demand with Soil Bulk Density and Tillage Depth

Figure 5.31 shows the variation of fuel demand (l/ha) with depth of tillage. The exponential shape of the curve indicates that energy consumption increases rapidly with depth of tillage. This conclusion agrees with the finding of Adewoyin and Ajav (2013) who reported that fuel consumption for tillage operation increases rapidly with depth, although they proposed a linear relation.

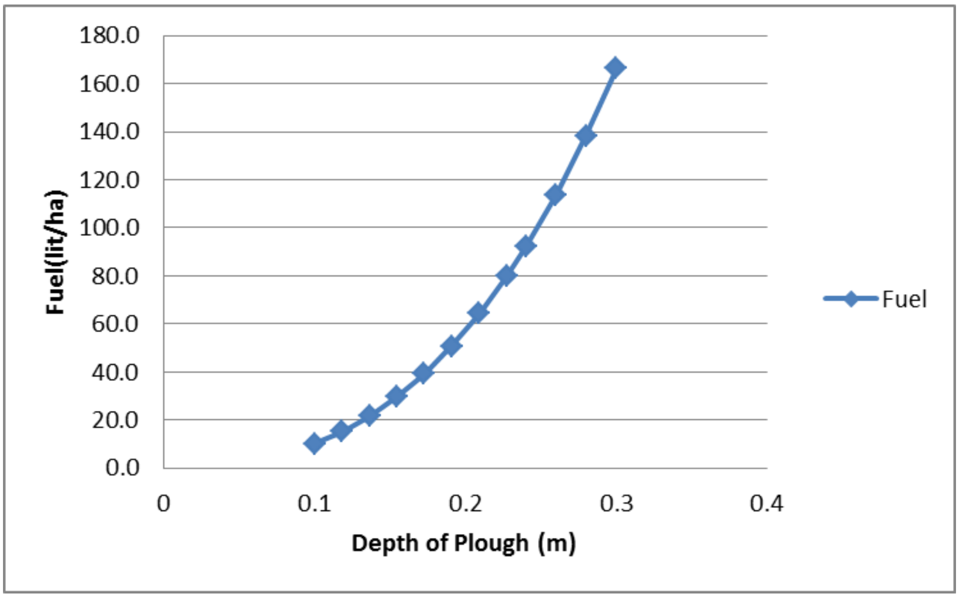


Fig 5.31. Tillage Energy demand under varying tillage depth.

Figure 5.32 shows the impact of tractor forward speed on the fuel consumption during ploughing. Although the slopes of the graph appear gentle, they become steeper at greater tillage depths; meaning that changes in speed has greater effects on the fuel consumption rates at greater depths. This result is in agreement with Fathollahzadeh et al.,(2010) who found a positive correlation between speed and fuel consumption of tractor.

From the above charts, it can be deduced that soil cone index, depth of tillage and forward speed are critical to fuel efficiency in tillage operation and for a commercial tractor hiring services. These factors can determine profitability by cutting down on fuel related expenditure. By implication, type of soil and the moisture status of the soil should be considered in fixing the hiring tariff based on their impact on fuel consumption.

In general, tillage operations involve applying ashear force larger than the bearing capacity or strength of the soil such that the soil fails or shatters. Higher soil bulk density results from low porosity and high clay content whilehigher cone index means greater shear strength.Soil shear strength increases with these two properties hence, greaterwork is required to overcome the shear strengthto shatter the soil and move the soil clods. All these translate to greater tractor fuel consumption. Thus it is expected that more fuel will be consumed in ploughing a fadama soil than the common sandy loam soils.

### 5.16 Testing the Model forOther Sites within the Southern Guinea Savanna Zone

To test the model’s ability to predict energy demand in soil from southern guinea savannah location outside Gui environment, soil bulk density and cone index data for National Centre for Agricultural Mechanization (NCAM) Ilorin weretaken from Ahaneku and Ogunjirin (2005) and Faleye *et al.*, (2013) were applied to the model to predict diesel demand for ploughing, harrowing and ridging operations. The predicted results were compared with actual field measurement at these sites as reported by Ahaneku *et al*.,(2010). Figure 5.32 shows the plot of predicted fuel consumption and the reported field data. A linear relationship with a coefficient of determination of 0.59 indicates a fairly good correlation . The Pearson product moment correlation coefficient, r, was calculated from equation 2.4 as 0.768 which shows that the model has good predictive capability.

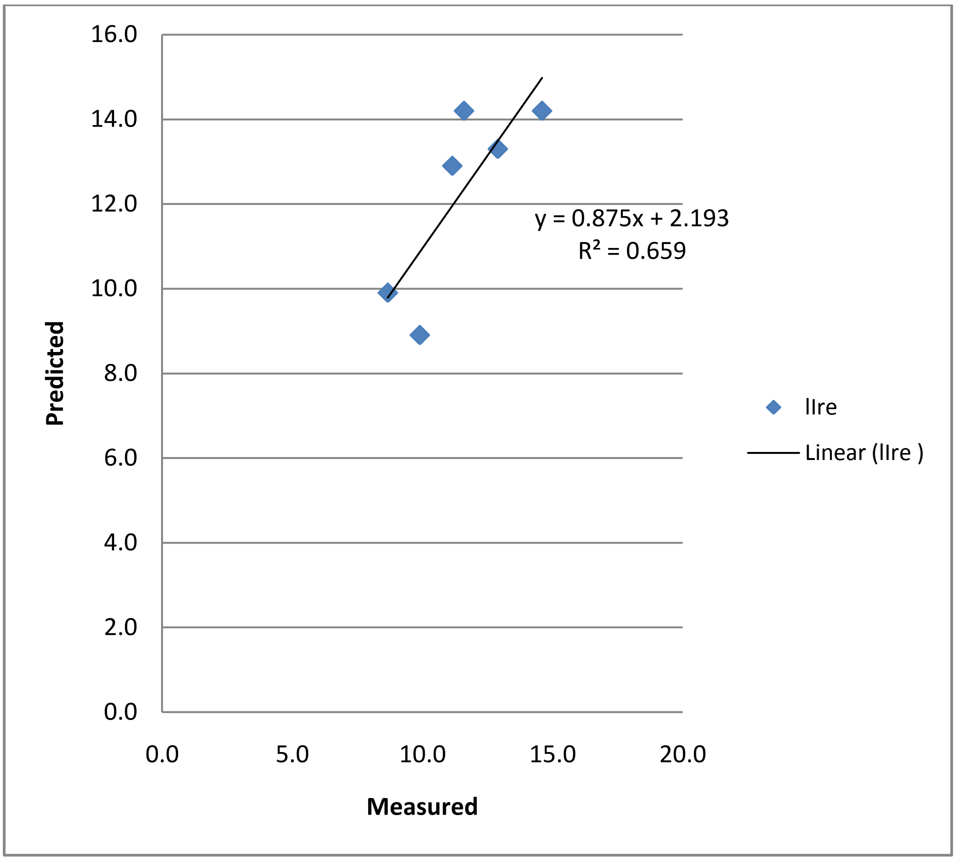


Fig. 5.32 Predicted fuel consumption versus field data for sites in Ilorin, kwara state

## 5.17 Maize Yield

Table 5.5 shows the yield per hectare as measured from the field trial. Although the study was not aimed at comparative yield evaluation, it was thought desirable to compare the average yield from the tillage systems used to see if the energy input actually affect the yield obtainable. TheANOVA (table 5.16) shows that yield was not significantlyaffected by mechanization level. Planting with the mechanical planter.

Table 5. 15 Maize Yield(kg/ha)

| Year | Replication | R1 | R2 | R3 |
|---|---|---|---|---|
| 2010 | T1 | 3147.85 | 3347.62 | 3008.36 |
|  | T2 | 2153.3 | 3393.66 | 3376.24 |
|  | T3 | 2175.25 | 3117.86 | 3357.65 |
| 2011 | T1 | 2351.24 | 2772.88 | 3449.95 |
|  | T2 | 2085.24 | 3167.84 | 2451.79 |
|  | T3 | 2928.66 | 2840.15 | 3445.78 |
| 2012 | T1 | 3242.66 | 2636.69 | 3341.42 |
|  | T2 | 2413.7 | 2200.31 | 2666.47 |
|  | T3 | 3531.22 | 3557.22 | 3457.09 |

Table 5.16: ANOVA for  maize yield

| Source of variation | Degrees of freedom | Sum of squares | Mean square | Computed F | Tabular F |  |
|---|---|---|---|---|---|---|
|  |  |  |  |  | 5% | 1% |
| Between Replication | 2 | 1178666.45 | 589333.2 | 3.753 | 3.63 | 6.23 |
| Between Treatment | 8 | 2489502.26 | 311187.8 | 1.982 | 2.66 | 3.78 |
| Between Operation (P) | 2 | 1222255.56 | 611127.8 | 3.892 | 3.63 | 6.23 |
| Technology (T) | 2 | 182349.15 | 91174.6 | 0.581 | 3.63 | 6.23 |
| P x T | 4 | 1084897.55 | 271224.4 | 1.727 | 3.01 | 4.77 |
| Residual | 16 | 2512654.84 | 157040.9 | 1.000 |  |  |
| Total | 26 | 8670325.80 |  |  |  |  |

tends to give higher plant population than manual planting leading to higher yield average per ha. But the difference was not significant even at 95% confidence level

It may be noted that studies which reported significant influence of energy input on yield took into account the indirect energy (fossil fuel feedstock) used in manufacture of fertilizer and pesticides both of which are outside the framers’ control and thus not pertinent to the aims of this study.

# Chapter 6

## SUMMARY, CONCLUSION AND RECOMMENDATIONS

The amount of energy consumed during tillage operations and its cost implication can make the difference between a profitable and an unprofitable farming year. Thecapacity to predict and optimize the energy required for each tillage operation will not only save the farmer's money but contribute to reducing environmental impact of fossil fuel usage. Modelling tillage energy has thus attracted much research attention. This study aimed at developinga mathematical model for predicting energy required for the tillage operations in maize production. To achieve thisaim, a theoretical framework was proposed in which the pertinent variables that determine tillage energy were identified and through a procedure of dimensional analysis energy demand equations governing ploughing, harrowing and ridging operations were developed using the data from two years of field experiment and validated with data from a third year

Three categories of parameters : soil type parameters (soil shear strength, cone index and bulk density) , tool parameters( width of cut) and operation parameters (speed and depth of tillage) wereconsidered based on Grisso and Perumpral (1985), Al-Hamed and Aljanobi(2001) and Yusuf(2006).

The model developed was tested using data from thirdyear of field trial at three levels of mechanization and was found to be in good fit with the field data.

A computer programme was developed in Visual Basic language using Microsoft Excel to execute the model such that farmers only needed to enter the relevant soil and operation parameters while the model predicts the energy demand automatically.

Using the model, energy demand for ploughing, harrowing and ridging operations were predicted for selected tractor speeds and implement depths. The results compared favourably with actual field measurement of fuel consumption by the tractor at these speeds and depths of operation.

The following can be concluded from the study.
Energy demand for maize production depends on the level of mechanization. For each specific tillage operation, the energy demand and consequently, the volume fuel consumed is a cubic function of depth of tillage, a quadratic function of speed of operation, a linear function of soil bulk density, soil shear strength and width of cut.

Analysis of total energy demand showed that very significant difference exists between the treatments. Total energy input was highest in the maximum mechanized treatment and least in the manual cultivation system.
Based on field measurements, the energy required for land preparation (land clearing, ploughing, harrowing and ridging) in sandy loam soils within the southern guinea vegetation, ranges from 1113.84MJ/ha in mechanized treatment to 28.33 MJ/ha in manual system. Total energy input ranged from 1986.84 MJ/ha under full mechanization to 150 MJ/ha in manualsystem. For the purpose of saving energy, environment and lowering production cost per tonne of maize, the selective mechanization system is recommended whereby ridging operation is omitted, with manual fertilizer application.

The study shows that energy can be saved if the tillage operation is done at an optimal speed and when operations are selectively mechanized.

## 6.1 Recommendations

From the result of the study, it is recommended that farm tillage operations be done the following optimum tillage speeds of 5.6km/h for ploughing, 7.8km/h for harrowing, and 4.8 km/h for ridging to ensure optimal energy consumption.

Where vegetation and soil condition permit maize farmers should adopt selective mechanization whereby ridging operation is omitted and fertilizer application is done manually. This will save energy and environment as well as cost thus improving profitability.

The analyses showed that there were significant differences both within and between the treatments. Total energy input were highest in the mechanized treatment and least in the manual cultivation system. The above trends show that energy will be saved if the tillage operation is done at an optimal speed of 6.5km/h (1.8m/s) and when operations are selectively mechanized.

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## Appendix A: Energy Consumed per operation in Mechanization level 1 (MJ/ha)

| | 2010 | | | 2011 | | | 2012 | | |
|---|---|---|---|---|---|---|---|---|---|
| | R1 | R2 | R3 | R1 | R2 | R3 | R1 | R2 | R3 |
| Ploughing | 718.29 | 689.17 | 626.08 | 715.87 | 689.17 | 667.33 | 715.87 | 703.73 | 650.35 |
| Harrowing | 395.55 | 407.68 | 431.95 | 383.41 | 407.68 | 431.95 | 397.97 | 407.68 | 431.95 |
| Ridging | 623.65 | 509.60 | 490.19 | 453.79 | 509.60 | 490.19 | 453.79 | 509.60 | 490.19 |
| Planting | 211.12 | 194.13 | 228.11 | 206.27 | 189.28 | 208.69 | 211.12 | 194.13 | 215.97 |
| Weeding1 | 15.00 | 13.33 | 13.33 | 13.33 | 15.00 | 13.33 | 13.33 | 14.17 | 13.33 |
| Fertilizer | 10.00 | 9.17 | 10.83 | 23.33 | 22.50 | 23.33 | 23.33 | 25.00 | 23.33 |
| Weeding2 | 13.33 | 13.33 | 12.50 | 13.33 | 13.33 | 12.50 | 13.33 | 15.00 | 12.50 |

Appendix B: Energy Consumed per operation for Mechanization level 2 (MJ/ha)

| | 2010 | | | 2011 | | | 2012 | | |
|---|---|---|---|---|---|---|---|---|---|
| | R1 | R2 | R3 | R1 | R2 | R3 | R1 | R2 | R3 |
| Ploughing | 588.47 | 569.05 | 532.65 | 362.79 | 399.19 | 387.05 | 345.80 | 326.39 | 314.25 |
| Harrowing | 345.80 | 399.19 | 387.05 | 370.07 | 399.19 | 411.32 | 345.80 | 326.39 | 314.25 |
| Ridging | 502.32 | 509.60 | 490.19 | 453.79 | 509.60 | 490.19 | 453.79 | 509.60 | 490.19 |
| Planting | 20.00 | 23.33 | 21.67 | 20.83 | 22.50 | 21.67 | 20.00 | 20.00 | 21.67 |
| Weeding1 | 26.67 | 28.33 | 23.33 | 23.33 | 23.33 | 23.33 | 23.33 | 23.33 | 23.33 |
| Fertilizer | 23.33 | 25.00 | 23.33 | 23.33 | 26.67 | 23.33 | 23.33 | 24.17 | 23.33 |
| Weeding2 | 20.00 | 20.00 | 20.00 | 28.33 | 21.67 | 22.50 | 20.00 | 16.67 | 20.00 |

Appendix C: Energy Consumed per Operation in Completely Manual System (MJ/ha)

| | 2010 | | | 2011 | | | 2012 | | |
|---|---|---|---|---|---|---|---|---|---|
| | R1 | R2 | R3 | R1 | R2 | R3 | R1 | R2 | R3 |
| Ploughing | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Harrowing | 24.17 | 28.33 | 26.67 | 24.17 | 28.33 | 26.67 | 26.67 | 28.33 | 23.33 |
| Ridging | 30.00 | 26.67 | 29.17 | 30.00 | 26.67 | 29.17 | 26.67 | 26.67 | 25.00 |
| Planting | 22.50 | 20.83 | 21.67 | 22.50 | 20.83 | 21.67 | 22.50 | 20.83 | 21.67 |
| Weeding1 | 23.33 | 26.67 | 23.33 | 23.33 | 26.67 | 23.33 | 21.67 | 21.67 | 23.33 |
| Fertilizer | 25.00 | 23.33 | 26.67 | 25.00 | 23.33 | 26.67 | 26.67 | 23.33 | 26.67 |
| Weeding2 | 25.00 | 21.67 | 20.83 | 25.00 | 21.67 | 20.83 | 19.17 | 16.67 | 20.00 |

## Appendix F: Pi-terms for Harrowing Operation

Harrowing 2010

| $\pi_1$ | $\pi_2$ | $\pi_3$ | $\pi_4$ |
|---|---|---|---|
| 54.7 | 10.68 | 0.14 | 3.0 |
| 49.6 | 9.40 | 0.12 | 2.7 |
| 41.1 | 7.28 | 0.11 | 2.2 |
| 34.6 | 5.65 | 0.10 | 1.8 |
| 32.2 | 5.05 | 0.10 | 1.7 |
| 30.0 | 4.50 | 0.09 | 1.6 |
| 28.0 | 4.00 | 0.09 | 1.4 |
| 26.2 | 3.55 | 0.08 | 1.3 |
| 26.1 | 3.53 | 0.08 | 1.3 |
| 26.2 | 3.55 | 0.08 | 1.3 |
| 27.2 | 3.80 | 0.08 | 1.3 |

Harrowing 2011

| $\pi_1$ | $\pi_2$ | $\pi_3$ | $\pi_4$ |
|---|---|---|---|
| 53.5 | 9.375 | 0.14 | 3.0 |
| 49.1 | 8.275 | 0.12 | 2.7 |
| 41.1 | 6.275 | 0.11 | 2.2 |
| 35.0 | 4.75 | 0.10 | 1.8 |
| 32.5 | 4.125 | 0.10 | 1.7 |
| 30.3 | 3.575 | 0.09 | 1.5 |
| 28.3 | 3.075 | 0.09 | 1.4 |
| 27.4 | 2.85 | 0.08 | 1.4 |
| 26.7 | 2.675 | 0.08 | 1.3 |
| 26.8 | 2.7 | 0.08 | 1.3 |
| 33.0 | 4.25 | 0.08 | 1.3 |

## Appendix D: Pooled Energy Consumption data from 3 years field trials.

| | | 2010 | | | 2011 | | | 2012 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | R1 | R2 | R3 | R1 | R2 | R3 | R1 | R2 | R3 |
| **T1** | P1 | 1113.84 | 1096.85 | 1058.03 | 1099.28 | 1096.85 | 1099.28 | 1113.84 | 1111.41 | 1082.29 |
| | P2 | 623.65 | 509.60 | 490.19 | 453.79 | 509.60 | 490.19 | 453.79 | 509.60 | 490.19 |
| | P3 | 211.12 | 194.13 | 228.11 | 206.27 | 189.28 | 208.69 | 211.12 | 194.13 | 215.97 |
| | P4 | 10.00 | 9.17 | 10.83 | 23.33 | 22.50 | 23.33 | 23.33 | 25.00 | 23.33 |
| | P5 | 28.33 | 26.67 | 25.83 | 26.67 | 28.33 | 25.83 | 26.67 | 29.17 | 25.83 |
| **T2** | P1 | 934.27 | 968.24 | 919.71 | 732.85 | 798.37 | 798.37 | 691.60 | 652.77 | 628.51 |
| | P2 | 502.32 | 509.60 | 490.19 | 453.79 | 509.60 | 490.19 | 453.79 | 509.60 | 490.19 |
| | P3 | 20.00 | 23.33 | 21.67 | 20.83 | 22.50 | 21.67 | 20.00 | 20.00 | 21.67 |
| | P4 | 23.33 | 25.00 | 23.33 | 23.33 | 26.67 | 23.33 | 23.33 | 24.17 | 23.33 |
| | P5 | 46.67 | 48.33 | 43.33 | 51.67 | 45.00 | 45.83 | 43.33 | 40.00 | 43.33 |
| **T3** | P1 | 24.17 | 28.33 | 26.67 | 25.00 | 28.33 | 23.33 | 26.67 | 28.33 | 23.33 |
| | P2 | 30.00 | 26.67 | 29.17 | 26.67 | 30.00 | 28.33 | 26.67 | 26.67 | 25.00 |
| | P3 | 22.50 | 20.83 | 21.67 | 22.50 | 23.33 | 21.67 | 22.50 | 20.83 | 21.67 |
| | P4 | 25.00 | 23.33 | 26.67 | 20.83 | 23.33 | 26.67 | 26.67 | 23.33 | 26.67 |
| | P5 | 48.33 | 48.33 | 44.17 | 40.83 | 38.33 | 43.33 | 40.83 | 38.33 | 43.33 |

T1=Maximum Mechanization T2= Semi-mechanization, T3= Zero Mechanization.

P1= land preparation(pre-ridging), P2=Ridging, P3=Planting, P4= Fertilizer application, P5= weed control

## Appendix E: Pi-terms for Ploughing operation

Ploughing 2010

| $\pi_1$ | $\pi_2$ | $\pi_3$ | $\pi_4$ |
|---|---|---|---|
| 118.1 | 12.75 | 0.12 | 3.3 |
| 104.9 | 10.55 | 0.11 | 3.0 |
| 96.3 | 9.12 | 0.11 | 2.7 |
| 89.0 | 7.91 | 0.10 | 2.5 |
| 76.7 | 5.85 | 0.10 | 2.2 |
| 65.5 | 3.98 | 0.09 | 2.0 |
| 65.3 | 3.95 | 0.09 | 1.9 |
| 57.3 | 2.61 | 0.08 | 1.6 |
| 54.4 | 2.14 | 0.08 | 1.5 |
| 55.4 | 2.30 | 0.08 | 1.5 |
| 51.8 | 1.70 | 0.08 | 1.4 |

Ploughing 2011

| $\pi_1$ | $\pi_2$ | $\pi_3$ | $\pi_4$ |
|---|---|---|---|
| 122.9 | 25.54 | 0.12 | 3.3 |
| 94.7 | 16.72 | 0.11 | 2.7 |
| 77.2 | 11.25 | 0.09 | 2.0 |
| 63.5 | 6.97 | 0.09 | 1.7 |
| 56.4 | 5.88 | 0.08 | 1.6 |
| 49.3 | 5.25 | 0.08 | 1.5 |
| 55.2 | 4.38 | 0.08 | 1.5 |
| 53.2 | 3.75 | 0.08 | 1.5 |
| 54.2 | 4.07 | 0.08 | 1.5 |
| 55.4 | 4.44 | 0.08 | 1.5 |
| 53.9 | 3.32 | 0.08 | 1.4 |

## Appendix G: Pi-terms for Ridging Operation

Ridging 2010

| $\pi_1$ | $\pi_2$ | $\pi_3$ | $\pi_4$ |
|---|---|---|---|
| 108.8 | 15.14 | 0.14 | 4.1 |
| 105.9 | 14.65 | 0.12 | 3.7 |
| 91.8 | 12.30 | 0.11 | 3.0 |
| 78.0 | 10.00 | 0.10 | 2.5 |
| 72.7 | 9.12 | 0.10 | 2.3 |
| 67.7 | 8.29 | 0.09 | 2.1 |
| 63.2 | 7.54 | 0.09 | 2.0 |
| 59.4 | 6.90 | 0.08 | 1.8 |
| 59.9 | 6.99 | 0.08 | 1.8 |
| 60.3 | 7.05 | 0.08 | 1.8 |
| 61.2 | 7.20 | 0.08 | 1.8 |

Ridging 2011

| $\pi_1$ | $\pi_2$ | $\pi_3$ | $\pi_4$ |
|---|---|---|---|
| 108.8 | 19.20 | 0.14 | 3.1 |
| 105.9 | 18.48 | 0.12 | 2.7 |
| 101.2 | 17.30 | 0.11 | 2.5 |
| 78.0 | 11.50 | 0.10 | 1.9 |
| 72.7 | 10.18 | 0.10 | 1.7 |
| 67.7 | 8.93 | 0.09 | 1.6 |
| 68.3 | 9.08 | 0.09 | 1.6 |
| 59.4 | 6.85 | 0.08 | 1.4 |
| 59.9 | 6.98 | 0.08 | 1.3 |
| 60.3 | 7.08 | 0.08 | 1.3 |
| 59.7 | 6.93 | 0.08 | 1.3 |

## Appendix H: Simulated and Measured Energy Consumption for Ploughing at different Speeds (MJ/ha)

| Travel Speed(m/s) | Plough Depth (115) | | Plough Depth (150) | | Plough Depth (200) | |
|---|---|---|---|---|---|---|
| | Measured | Predicted | Measured | Predicted | Measured | Predicted |
| 1.8 | 833.32 | 853.1 | 920.0 | 1183.6 | 670 | 772.464 |
| 2 | 834.25 | 901.1 | 868.7 | 1179.0 | 625.01 | 749.122 |
| 2.4 | 920.73 | 985.9 | 905.2 | 1158.7 | 642.33 | 705.958 |
| 2.6 | 923.54 | 1022.6 | 800.0 | 1142.8 | 605.63 | 674.102 |
| 2.75 | 1078.16 | 1132.1 | 689.0 | 1042.0 | 840.43 | 879.076 |

## Appendix I: Simulated Variation of fuel demand with Cone index and depth(l/ha)

| S | p | D115 | D150 | D200 |
|---|---|---|---|---|
| 5600 | 1444 | 10.16 | 17.95 | 33.6 |
| 6100 | 1711 | 10.88 | 19.02 | 35.1 |
| 6840 | 1857 | 11.76 | 20.66 | 38.4 |
| 7600 | 1925 | 12.59 | 22.37 | 42.2 |
| 8330 | 2225 | 13.57 | 23.95 | 44.8 |
| 9070 | 2244 | 14.34 | 25.62 | 48.7 |
| 9800 | 2777 | 15.51 | 27.15 | 50.2 |
| 10500 | 2825 | 16.26 | 28.73 | 53.8 |
| 11300 | 3044 | 17.26 | 30.49 | 57.1 |
| 12040 | 3228 | 18.16 | 32.12 | 60.2 |
| 12780 | 3311 | 18.98 | 33.78 | 63.8 |
| 13530 | 3725 | 20.08 | 35.38 | 66.02 |

## Appendix J: Variation of fuel consumption with speed and depth of tillage (l/ha)

| Travel Speed(m/s) | Ed115 | Ed150 | Ed200 |
|---:|---:|---:|---:|
| 1.20 | 8.98 | 15.29 | 27.22 |
| 1.40 | 10.48 | 17.83 | 31.73 |
| 1.60 | 11.97 | 20.37 | 36.24 |
| 1.80 | 13.46 | 22.91 | 40.76 |
| 2.00 | 14.95 | 25.45 | 45.26 |
| 2.20 | 16.45 | 27.98 | 49.77 |
| 2.40 | 17.93 | 30.50 | 54.23 |
| 2.60 | 19.42 | 33.03 | 58.72 |
| 2.70 | 20.16 | 34.30 | 60.95 |
| 2.72 | 20.31 | 34.55 | 61.40 |
| 2.73 | 20.39 | 34.68 | 61.64 |
| 2.75 | 20.53 | 34.92 | 62.06 |

## Appendix K: Prediction of fuel consumption for ploughing based on data from NCAM , Ilorin

| Width of cut(m)* | Weight of Implement(Kg) | shear strength(kPa)*** | Soil bulk density (kg/m3)* | Speed of Operation(m/s) ** | Depth of Tillage * | E (MJ/ha) | l/ha* | l/ha*** |
|---|---|---|---|---|---|---|---|---|
| 1.3 | 650 | 38.2 | 1390 | 1.81 | 0.15 | 820.6 | 22.5 | 20 |
| 1.3 | 650 | 40.79 | 1390 | 1.52 | 0.2 | 905.6 | 24.9 | 24.25 |
| 1.3 | 650 | 43 | 1380 | 1.40 | 0.25 | 728.9 | 20.0 | 23.58 |
| 1.3 | 650 | 47.89 | 1400 | 2.22 | 0.115 | 1235.7 | 33.9 | 27.23 |

* Source: Faleye *et al* (2013) , ** Source: Ahaneku et al (2010),

*** predicted from NCAM Data using the model

## Appendix L: Source Code for Tillage Energy Computation Model

```
Private Sub CommandButton3_Click()
End Sub
Private Sub MultiPage1_Change()
End Sub
Private Sub PlowClear_Click()
'clear the data
Me.PlowDptTextBox.Value = ""
Me.PlowSBDTextBox.Value = ""
Me.PlowWidthTextBox.Value = ""
Me.PlowSpeedTextBox.Value = ""
Me.PlowSCITextBox.Value = ""
Me.PlowSoilShTextBox.Value = ""
End Sub
Private Sub PlowRecord_Click()
Dim iRow As Long
Dim ws As Worksheet
Set ws = Worksheets("Datasheet")
Set ws = ActiveSheet
 'Find first empty row in database
 'iRow = ws.Cells(Rows.Count, 3).End(xlUp).Offset(1).Row
```

```
Set ws = ActiveSheet

Range("B2:J2").Select

    Selection.ClearContents

  iRow = ws.Cells(Rows.Count, 2).End(xlUp).Offset(1).Row

 'copy the data to the database

ws.Cells(iRow, 2).Value = Me.PlowDptTextBox.Value

ws.Cells(iRow, 3).Value = Me.PlowSpeedTextBox.Value

ws.Cells(iRow, 4).Value = Me.PlowWidthTextBox.Value

ws.Cells(iRow, 5).Value = Me.PlowSCITextBox.Value

ws.Cells(iRow, 6).Value = Me.PlowSBDTextBox.Value

ws.Cells(iRow, 7).Value = Me.PlowSoilShTextBox.Value

ws.Cells(iRow, 8).Value = PlowDiesel.Value

ws.Cells(iRow, 9).Value = PlowEnergyTextBox.Value

ws.Cells(iRow, 10).Value = 1.2 * (PlowEnergyTextBox.Value)


End Sub

Private Sub Sandyloam3Button_Click()

www$ = UCase(InputBox("is soil data available?(Y/N)"))


Select Case www$

      Case "N"

Call d1800

Me.PlowSBDTextBox.Enabled = False
```

```
Me.PlowSoilShTextBox.Enabled = False
Me.PlowDptTextBox.SetFocus
'Call computing
Exit Sub

Case "Y"
MsgBox "enter data now"
End Select

End Sub

Private Sub PlowComput_Click()
Dpt = 0
SBD = 0
Cutwidth = 0
Speed = 0
SCI = 0
Soilsh = 0
plough = 0
PlowDiesel = 0
If Me.PlowDptTextBox.Value = "" Then Dpt = 0 Else Dpt = Me.PlowDptTextBox.Value
If Me.PlowSBDTextBox.Value = "" Then SBD = 0 Else SBD =
Me.PlowSBDTextBox.Value
```

```
If Me.PlowWidthTextBox.Value = "" Then Cutwidth = 0 Else Cutwidth = Me.PlowWidthTextBox.Value
If Me.PlowSpeedTextBox.Value = "" Then Speed = 0 Else Speed = Me.PlowSpeedTextBox.Value
If Me.PlowSCITextBox.Value = "" Then SCI = 0 Else SCI = Me.PlowSCITextBox.Value
If Me.PlowSoilShTextBox.Value = "" Then Soilsh = 0 Else Soilsh = Me.PlowSoilShTextBox.Value
PlowEnergy = =  6*(Speed^2 * Dpt^2 * SBD* Cutwidth) + 1532.6 * SCI* Speed*Dpt ^2 + 34.2 * Soilsh * Dpt -1587* Speed ^ 2 * Dpt^3 * SBD
 PlowEnergyTextBox.Value = Round(PlowEnergy, 2)
 plough = Round(PlowEnergy, 2)
 PlowDiesel = Round(PlowEnergy / 36.4, 2)
PlowDiesel.Value = PlowDiesel
'PlowDiesel.Value = plowenergy1


End Sub


Private Sub PlowExit_Click()
End
End Sub
Sub d1800()
'typical soil data
Me.PlowSBDTextBox.Value = 1220 'kg/m3
Me.PlowSoilShTextBox.Value = 30.18
```

```
End Sub

'Sub d1801()

'Me.PlowSBDTextBox.Value = 1.3

'Me.PlowSoilShTextBox.Value = 50

'End Sub

Sub computing()

SBD = 0

Cutwidth = 0

Speed = 0

SCI = 0

Soilsh = 0

If Me.PlowDptTextBox.Value = "" Then Dpt = 0 Else Dpt = Me.PlowDptTextBox.Value

If Me.PlowSBDTextBox.Value = "" Then SBD = 0 Else SBD = Me.PlowSBDTextBox.Value

If Me.PlowWidthTextBox.Value = "" Then Cutwidth = 0 Else Cutwidth = Me.PlowWidthTextBox.Value

If Me.PlowSpeedTextBox.Value = "" Then Speed = 0 Else Speed = Me.PlowSpeedTextBox.Value

If Me.PlowSCITextBox.Value = "" Then SCI = 0 Else SCI = Me.PlowSCITextBox.Value

If Me.PlowSoilShTextBox.Value = "" Then Soilsh = 0 Else Soilsh = Me.PlowSoilShTextBox.Value

PlowEnergy =  6*(Speed^2 * Dpt^2 * SBD* Cutwidth) + 1532.6 * SCI* Speed*Dpt ^2 + 34.2 * Soilsh * Dpt -1587* Speed ^ 2 * Dpt^3 * SBD

 PlowEnergyTextBox.Value = Round(PlowEnergy, 2)
```

```
 PlowDiesel = PlowEnergy / 36.4

PlowDiesel.Value = Round(PlowDiesel, 2)

End Sub

Private Sub PlowDptTextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)

Validator PlowDptTextBox, KeyAscii

End Sub

Private Sub PlowSpeedTextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)

Validator PlowSpeedTextBox, KeyAscii

End Sub

Private Sub PlowWidthTextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)

Validator PlowWidthTextBox, KeyAscii

End Sub

Private Sub PlowSCITextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)

Validator PlowSCITextBox, KeyAscii

End Sub

Private Sub PlowSBDTextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)

Validator PlowSBDTextBox, KeyAscii

End Sub

Private Sub PlowSoilShTextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)

Validator PlowSoilShTextBox, KeyAscii

End Sub
```

```
'*****************End of Ploughing Energy computation


Private Sub Sandyloam2Button_Click()

www$ = UCase(InputBox("is soil data available?(Y/N)"))


Select Case www$

    Case "N"

Call d1900

Me.HarrowSBDTextBox.Enabled = False

Me.HarrowSoilShTextBox.Enabled = False

Me.HarrowDptTextBox.SetFocus

'Call computing2

Exit Sub

Case "Y"

MsgBox "enter data now"

End Select


End Sub

Sub d1900()

'typical soil data

Me.HarrowSBDTextBox.Value = 1220 'kg/m3

Me.HarrowSoilShTextBox.Value = 30.18

End Sub
```

```
Sub d1901()
Me.HarrowSBDTextBox.Value = 1.3
Me.HarrowSoilShTextBox.Value = 50
End Sub
Sub computing2()
SBD = 0
Cutwidth = 0
Speed = 0
SCI = 0
Soilsh = 0
If Me.HarrowDptTextBox.Value = "" Then Dpt = 0 Else Dpt =
Me.HarrowDptTextBox.Value
If Me.HarrowSBDTextBox.Value = "" Then SBD = 0 Else SBD =
Me.HarrowSBDTextBox.Value
If Me.HarrowWidthTextBox.Value = "" Then Cutwidth = 0 Else Cutwidth =
Me.HarrowWidthTextBox.Value
If Me.HarrowSpeedTextBox.Value = "" Then Speed = 0 Else Speed =
Me.HarrowSpeedTextBox.Value
If Me.HarrowSCITextBox.Value = "" Then SCI = 0 Else SCI =
Me.HarrowSCITextBox.Value
If Me.HarrowSoilShTextBox.Value = "" Then Soilsh = 0 Else Soilsh =
Me.HarrowSoilShTextBox.Value
HarrowEnergy = =  4*(Speed^2 * Dpt^2 * SBD* Cutwidth) + 680.86 * SCI* Speed*Dpt
^2 + 16.86 * Soilsh * Dpt -66* Speed ^ 2 * Dpt^3 * SBD
 HarrowEnergyTextBox.Value = Round(HarrowEnergy, 2)
```

```
 HarrowDiesel = HarrowEnergy / 36.4
HarrowDiesel.Value = Round(HarrowDiesel, 2)
End Sub

Private Sub HarrowComput_Click()
Dpt = 0
SBD = 0
Cutwidth = 0
Speed = 0
SCI = 0
Soilsh = 0
plough = 0
HarrowDiesel = 0
If Me.HarrowDptTextBox.Value = "" Then Dpt = 0 Else Dpt = Me.HarrowDptTextBox.Value
If Me.HarrowSBDTextBox.Value = "" Then SBD = 0 Else SBD = Me.HarrowSBDTextBox.Value
If Me.HarrowWidthTextBox.Value = "" Then Cutwidth = 0 Else Cutwidth = Me.HarrowWidthTextBox.Value
If Me.HarrowSpeedTextBox.Value = "" Then Speed = 0 Else Speed = Me.HarrowSpeedTextBox.Value
If Me.HarrowSCITextBox.Value = "" Then SCI = 0 Else SCI = Me.HarrowSCITextBox.Value
If Me.HarrowSoilShTextBox.Value = "" Then Soilsh = 0 Else Soilsh = Me.HarrowSoilShTextBox.Value
```

```
HarrowEnergy =  =  4*(Speed^2 * Dpt^2 * SBD* Cutwidth) + 680.86 * SCI* Speed*Dpt ^2 + 16.86 * Soilsh * Dpt -66* Speed ^ 2 * Dpt^3 * SBD
 HarrowEnergyTextBox.Value = Round(HarrowEnergy, 2)
 plough = Round(HarrowEnergy, 2)
 HarrowDiesel = Round(HarrowEnergy / 36.4, 2)
HarrowDiesel.Value = HarrowDiesel
'HarrowDiesel.Value = Harrowenergy1


End Sub
Private Sub HarrowExit_Click()
End
End Sub
Private Sub HarrowDptTextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)
Validator HarrowDptTextBox, KeyAscii
End Sub
Private Sub HarrowSpeedTextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)
Validator HarrowSpeedTextBox, KeyAscii
End Sub
Private Sub HarrowWidthTextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)
Validator HarrowWidthTextBox, KeyAscii
End Sub
Private Sub HarrowSCITextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)
```

```
Validator HarrowSCITextBox, KeyAscii
End Sub
Private Sub HarrowSBDTextBox_KeyPress(ByVal KeyAscii As
MSForms.ReturnInteger)
Validator HarrowSBDTextBox, KeyAscii
End Sub
Private Sub HarrowSoilShTextBox_KeyPress(ByVal KeyAscii As
MSForms.ReturnInteger)
Validator HarrowSoilShTextBox, KeyAscii
End Sub
'******************End of Harrowing Energy computation
Private Sub SandyloamButton_Click() 'Begining of computation for Ridger

www$ = UCase(InputBox("is soil data available?(Y/N)"))

Select Case www$
    Case "N"
Call d1700
Me.RidgerSBDTextBox.Enabled = False
Me.RidgerSoilShTextBox.Enabled = False
'Me.RidgerDptTextBox.SetFocus
'Call computing3
Exit Sub
```

```
Case "Y"
MsgBox "enter data now"
End Select


End Sub
Sub d1700()
'typical soil data
Me.RidgerSBDTextBox.Value = 1220 'kg/m3
Me.RidgerSoilShTextBox.Value = 30.18
End Sub
Sub d1701()
Me.RidgerSBDTextBox.Value = 1.3
Me.RidgerSoilShTextBox.Value = 50
End Sub
Sub computing3()
SBD = 0
Cutwidth = 0
Speed = 0
SCI = 0
Soilsh = 0
If Me.RidgerDptTextBox.Value = "" Then Dpt = 0 Else Dpt = Me.RidgerDptTextBox.Value
```

```
If Me.RidgerSBDTextBox.Value = "" Then SBD = 0 Else SBD = Me.RidgerSBDTextBox.Value

If Me.RidgerWidthTextBox.Value = "" Then Cutwidth = 0 Else Cutwidth = Me.RidgerWidthTextBox.Value

If Me.RidgerSpeedTextBox.Value = "" Then Speed = 0 Else Speed = Me.RidgerSpeedTextBox.Value

If Me.RidgerSCITextBox.Value = "" Then SCI = 0 Else SCI = Me.RidgerSCITextBox.Value

If Me.RidgerSoilShTextBox.Value = "" Then Soilsh = 0 Else Soilsh = Me.RidgerSoilShTextBox.Value

RidgerEnergy =  6*(Speed^2 * Dpt^2 * SBD* Cutwidth) + 1261.2 * SCI* Speed*Dpt ^2 + 30.93 * Soilsh * Dpt -120.57* Speed ^ 2 * Dpt^3 * SBD

 RidgerEnergyTextBox.Value = Round(RidgerEnergy, 2)

 RidgerDiesel = RidgerEnergy / 36.4

RidgerDiesel.Value = Round(RidgerDiesel, 2)

End Sub

Private Sub RidgerComput_Click()

Dpt = 0

SBD = 0

Cutwidth = 0

Speed = 0

SCI = 0

Soilsh = 0

plough = 0

RidgerDiesel = 0
```

```
If Me.RidgerDptTextBox.Value = "" Then Dpt = 0 Else Dpt = Me.RidgerDptTextBox.Value

If Me.RidgerSBDTextBox.Value = "" Then SBD = 0 Else SBD = Me.RidgerSBDTextBox.Value

If Me.RidgerWidthTextBox.Value = "" Then Cutwidth = 0 Else Cutwidth = Me.RidgerWidthTextBox.Value

If Me.RidgerSpeedTextBox.Value = "" Then Speed = 0 Else Speed = Me.RidgerSpeedTextBox.Value

If Me.RidgerSCITextBox.Value = "" Then SCI = 0 Else SCI = Me.RidgerSCITextBox.Value

If Me.RidgerSoilShTextBox.Value = "" Then Soilsh = 0 Else Soilsh = Me.RidgerSoilShTextBox.Value

RidgerEnergy = 6*(Speed^2 * Dpt^2 * SBD* Cutwidth) + 1261.2 * SCI* Speed*Dpt ^2 + 30.93 * Soilsh * Dpt -120.57* Speed ^ 2 * Dpt^3 * SBD

 RidgerEnergyTextBox.Value = Round(RidgerEnergy, 2)

 plough = Round(RidgerEnergy, 2)

 RidgerDiesel = Round(RidgerEnergy / 36.4, 2)

RidgerDiesel.Value = RidgerDiesel

'RidgerDiesel.Value = Ridgerenergy1

End Sub

Private Sub RidgerExit_Click()

End

End Sub

Private Sub RidgerDptTextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)

Validator RidgerDptTextBox, KeyAscii
```

```
End Sub
Private Sub RidgerSpeedTextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)
Validator RidgerSpeedTextBox, KeyAscii
End Sub
Private Sub RidgerWidthTextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)
Validator RidgerWidthTextBox, KeyAscii
End Sub
Private Sub RidgerSCITextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)
Validator RidgerSCITextBox, KeyAscii
End Sub
Private Sub RidgerSBDTextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)
Validator RidgerSBDTextBox, KeyAscii
End Sub
Private Sub RidgerSoilShTextBox_KeyPress(ByVal KeyAscii As MSForms.ReturnInteger)
Validator RidgerSoilShTextBox, KeyAscii
End Sub
Private Sub Validator(ByRef TB As MSForms.TextBox, ByRef KeyAscii As MSForms.ReturnInteger)
    'Allow keyboard entries of 0-9, one decimal, and one leading minus.
    With TB
        Select Case KeyAscii
```

```
            Case Asc("0") To Asc("9")

            Case Asc("."): If InStr(.Value, ".") Then KeyAscii = 0: Beep

            Case Asc("-"): If Len(.Value) Then KeyAscii = 0: Beep

            Case Else: KeyAscii = 0: Beep

        End Select

    End With

End Sub
```