

**THE OPTIMISATION OF PRIMARY AND SECONDARY
TILLAGE OPERATIONS IN SOUTH-WEST NIGERIA**

BY

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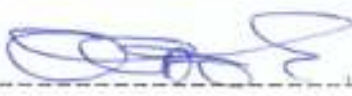
CERTIFICATION

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DEDICATION

"My soul doth magnify the Lord and my spirit hath rejoiced in God my saviour. For He that is mighty hath done me great things and holy is His name". Luke 1: 46-49.

"Now unto the King eternal, immortal, invisible, the only wise God, be honour and glory for ever and ever. Amen.

UNTO THEE, O LORD



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ABSTRACT

The level of tillage mechanisation in south-west Nigeria is low because of the high cost : benefit ratio of tillage machinery. This is due not only to few hours of tractor utilisation per annum, but also due to the low values of field efficiency obtained during tillage operations.

In this study, an investigation into the optimum use of tillage machinery for primary and secondary tillage operations was carried out. The effects of soil type, moisture content, field size, field shape, implement type, implement size and forward speed on tillage costs and tillage effectiveness were investigated. It was found that moisture content in the range of 12 to 18% on sandy loam soil and 14 to 21% on clayey loam soil is optimum for tillage operations in south-west Nigeria. The maximum values of field efficiency obtained during primary and secondary tillage operations were 76.5% and 71% respectively. It was also found that tillage costs per hectare reduces with increase in annual use, forward speed and field efficiency. However, the field efficiency and the cost of production were higher during primary tillage operation than during secondary tillage operation.

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NOMENCLATURE

Symbol	Nomenclature
A_s	Actual travel speed
b	Width of farmland
F	Force
I	Interest
L	Length of farmland
N_h	Number of trips at headland
N_t	Number of tines
n_t	Number of trips on the farmland
P	Power
PP_c	Purchase price of cultivator
PP_p	Purchase price of plough
q, r, s	Cost coefficients
S_o	No load travel speed
T	Total time for turning at the headland
T_t	Turning time per trip
t_t	Theoretical time
V	Forward speed of machine
W	Width of machine.

CHAPTER ONE

1. INTRODUCTION

Feeding is an important part of human living that is compulsory irrespective of age, status, profession or race. The quantity and quality of food taken by an individual determine the rate of his physical and mental developments. Thus, food production from the foregoing is the bedrock of human existence. Agriculture is that branch of science that deals with crop or animal husbandry to meet the urgent but increasing human demand for food.

There are various processes involved in the crop production cycle. These include, land clearing, tillage, planting, crop establishment, harvesting and post harvest operations. Tillage as a process in the production cycle is normally referred to as the mechanical manipulation of the soil to obtain a suitable tilth for plant growth. One of the major objectives of tillage is to create optimum environmental conditions for plant growth. Tillage involves breaking, stirring, turning and conditioning the soil to a certain depth in conformity with the root development of the selected crop.

Conventional tillage operation can be classified as primary, secondary or tertiary tillage operation. The initial breaking up of the soil is generally called primary tillage and subsequent operations carried out to break down clods and prepare the seedbed ready for planting is called secondary and tertiary tillage operations. However, in order to minimise time, cost and energy involved in tillage operations, the concept of minimum tillage and zero tillage has evolved.

The South-Western part of Nigeria, which is the study area, lies between 5° and 7° north of the equator and between 4° and 14° east of the greenwich meridian. The area is located in the tropical rainforest with 1250mm to 2000mm of rainfall per annum. Arable crops such as maize, cowpea, okro, tomatoes, cassava and yam are commonly grown in the area. Conventional tillage is the tillage type adopted in the area. However, manual tillage operation is labour intensive. The drudgery involved in tillage operations has drastically reduced the percentage of the working class involved in crop production. This problem led to the acceptance and adoption of tillage mechanisation as a means of increasing food production in the study area.

Agricultural machines are costly to purchase and to operate. Thus the quantity of these machines available for crop production operations is highly limited. These resources must of necessity be put to optimum use.

The unique problem in developing countries is either under-utilisation or over-utilisation of tillage machinery. Under-utilisation results in a poor return on investment and an overall waste of resources while over-utilisation results in poor performance of the machine and reduction in its life-span. Under-utilisation is caused by low annual usage of tillage machinery. Both under-utilisation and over-utilisation may be due to improper selection of crop combination as it disallows the even spread of machinery use throughout the year. This fluctuation in the annual use of tillage machinery can be minimised by optimising primary and secondary tillage operations.

There are various mathematical methods of obtaining an optimal solution to any engineering problem. However, optimisation broadly means the act of obtaining the best result under given circumstances. It is either the minimisation of the effort required or the maximisation of the desired benefits.

Tillage operation is the greatest power consuming process in the crop production cycle and could amount to about 50% of the cost of production. Optimising tillage will lead to a notable reduction in the cost of production, thus encouraging agricultural mechanisation. Tillage optimisation does not only lead to reduction in tillage costs but also influences increase in crop yield and overall increase in food production.

The consideration of some soil, implement and operational parameters is essential in optimising tillage operations. The soil parameters include, soil type, moisture content, soil compaction and soil pulverization. The implement parameters include, implement type, implement size and shape, while forward speed, operating depth and rake angle are the operational parameters.

In this study the effects of soil parameters, such as soil type, moisture content, implement parameters such as implement type, implement size, operational parameters such as forward speed, on field efficiency and tillage costs were studied. These parameters were evaluated by carrying out primary and secondary tillage operations on the farm and studying the soil-implement interactions as it affects tillage costs. The data obtained were used to determine the optimum values of tillage parameters and to estimate the cost of tillage operations.

Therefore, the objectives of this study are as follows:

1. Evaluation of the present level of tillage mechanisation.
2. Evaluation of the present use of tillage machinery.
3. To show the effect of various soil, implement and operational parameters on field efficiency and the over-all effectiveness of tillage operations.
4. To determine the optimum values of soil and implement parameters for effective tillage operations.
5. Minimisation of the fluctuation in the use of tillage machinery.
6. Determination of the cost of tillage operations at various soil, implement and operational parameters.
7. To recommend the optimal use of tillage machinery.
8. And to present a data concerning the optimal use of these machines to farm managers for effective farm mechanisation planning.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 AGRICULTURAL MECHANISATION

2.1.1 The need for mechanisation

Agricultural mechanisation may be defined in various ways. To some it is synonymous with tractorization, while others take it to imply increase in production per worker and per hectare of farmland cultivated. Ademosun (1986) defined agricultural mechanisation as the utilisation, selection, operation and maintenance of mechanical devices and systems in agricultural production.

Modern farming involves the use of several inputs to the production cycle. These include seeds, irrigation water, fertilizer, herbicides and farm equipment. A successful farmer utilises these inputs to maximise production at minimum cost while maintaining the desired quality. Farm equipment does not themselves multiply production but act as a device to ensure that other inputs give the desired results. Thus it may be inferred that farm equipment and the techniques associated with their use constitute the field of agricultural mechanisation.

According to Ademosun (1986), the objectives of mechanisation include:

Reduction of human drudgery.

Improvement of timeliness in agricultural production.

Improvement in the efficiency of farm operations.

Increasing agricultural productivity.

Improvement and preservation of the quality of agricultural products.

Achievement of better utilisation of natural resources.

Increasing food varieties.

Reduction in human labour inputs in agriculture for use in other industries.

Increasing the supply of raw materials for industrial use.

Controlling the price ~~and~~ supply of food items.

Improving the living standards of rural dwellers.

Farm mechanisation attempts to provide machines to perform several operations of the production cycle as shown in Figure 1 below. However, research efforts are being made to improve the efficiency of machines for each operation of the production cycle at different levels.

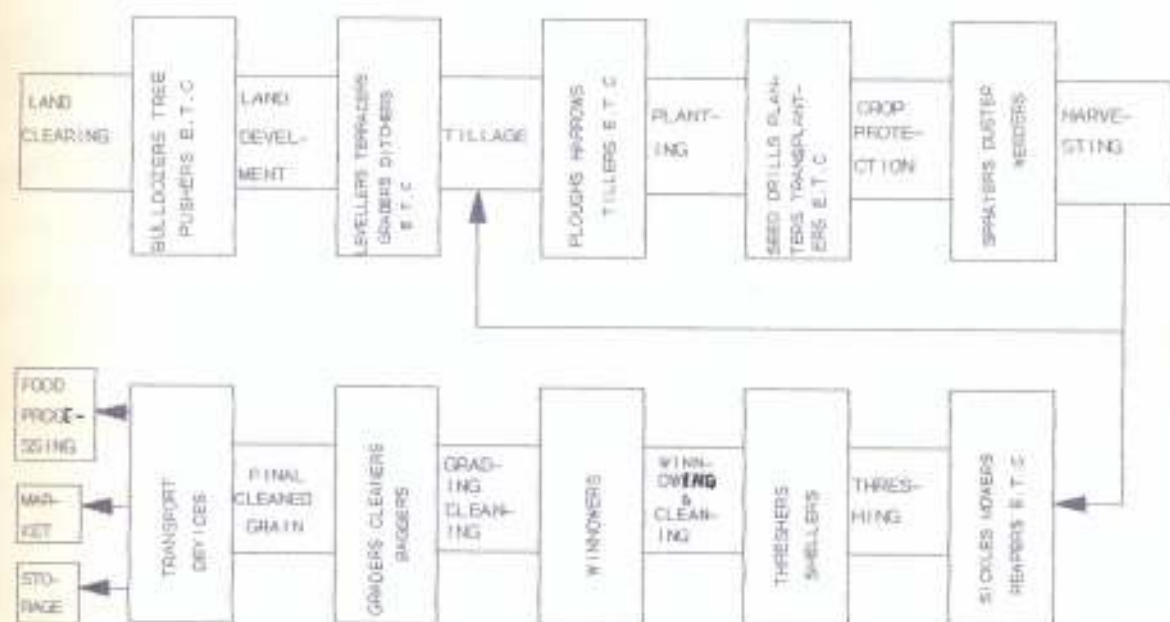


Fig. 1: TYPICAL CROP PRODUCTION OPERATIONS SHOWING THE EQUIPMENT INVOLVED IN EACH STAGE.

Adapted from - Macmillan Intermediate Agricultural Series Introduction to Agricultural Mechanisation; Kaul and Egbo (1991)

2.1.2 Problems of Mechanisation

Culpin (1975) describe the mechanisation of agriculture as a progressive development of steadily increasing scope and importance. However, there is a widening gap between the level of mechanisation in the developed countries and the developing countries. Thus the type of machines available and useable for agricultural production vary widely from place to place. There are two extremes, in that equipment ranges from the manually powered hoe to the more sophisticated combine and from loads carried on the head to loads carried by modern farm trucks and trailers.

In developing countries, human power still predominates even though it could be substituted by animal power or mechanical power. Kaul and Egbo (1989) blamed this on lack of technical personnel, good exposure and non-availability of capital for investment.

Agricultural mechanisation is faced with numerous problems in developing countries. Some of the general ones include:

High cost of machines: Agricultural machines are rather very costly especially the tractor and is almost unaffordable for individual farmers. Thus farmers have to resort to other crude methods or hiring of machines. The high cost of machines could be traced to poor value of the naira. The tractor and many of its accessories are still imported, this also leads to increase in price. As a result of these problems, selective mechanisation of a few operations of the production cycle had been adopted.

Low annual usage of farm equipment: Developing countries (e.g. Nigeria) are blessed with good land and natural resources, but improper planning hinders sufficient tapping of these resources.

This leads to low annual requirement for use of agricultural machinery. The cumulative effect is a high cost of production, which makes the product of a farm compete unfavourably with products from other farms. With good planning however, machinery could be increased appreciably.

Requirement of skilled labour for farm operation and Management: The efficient output required from farm machines can not be compromised. Availability of skilled labour is the only guarantee for efficient output in agricultural machines. This is not easily available. The overall result is an unwanted increase in non-productive operating time.

Change in farming systems: Agricultural mechanisation more often than not desires some legitimate changes which must be made by farmers. This may include, adoption of a completely new farming method or improved hybrid of seeds. Farmers in developing countries find it difficult to easily adjust to this compulsory but necessary changes.

Difficulty in obtaining spare parts: Agricultural mechanisation (apart from the problem of getting imported spare parts) is also faced with the problem of adapting imported machines to local conditions. At times imported machines do not fit at all into local use, even when it could be used, it is prone to constant damage or malfunctioning.

Lack of access roads to farms: Good roads are concentrated in urban areas. The roads where agricultural machines are used are either bad or not available at all. This hinders smooth progress of agricultural mechanisation. It also makes it difficult for

engineers and/or extension workers to extend innovations to farmers.

Increase in population: Agricultural mechanisation in developing countries is challenged by the rapidly increasing population of the developing countries, the population in West Africa is growing at a geometrical rate. Mechanisation should therefore be made to promote self reliance in food production.

These problems can be eliminated or drastically reduced by finding lasting solutions from all quarters of governance. A better policy on agricultural loan to farmers will definitely be a step in the right direction.

Land management and ownership should also be improved to turn the vast expanse of agricultural land into profitable use. Hitherto, the major part of agricultural land are uncultivated, due to low level of mechanisation and poor financial stand of intending farmers. A government project (aimed at cultivating the land (tillage) and a few other operations done before leasing the portion of land out to farmers for that season) will reduce the human drudgery and increase the amount of agricultural land cultivated annually.

A complete re-orientation of interest in the Nigerian youths including the university graduates to embrace farming rather than the less profitable white collar jobs will be a step in the right direction. In other words, productivity not only in the agricultural sector, but in all areas of human endeavour, should be introduced into the way and manner of life of all Nigerians.

The nation as a whole must reconsider her priority and put agricultural mechanisation in its right place. We cannot go back any longer to the cutlass and hoe, implements for agricultural

production. Some simple indigenous machines developed in the university(ies) must be produced for mass distribution to bail us out of the present predicament.

The way forward is to increase and improve agricultural production through efficient and affordable agricultural mechanisation.

2.1.3 Appropriate mechanised farming

Mechanisation is a crucial factor that fosters productivity in the food, fibre and forestry sector. However, there exist different levels of mechanisation round the globe. This is largely due to the different levels of development across the globe. Agricultural engineers and other research workers concerned with improved and increased agricultural production have therefore advocated for appropriate mechanised farming. This is aimed at providing different solutions at each locality to meet the pressing need for mechanisation.

Appropriate mechanisation involves developing agricultural machines and implements in the simplest way possible and with the least feasible price to meet the urgent need for increased food production. In other words, faced with the problems mentioned in 2.1.2, appropriate mechanised farming attempts to use the little resources available to provide and utilise mechanical devices and systems to alleviate human drudgery and increase food production.

A good consideration and implementation of this concept will definitely pave the way forward for increased agricultural productivity. The history of the development in agricultural

mechanisation in the developed countries shows a notable trend of appropriate level of mechanisation at each stage. This should therefore be copied by the developing countries, such that we do not fold our arms until we are able to afford the very costly agricultural equipment.

Appropriate level of mechanisation also calls for the design, fabrication and utilisation of suitable indigenous machines to cope with the problems of a locality which may not be found elsewhere. It has been discovered that many imported machines are not adaptable to local conditions.

Experience in south-east Asia indicates that mechanisation of tropical agriculture with small machines can raise food production and raise farmers' living standards considerably. In northern Nigeria, light mould-board ploughs are still being successfully drawn by work bulls. This and other forms of appropriate mechanisation when adopted will help promote increased food production. Khan et al (1987) studied the effect of small scale mechanisation on rice farms in the Philipines and reported that there was an appreciable increase in output of all farming operations. Agbetoye (1986) also explained the need for appropriate levels of mechanisation to meet the compulsory but immediate need for increased food production. From the analysis of the catalogue of machines designed and fabricated in Nigerian universities, the need for appropriate levels of mechanisation is stressed to alleviate the problems of mechanisation in our locality.

2.2 TYPES OF TILLAGE OPERATIONS

Odigboh (1991) defined tillage as the operation of tilling the land, involving the mechanical manipulation of soil for any purpose, especially that of changing the soil conditions for crop production. In general tillage has been defined as the mechanical practice of modifying the state of the soil in order to provide conditions favourable to plant growth. It involves breaking, stirring, turning or conditioning the soil surface to create optimum environmental conditions for plant growth. Some of the objectives of tillage as presented by Kepner et al (1978) are:

Development of desirable soil structure for a seedbed or rootbed. This is done to allow rapid infiltration and good retention of rainfall, to provide adequate air capacity and exchange within the soil and to minimize resistance to root penetration.

Tillage is also done to control weeds and to remove unwanted crops (thinning).

Management of plant residues. Thorough mixing of trash is desirable for good tilth and decomposition, however trash present in the top layer prevents erosion but obstructs precision operations such as planting and drilling.

Reduction of soil erosion. Tillage is also done to reduce soil erosion by following such practices as contour tillage, listing and proper placement of trash.

Incorporation and mixing of fertilizers and soil amendments or pesticides into the soil. Segregation is also accomplished during tillage operations. This is done by moving soil from one layer to another, removal of rocks and other foreign objects.

According to Odigboh (1991), tillage can be classified into the following:

2.2.1 Primary Tillage

This is the initial major soil working operation normally designed to reduce soil strength, cover plant residues and re-arrange soil aggregates. It cuts and shatters the soil with relatively deep penetrating tools, leaving a rough surface texture. Depending on the operation, penetration may be from 152mm to 762mm. Planting may follow primary tillage due to individual farmer's choice which might be based on economic considerations and nature of crop or soil.

2.2.2 Secondary Tillage

Secondary tillage is any of a group of different operations following primary tillage which are designed to create refined soil conditions and provide desired soil tilth before the seed is planted. It is used to pulverize, level and firm the soil in order to prepare a good seed bed and to control weeds and conserve moisture. Secondary tillage normally works the soil to a shallower depth about 51mm to 152mm.

2.2.3 Tertiary Tillage

This may be necessary in some cases where further pulverization is desirable, especially when crops with tiny seeds like amaranthus are planted. It refers to any tillage operation performed after secondary tillage for the purpose of further pulverization.

2.2.4 Conventional Tillage

This is a common tillage system which involves the combination of primary and secondary tillage operations in a consecutive manner

for a particular area of land. This involves ploughing the field first and then harrowing and packing the soil.

2.2.5 Minimum Tillage

This is a tillage system involving the minimum soil manipulation necessary for crop production or necessary for meeting tillage requirements under specific soil conditions.

2.2.6 Mulch Tillage

Mulch tillage is that system of tillage or technique of soil preparation done in such a way that plant residues or other mulching materials are purposely and specifically left on or near the soil surface for reasons of moisture conservation or erosion control.

2.2.7 Listing

Listing is a land forming tillage operation using a tool which splits the soil and turns two furrows laterally in opposite directions thereby providing a ridge and furrow soil configuration required in lister planting.

2.2.8 Deep Tillage

This is the system of primary tillage which manipulates the soil to a greater depth than normal ploughing. This is accomplished with heavy-duty mould board or disc ploughs which invert the soil or with chisel ploughs or subsoilers which shatter the soil.

2.2.9 Strip Tillage

This is the system of tillage in which only well delineated bands of soil along the plant rows are tilled, in contrast to the more common system of broadcast tillage where the entire area is covered.

2.2.10 Zero Tillage

Zero tillage refers to the system of the so called no-tillage planting whereby seeds are sown directly into an essentially untilled seedbed. The entire field is not ploughed or disked, leaving surface plant residues standing. Lime is not incorporated into the soil and the only fertilizer incorporated is by banding it during planting.

Reduced tillage practices are becoming more frequently employed because they result in less compaction, lower fuel costs, reduced erosion losses and less time spent cultivating. Experiments to find the minimum amount of tillage for maximum yields have been done in various places. An example is the tillage study carried out at the International Institute of Tropical Agriculture (IITA) in Ibadan and presented in table 1.

Table 1: Tillage and Crop Yield for various Tillage Method

Tillage method	Yield of cowpea kg/ha
Ploughed and ridged	1185
Ploughed flat seeded	1273
Strip tillage	1538
Zero tillage	1649

2.3 EFFECTS OF TILLAGE OPERATIONS

2.3.1 Effect on plant growth

For optimum germination and growth the soil must optimally supply water, oxygen, nutrients and heat; additionally the soil must be loose enough to allow root penetration and seedling emergence through the soil surface. Soil tillage helps to improve looseness, oxygen supplies and water intake, among other things.

Tillage to prepare seedbed is most needed when planting small and/or high cost seed like (lettuce, tomatoes, sugar beets). It is less critical for vigorous large-seeded plants (corn, small grains, soybean, dry beans and sorghum). According to Donahue et al (1990), when the planting and working of soil are done in a moist soil rather than in dryer soil followed by wetting, emergence of seedling is usually easier.

Once crop seeds germinate, weed control is essential because weeds compete with the crop for water, nutrients and light. Until herbicides became available, tillage for weed control was an integral part of crop production. Tillage for weed control is still effective, although crop rotation has been identified as a solution to weed control. However, Parochetti (1980) has suggested tillage rotation (deep and shallow alternate tillage) as an improvement in management.

2.3.2 Effect on soil tilth

Tilth is the term for the physical condition of a tilled soil, including its moisture condition. Coarse-textured soils usually have a good physical condition but too small a capacity for supplying enough water and plant nutrients. Fine textured

soils normally have a satisfactory nutrient and water reserve but often contain too little air because the soil particles are packed closely together. Tillage has little impact on coarse soils but it has a profound positive impact on fine textured soils. According to Donahue et al (1990) tillage temporarily aerates the soil and controls weeds, but year by year it destroys desirable soil structure and eventually reduces aeration.

The loss of organic matter is intimately related to loss of soil structure. To maintain good structure or improve poor structure by addition of organic matter, a permanent cover of mixed perennial grasses and legumes is probably the best vegetation. In contrast, continuous tillage seems to be the worst land use practice for maintaining desirable structure.

2.3.3 Effects on soil water

Tillage destroys soil crust, loosens the soil and generally increases water intake when water is next applied after tillage; but tillage should be minimal and the land kept as rough as possible (feasible) to still have good seedling emergence and establishment. Crop residues help to keep cultivated soil porous. Burwell et al (1968) explained that infiltration increases drastically with increased degree of pulverization.

The higher water storage in the root zone resulting from deep tillage permits irrigation before planting and fewer irrigations during crop growth. It has been discovered that much water will be available for crop use if a fallow year precedes each cropped year on a piece of land. Table 2 shows the amount of water available for use in cropped year from each fallow year.

Table 2: The increase in amount of water carried over into the cropped year

Location and Years	Straw much left on soil kg/ha	Soil water increase mm	Total annual precipitation mm
Sidney, Montana	0	60	315
4 years average	1681	72	
	3362	87	
	6724	98	
Akron, Colorado	1681	152	412
5 years average	3362	170	
	6724	192	
North Plate, Nebraska	0	162	
7 years average	3362	205	
	6724	232	

Source: Selected data from Greb *et al* (1970)
 "Water conservation with stubble mulch fallow"



2.4 FIELD PATTERNS

2.4.1 Fieldwork Patterns

Field pattern is one of the factors affecting the field efficiency of tillage operations. Although pattern considerations can be studied differently, it is closely related to the size and shape of the field.

According to Hunt (1974), the primary objective in establishing an efficient field pattern is to minimize the amount of field travel. An efficient field pattern therefore should reduce all non-productive users of valuable time to the bearest minimum.

Agriculturists may have other objectives other than time minimization which modify the choice of field pattern. The nature of the field whether flat, slopy or undulating affects the choice of a field pattern. Other managerial decisions which are affected by field patterns include efficient planting and harvesting patterns. These decisions are taken by evaluating which practice takes precedence over the other. Tillage however, requires both soil and time conservation, thus an optimum balance is required between soil conservation and time conservation.

The following terminologies are commonly used in relation to field patterns:-

A round refers to the travel of the machine across or around a field from a selected starting point to a point adjacent to the first. A trip is half a round.

Operating in lands describes the practice of dividing the field into subareas and operating on these subareas individually.

Turn strips refer to unprocessed areas that provide room for making turns. The turn strips at the end of a field are called headland.

Headland pattern has strips that parallel each other and allows turns at 180° over the headland.

Circuitous pattern describes the operation where the implement operation parallels each of the lands boundaries and is commonly referred to as going round the field.

Alternation pattern is sometimes used in processing row established row-crops. The trips are not adjacent to provide a turn that is easy to negotiate.

Figure 2 illustrates the common patterns for straight-sided fields.

Field patterns cannot be completely analysed without considering the turning radius of implements. Turning radius affects the time loss in end travel and at corners. Although, turning radius is not generally specified by manufacturers, the manoeuvring ability of a machine ought not to be overlooked as an important factor in field efficiency.

2.4.2 Pattern Comparison

According to Witney (1988), the most important choice of field patterns is for ploughing using conventional plough which only throws the furrows to the right.

For conventional ploughing, the field is set out in lands (Figure 2).

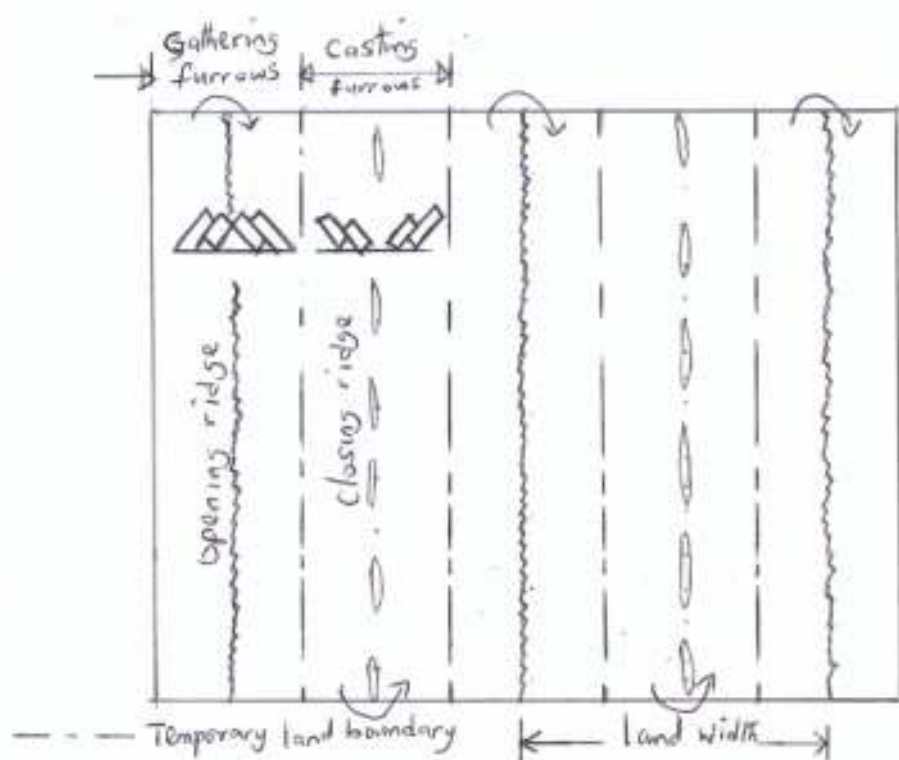


Figure 2: Ploughing in lands to minimise idle running time.

An opening ridge is formed at the centre line of the first and subsequent half lands. By ploughing along both sides of these opening ridges in a clockwise direction, the furrows are gathered, or lean towards, the mid line until half the land is completed. The intervening half lands are ploughed in the opposite direction to cast the furrows and leave an open furrow equidistant between each pair of open ridges. Either gathering or casting too large an area gives excessive wasted time in headland travel.

The common ploughing problem encountered with headland pattern is how to lay out the most efficient number of lands. If the lands are made too small, excessive time is used to finish the numerous dead furrows. Culpin (1981) gave the width of the headland for an outfit of medium size to be about 7.3m.

Circuitous pattern appears to be the most effective of the three field patterns. However, turning radius and missed crescent areas are typical problems associated with this pattern. Tillage patterns that require the least turning time obviously exhibit higher field efficiency. Hunt (1974) and Witney (1988) favoured headland pattern for tillage operations. Table 3 shows the different types of ploughing pattern and its corresponding pattern efficiency.

Table 3 : Pattern Comparisons

Ploughing pattern Comparisons		Rectangular Fields
Pattern	Comments	Pattern efficiency %
Headlands	28 acres $n = 7$ (optimum)	95.8%
Continuos	28 acres $t = 10$ secs	95.2%
Circuitous diagonal turn strips	$s = 9m$ $s =$ width of turn strips	94.4%
Circuitous rounded-corners	90° corners $r_o = 3m$ $r = 6m$	92.3%
Circuitous 270° turn	$r_o = 3m$	91.4%

(Adapted from Hunt, 1974)

The headland pattern produces the highest efficiency especially for ploughing operation. Tillage implements, other than ploughs make good use of rounded corner, circuitous pattern, if their turning radii are not greater than the effective width of the implement. The extra pass problem occuring in circuitous pattern could be replaced with diagonal finishing trips. The rounded corner, circuitous pattern when used for planting yields a pattern efficiency of 100%, but the effective area of the field is reduced by the missed crescent shaped area. The alternation pattern efficiency can surpass other types of headland pattern, when the easier turn permitted by processing alternate set of rows result

in less time for turning.

The number of lands in a given field is not only dependent on the tillage efficiency but also depend on the time required to exhaust the grain in the hopper during planting. This in turn reduces the time loss due to refilling. A reasonable compromise should be reached between these extremes to optimise the number of lands during tillage operations.

2.5 TILLAGE IMPLEMENTS

According to tillage operations, implements are classified as primary tillage implements and secondary tillage implements (Figure 5)

2.5.1 Primary Tillage Implements

Ploughs

The mould-board plough and the disc plough are the implement generally used for primary tillage. Ploughing is often the most important operation of the arable farmer, not only because of its basic nature but also from the stand point of power requirement.

Mould-Board Plough

There are two main groups of mould-board ploughs

1. One-way ploughs: This group throws the soil in only one direction, usually to the right (when viewed from behind). The associated problem here is sunken pots and dead furrows.
2. Two-way plough: These have the bottoms so arranged that the right turning buttons can be quickly and readily replaced with a set that turns the soil to the left. With two-way ploughs, there are no dead furrows, no uneven or sunken pots. (Stone and Gulvin, 1977).

Plough components

Plough body refers to the complete assembly of working components for a single furrow. We have different plough body shapes as there are manufacturers. Examples of the different shapes are shown below:

Plough bottom: Essentially a mould board plough bottom is a three sided wedge with the land side and the horizontal plane of the share's cutting edge acting as flat sides and the top of the shear and the mould-board together acting as a curved side. The primary function of the plough bottom are to cut the furrow slice, shatter the soil and invert the furrow slice to cover the trash. The size of the mould-board plough bottom is the width of furrow it is designed to cut. Examples of mould-board plough bottom are shown below:

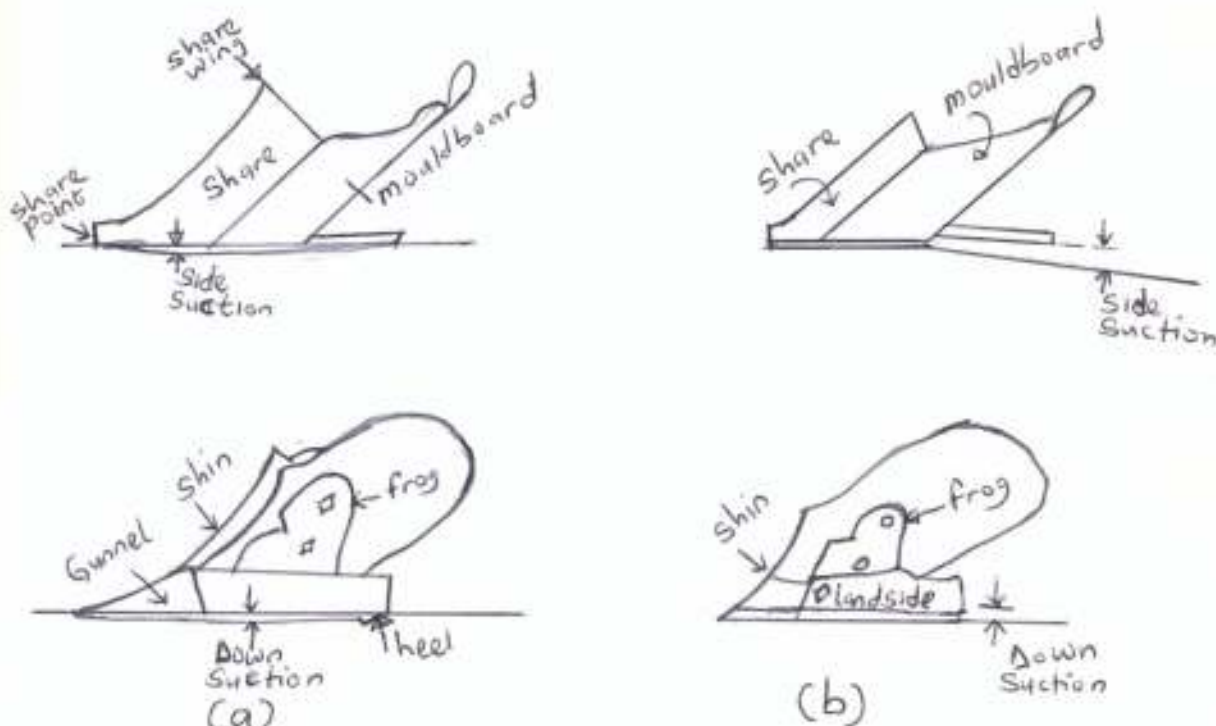


Figure 3: Typical mould-board plough bottoms

- (a) With gunnel-type share, showing method of measuring suction when no rear furrow wheel or depth control devices are used
- (b) With throw-away share, indicating clearances when a rear furrow wheel is used.

Shares: For many years most ploughs had shares of the type shown in (a) above. This type of share has a vertical portion, known as gunnel that acts as a forward extension of the land-side. This type of shares are removed and sharpened by forging when they become worn or dull. Practically all ploughs now manufactured have throw-away shares of the general type shown in (b) above. (Kepner et al, 1978). The throw-away type is about 1/3 the cost of the gunnel type and can therefore be economically replaced when worn. The share is the first part of the plough to enter the soil and cut a furrow slice. The cut soil is lifted upwards to the mould board where it is inverted by the curvature of this component.

The landside assists in making a neat furrow. It presses against the furrow wall, absorbing the side-ways thrust of the plough. It may have a detachable heel.

The FROG is the component that joins the share, mould-board and landside.

The STANDARD provides the connection between the plough and the source of power (tractors or animals).

Handles are provided on animal drawn ploughs for guidance by operators (Kaul and Egbo, 1989). These main components are shown in the figure below.

Plough body:

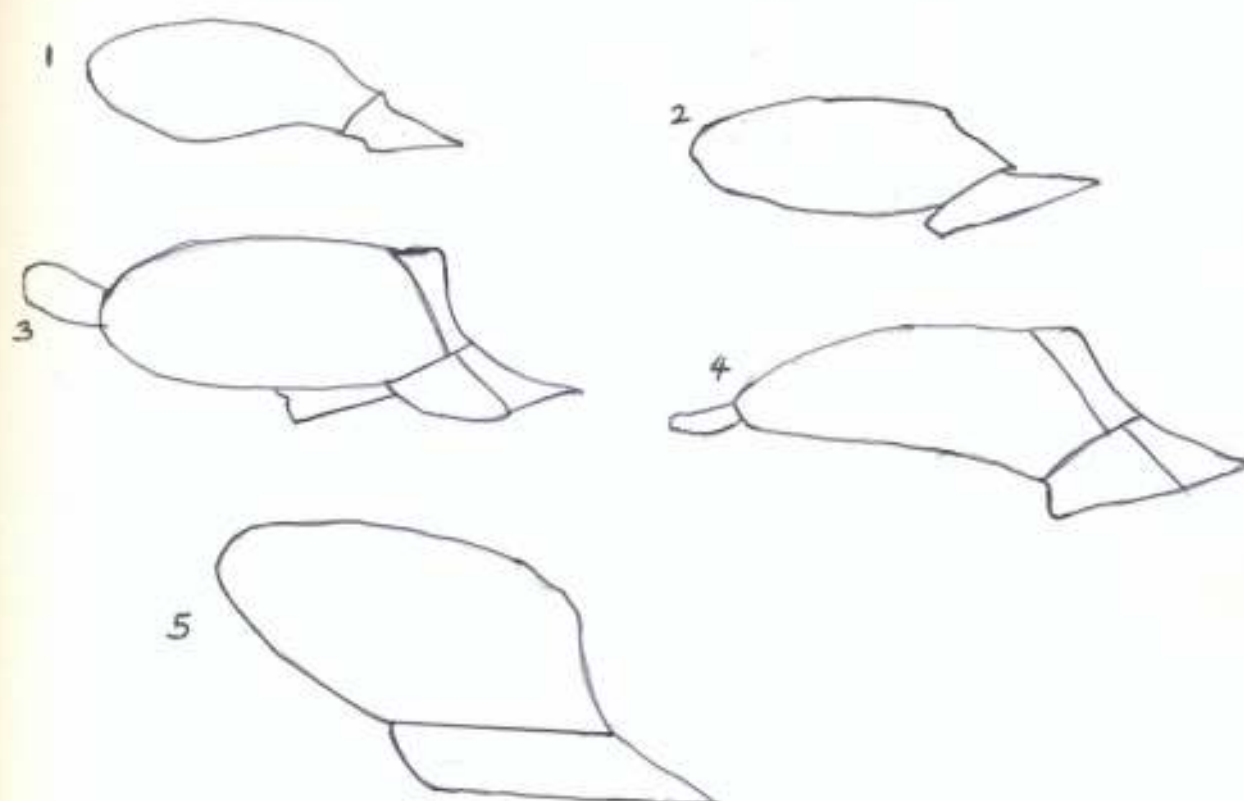


Figure 4: Typical plough body shapes

- 1 General purpose
- 2 Semi-digger
- 3 General purpose high speed type
- 4 Semi-digger high speed type
- 5 Deep digger.

'General purpose' implies a body suitable for unbroken shallow work (up to about 200mm deep).

'Semi-digger' implies suitability for partly broken medium-depth work (up to about 250mm deep).

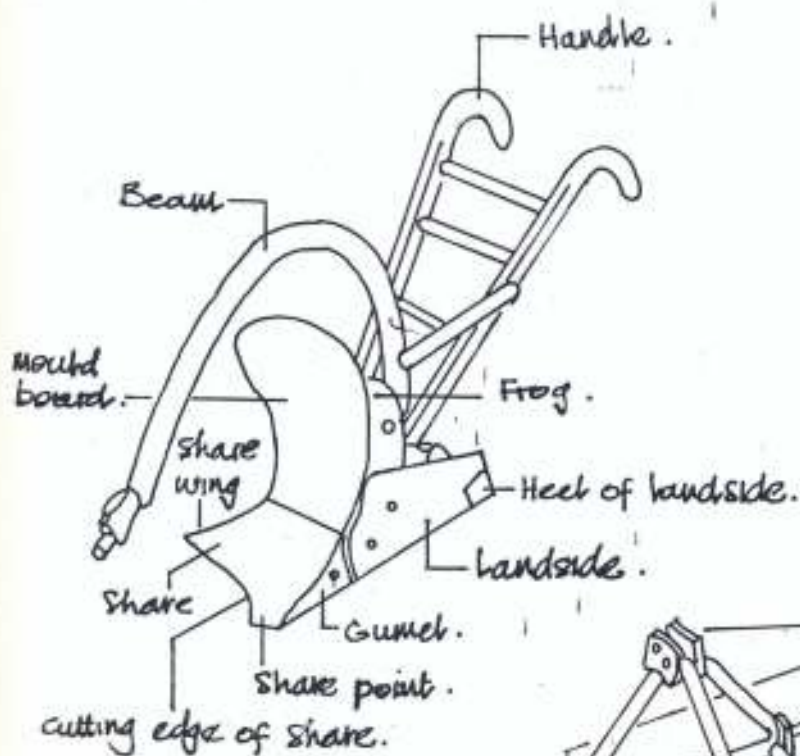
'Digger' indicates ability to produce broken work at a depth up to about 300mm.

Materials for mould-boards and shares. Wear resistance in abrasive soils and scouring in sticky soils such as clays and clay loams are two important problems that influence the choice of materials for plough bottoms. Mould-boards are usually made from soft-centre steel, with outer layers being high-carbon steel (0.9 to 1.05% carbon) and the centre layer being low carbon steel (0.08 to 0.13 carbon). Shares are generally made from solid steel C-1095 and hardened by heat treating to provide wear resistance. For extremely abrasive conditions, as in sandy soils, shares and replaceable slims are made from chilled cast iron.

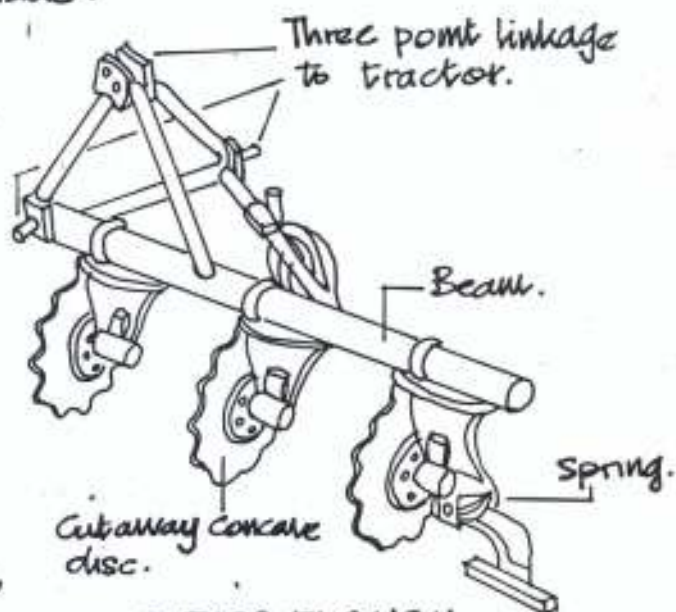
Attachment for mould-board ploughs. Rolling coulters are employed to help cut the furrow slice and to cut through the trash that might otherwise collect on the shin or beam and cause clogging (Figure. 5). Plain coulters are used in sod or relatively clean fields, notched coulters and ripple-edge coulters work well in heavy trash. (Kepner et al, 1978). Disc jointers, which are concave discs set at an angle to the direction of travel are sometimes used in place of the coulter. Mould board extensions, weed hooks to fold tall plant over just in front of the plough bottom, and various other devices are sometimes employed to improve trash coverage.

Disc Ploughs

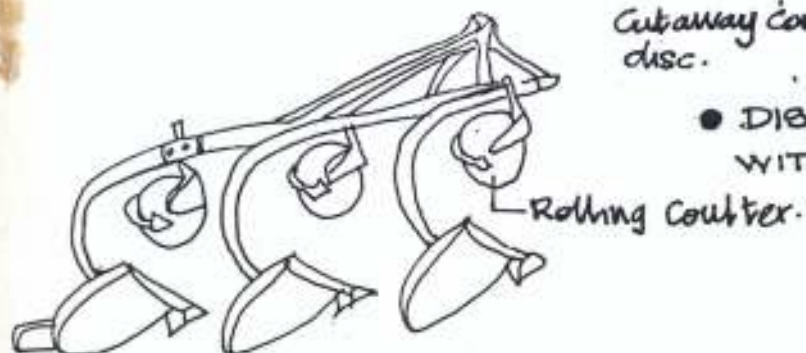
The two main types of disc ploughs are the standard and the vertical. The standard disc plough has one or more disc blades, each with its own bearings and each slanted at an angle to the vertical, and in some designs the discs can be adjusted to suit different soil conditions.



● ANIMAL DRAWN MOULDBOARD PLOUGH.



● DISC PLOUGH WITH SERRATED EDGES.

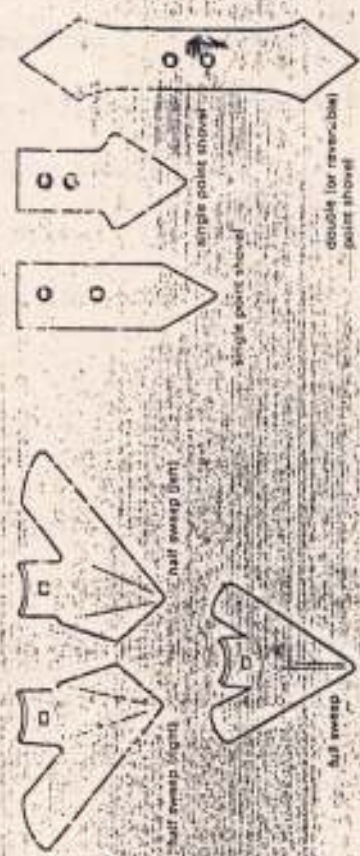


● TRACTOR DRAWN MOULDBOARD PLOUGH.

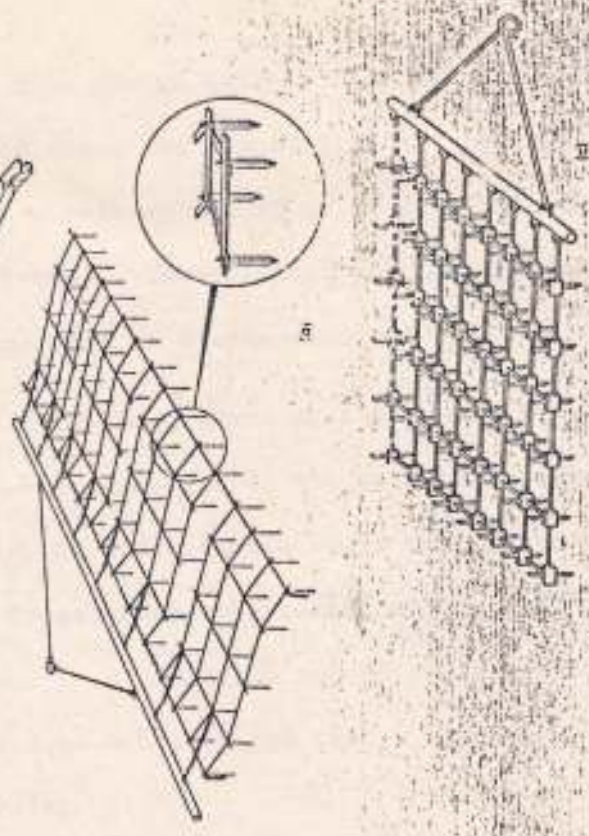
FIGURE 5: PRIMARY TILLAGE IMPLEMENTS.



Spring-tine cultivator



Different types of shovel and sweeps for cultivators



Three main types of harrow. (a) disc harrow, with emission gangs folded; (b) spike-tooth harrow; and (c) chain harrow

SECONDARY TILLAGE IMPLEMENTS

The vertical disc plough differs from the standard disc plough in that a series of discs are spaced at fixed distance apart on a common axle. They rotate as a unit at an angle of 35-50 degrees from the line of travel. The vertical disc plough is also known as disc tillers and will be discussed later. (Stone and Gulvin, 1977).

The standard disc ploughs are most suitable for conditions under which mould-board ploughs do not work satisfactorily, such as in hard, dry soils, in sticky soils where mould-board plough will not scour and in loose, push-type soils such as peat lands. A mould-board plough, in soils and moisture conditions where it works properly does a better job than a disc plough and has a lower specific draft.

The basic component of this plough type is the discs of a certain diameter and curvature. The disc(s) is mounted on a frame. Standard disc ploughs usually have from 3 to 6 disc blades, spaced to cut 18 to 30 cm per disc. The discs are tilted at angles relative to two different axes. One tilth is in relation to the vertical and is called the tilth angle. The other angle of tilth lies between the disc face and the direction of travel and is called disc angle.

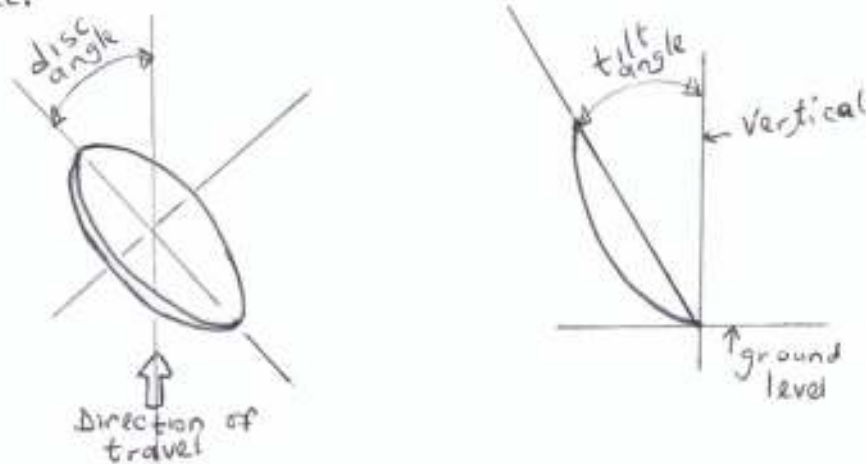


Figure 6: Disc angles

The tilt angle is usually of the order of 15° to 25° , and the disc angle of the order of 42° to 45° . Disc angle can influence the width of cut but a greater pull will be required if the angle is too great. Tilt angle affects the penetration of the plough or the depth of cut. Penetration is greatest when the tilt angle is closest to the vertical, that is, the greater the tilt angle the greater the depth of cut. (Kaul and Egbo, 1989). Disc diameters are commonly 61 - 71cm. Reversible disc ploughs have an arrangement whereby the disc angle can be reversed at each end of the field to permit one way ploughing.

Under most conditions, and particularly in hard, dry soils any disc tool must be forced into the ground by the effect of gravity upon its mass, rather than depending upon suction as does the mould-board plough. Consequently standard disc ploughs are built with heavy frames and wheels (total weight of 180 to 540kg per disc blade) and at times additional mass must be added. (Kepner et al, 1978).

The disc plough is, in a sense, just one or more rolling cutters. The soil and trash are cut and moved with a rolling action. Used alone without scrapers, the discs produce a mixing action rather than inversion. If scrapers are used, the plough will turn the soil some what like the regular mould-board plough but not so well. Maintenance cost is low. There are no shares to replace or resharpen. Plough discs last for years, but shares may last only a few days or weeks. Disc blades can be sharpened by grinding or forging the inside edge. (Stone and Gulvin, 1977)

2.5.2 Secondary Tillage Implements

Harrows

Harrows are examples of secondary tillage implements which can be employed for great variety of purposes such as the preparation of seed beds, the covering of seeds, the destruction of weeds, and the aeration of pastures.

There are four main types of harrows:-

1. Disc Harrow
2. Spike-Tooth Harrow
3. Spring-Tooth Harrow
4. Chain Harrow.

Disc Harrow

The basic component of the disc harrow is a disc having a given diameter and curvature. A number of these discs are mounted on an axle to constitute a 'gang' and several gangs may be mounted together to make a disc harrow. Some gangs arrangement are shown below.

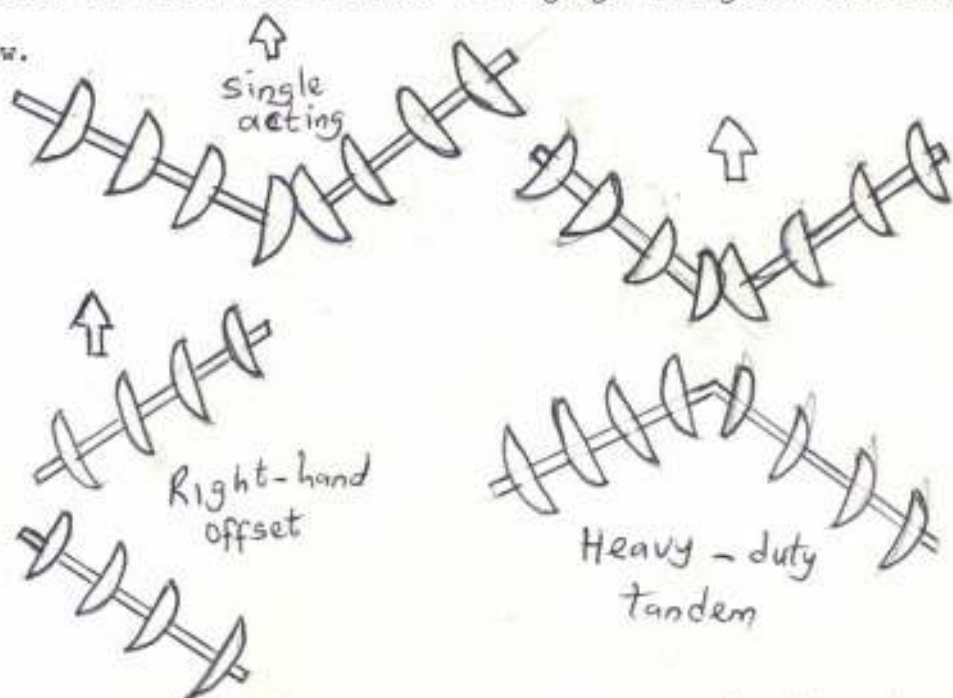


Figure 7: Gang arrangement in disc harrow
↑ represent direction of travel.

Blades on disc harrows are concave, usually representing sections of hollow spheres. The action of a concave disc is somewhat similar to the action of a mould-board plough in that the soil is lifted, pulverized, partially inverted and displaced to one side. Disc harrows have opposing gangs that move the soil in opposite directions.

Unlike the disc plough, the angle of the individual discs on the disc harrow is fixed, but the angle of the gang may be set in relation to the direction of travel. The greater the angle set, the greater the degree of pulverization of the soil.

Types of Disc Harrows

There are two main types

- (1) The regular - which comprises of the single-action-disc and the tandem disc harrow.
- (2) The offset.

The single action disc harrow usually consist of two gangs. A gang is an assembly of discs all rotating together with a common shaft or bolt through their centres. The two opposed gangs of disc blades both throwing soil outward from the centre of the tilled strip. This type is seldom used except when ridges or raised beds are to be split out.

The tandem harrow is the two-section type of disc harrow, with section trailing behind another. This is also called a double action harrow because the rear sections throw the soil back toward the centre as a second operation, thus tilling the soil

twice and leaving the field more nearly level, but with unfilled furrows along both sides of each pass.

Table 4: Typical sizes and masses of disc harrow

Type	Blade Diameter cm	Blade Spacing cm	Available widths m	Mass per unit of width kg/m
Tandem mounted	41,46,51,56	18-23	1.5-4.0	150-270
Tandem, wheel type light duty	46,51,56	18-24	2.4-6.4	270-370
Medium duty	46,51,56	19-24	3.4-9.5	370-480
Heavy duty	56,61,66	23-28	3.4-13.7	480-700
Offset, pull-type with wheels	56,61,66,71	23-28	2.1-7.3	400-750
No wheels	61,66,71	23-28	2.7-9.1	390-650

(Adapted from Principles of Farm Machinery, Kepner et al, 1978)

Spike-Tooth Harrow

This unit consist basically of a peg or spike, several of which are fixed on to a bar and mounted on a frame. The spike angle in relation to forward travel, is usually adjustable and can be set to achieve the required amount of soil breakdown.

The two main types are the rigid and the flexible harrow. The rigid harrow section has one piece end rails holding the tooth bars which make all the teeth cut the same depth. The

flexible harrow has jointed end rails which permit individual tooth bars to be raised vertically to go over obstructions. This type can be rolled up like a rug for transport or storage. The gangs of the first section throw the soil outward to the left and to the right. The rear section discs cut in half the ridges made by the front discs and turn the earth toward the middle - a push-pull action that works the soil twice.

An offset disc harrow has two gangs of discs. One gang is located behind the other. It is like one-half of a tandem harrow; but the gangs are connected differently. The offset harrow leaves the soil levelled. The furrow left by the last disc blade on the rear section is usually filled the next time around. This type works well close to shrubs and trees with low hanging branches. With a special hitch you can shift the path of the harrow to the right or to the left of the tractor.

The purpose of the disc harrow is to break up clods by means of steel discs; it mixes the soil thoroughly, bringing together vital plant food elements. It levels the ground, aerates the soil, kills weeds, prepares the ground for seedling and may be used to dig a ditch or make a seedbed. The penetration of the disc harrow is achieved by virtue of the weight of the implement and may be increased by the addition of extra weight to the pans attached to the frame for that purpose. Small diameter discs penetrate more readily than do large ones. Reducing the concavity and sharpening discs from concave side rather than the convex side also improve penetration. (McCreery and Nichols, 1956).

The purpose of the spike-tooth harrow is to thoroughly smooth and compact the top soil, fill up large air spaces left from ploughing and break up lumps and clods. It is a finishing tool used just before planting. It is also used for covering small seeds broadcast over the surface. It is an excellent tool for pre-emergence cultivation to break the rain-formed crust and destroy small weeds. (Micheal and Ojha, 1989).

The Spring Tooth Harrow

There are two types: the lift and the trailing type. The lift type may be raised by a hitch that is a part of the tractor. This makes transportation over grass ways and on the road quite simple. Some of the lift harrows are free to float behind the tractor while in working position and others are held to their depth by the hydraulic mechanism.

The trailing spring-tooth harrows have two types of runners. One type is attached by rivets or welds to the harrow frame. The teeth are raised for transport purposes. Another type is an adjustable transporting runner, the whole harrow is raised by lowering the runners, usually by tractor action. Most spring-tooth harrows uses levers and quadrants to raise and lower the teeth, one lever is provided for each section, either at the front or at the rear. Some have a sliding tongue and latch for raising and lowering the teeth as the tractor goes ahead or back. (Stone and Gulvin, 1977).

Chain Harrow

Chain harrows have no rigid frame, the original type consists

simply of a network of chain links, and is useful for such work as rolling up weeds which have been dragged out of arable land by other harrows. Spiked link harrows in which the teeth are formed by an extension of the link are generally useful. The most valuable types combine the advantages of flexibility and of teeth that will effectively penetrate into the soil. Such harrows may often be used with good effect on pastures as well as on arable land. On the heavy types of flexible harrow, the knives may be set such that different effects are obtained by turning them over and using the other side. Some harrows have turf blades on one side and arable land tines on the other. (Culpin, 1981).

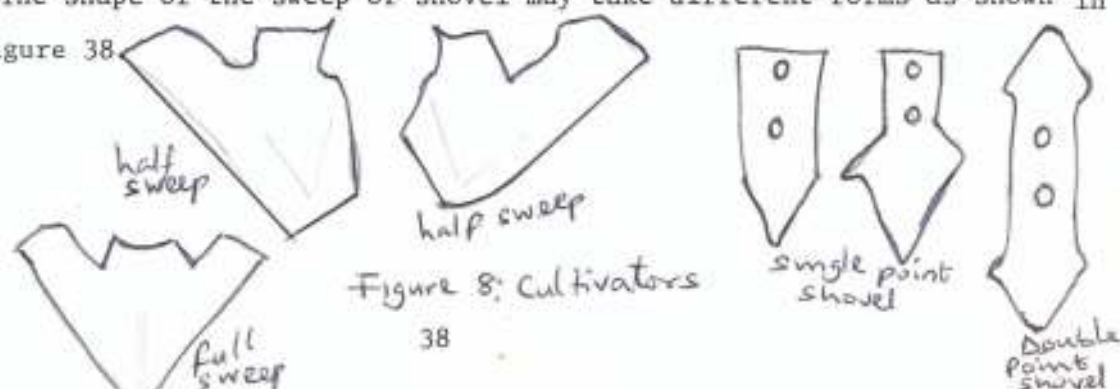
Cultivators

These implements comprise basically a set of soil working tines or share, mounted on a robust frame. Depending on the tines used, the cultivator can be classified as

- (a) Rigid-tine cultivator
- (b) Spring tine cultivator.

The rigid-tine cultivator has a strong tine with a cutting shovel or sweep. Several tines are mounted in either a single row or several rows, depending on the amount of power available to pull the cultivator. The tines are staggered and can be spaced to suit various plant spacing and thus provide effective weed hoeing.

The shape of the sweep or shovel may take different forms as shown in figure 38



The depth of operation may be altered by

1. Changing the position of the shovel on the tine by raising or lowering it;
2. changing the pitch by means of the top link;
3. using land wheel;
4. using the hydraulic system of the tractor.

The spring tine cultivator has tines made of spring steel, thus embracing them to withstand shocks when they hit an obstruction. As such this type of cultivator is to be preferred in situations where there are rocks and hard materials. The spring action also help to break down any clods of soil left by the plough. However, this type of cultivator works at a more shallow depth than the rigid type. (Kaul and Egbo, 1989).

Cultivators are primarily the type of tillage implements which are used after the crop has come up a few centimeters above the ground. But, they are also used for opening the land, preparing seed beds and sowing seeds. (Micheal and Ojha, 1989).

2.5.3 Other Tillage Implements

Ridger

A ridger is required for row planted crops. It is also used for making field furrows or channels, earthing up and similar other operations. The ridger can also be referred to as double mould-board plough or middle buster plough depending on the size of the furrows.

The ridger is commonly used in Nigeria, as ridge planting is practised in the cultivation of most crops. The ridger bodies,

mounted on a frame can be staggered to give the required spacing. Each ridger body carries a narrow share and two mould-boards. The mould-board spacing is usually adjustable.

Occasionally the ridges of the soil formed by the ridger are tied at intervals to help conserve soil and water. The ridges may be either tied manually or by means of a special attachment on a ridger. Ridgers are valuable in that about twice the quantity of land can be prepared for seeding in a given time as with a single mould-board plough. The ridger can be combined with a planter attachment and tilling and planting are done at the same time. Kaul and Egbo (1989), Stone and Gulvin (1977), Micheal and Ojha (1989).

Disc Tillers

The disc tiller is also known as vertical disc plough. It is half way between the standard disc plough and the disc harrow in its action. It carries the disc at approximately a 45-degree angle, cutting and throwing the soil in the same direction. The discs are smaller than those on the disc plough, usually 41-60cm in diameter - and have no scrapers to assist in inverting the soil. Disc tillers make a narrower and shallower cut than disc ploughs, the cut is about 10cm in width. They mix the soil with the trash instead of inverting the furrow slice and covering the trash. This mixing action retards drifting and blowing and keeps the soil in excellent condition to receive and hold moisture. Thus the disc tiller combines primary and secondary tillage in one operation.

Because the disc tiller is primarily a mixing tool, the draft is lower per meter than with the disc plough. With the same power, therefore, you can pull a wider implement, cover more ground, and

work faster than with the disc plough. A disc tiller can be substituted for a disc or mould-board plough, where trast mixed with the top soil is not objectionable and where it is not necessary to work the soil deeply.

Disc tillers vary considerably in the flexibility of the disc cylinder. Stone and Gulvin (1977) explained the differences between the major tiller types. The disc tiller is the best implement for terracing as it does it in one operation. At 6-7km per hour the large disc blades produce a slicing and tossing action. The rear discs carve the earth from the water channel and the others move it toward the terrace mound or ridge.

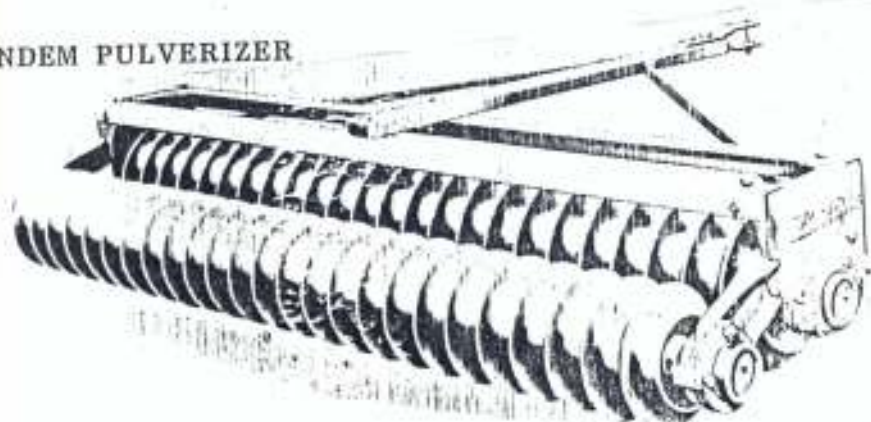
Some disc tillers require lubrication twice a day, while some require greasing once in three or four months. The disc blades are to be checked carefully before each operation, to detect loosed nuts and retighten. The disc blades could be sharpen when dull and should be replaced when worn. Disc tillers require good adjustment and proper weighting for good penetration and low draft. (Stone and Gulvin, 1977).

SOIL PULVERIZERS, PACKERS AND MULCHERS

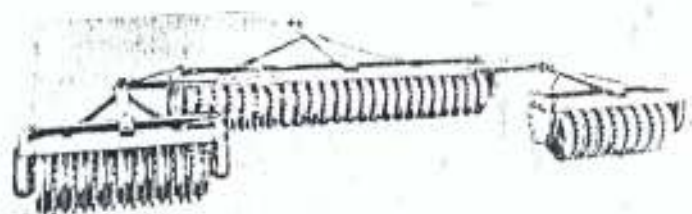
These are implements that put a finishing touch to the seedbed. The mulcher is a variation of the pulverizer, the packer is the same as the pulverizer. All three pulverize lumps and clods and pack the soil particles into small ridges, though they pulverize more than others.

Pulverizers come in single sections or in double sections. The draft of this machine is quite light. The tandem machine gives a

TANDEM PULVERIZER



SPROCKET-WHEEL PULVERIZER WITH SIDE ATTACHMENTS
(BRILLION IRON WORKS)



SEEDBED REFINING

FIGURE 9. TERZTIARY TILLAGE IMPLEMENTS

finer seedbed than the one single sectioned pulverizers, and does the work two times faster than the other. The wheel rims of the trailing section cut through the crown of the ridges left by the front wheels, giving double action.

Usually the rear section wheels are smaller than the front wheels, but there are some with identical wheels. Pulverizer wheels can be plain, serrated or wavy. This machine works by crushing the lumps and giving a little consolidation after ploughing and harrowing.

Mulchers: If pulverizing equipment is combined with harrow spring teeth, we have a mulcher. This is a two-in-one machine that is rather popular. The front of the tool has a roller unit, then two rows of spring teeth, followed by another roller unit. Seeders can be attached to a pulverizer assembly or mulcher and the two operations performed simultaneously.

Packers: These machines are made to follow directly behind a mould-board plough, to pack or push down the furrow slices. They are made in short lengths to work behind two and three bottom ploughs. (Stone and Gulvin, 1977).

2.6 POWER SOURCES FOR TILLAGE OPERATIONS

Power is needed on the farm for a variety of operations which may be either mobile or stationary. Examples of mobile operations are the transportation of produce, ploughing, spraying and so on. Stationary operations include operations like threshing, extracting and raising water and so on.

The following are the common sources of power available on the

farm:

- (a) Human power
- (b) Animal power
- (c) Wind power
- (d) Water power
- (e) Solar power
- (f) Electric power
- (g) Internal combustion engines 
 - Tractors
 - Automobiles.

These sources of power can be classified as Tractor power and Non-Tractor power. (a) to (f) can be classified as Non-Tractor power, while the Tractor is an internal combustion engine equipped to propel itself. (Kaul and Egbo, 1989)

2.6.1 Non-Tractor Power

Human power and animal power are the non-tractor powers generally employed in tillage operations.

Human power:- Human beings are the main source of power for operating small tools and implements. Over 80% of the cultivated area in Nigeria is tilled and farmed using hand-tool technology (Odigboh, 1991). Nowadays, there is a rapid decrease in the labour force available for farming because of the rural-urban drift and the fact that industrial jobs prove more rewarding. More often than not, subsistence farming is the outcome of human power, when predominantly used on the farm.

Odigboh (1991) reported the experimental bases for these facts as:

- (i) Humans are not efficient sources of power.

- (ii) Human power output is limited by the stress of high temperature and relative humidities prevalent in the tropics.
- (iii) On the average human beings can work at the rate of only 0.075KW.
- (iv) While the work rate efficiency of humans is about 50% in temperate climate, the efficiency is less than 10% in humid tropical climate such as we have in Nigeria (FAO, 1981).
- (v) Actual field rates for various tillage operations using hand tools as determined by Anazodo (1976) and reported by Odigboh (1976) are shown in table 2.6.1 below

Table 2.6.1: Some field operation rates by farmers using hand tools

Operation	Manual field work rate (man-days/ha*)
Land clearing	20.1 to 47.8 (32.6)
Ridging for cassava planting	29.7 to 64.5 (43.8)
Mound making for yams	35.0 to 93.0 (57.8)
Cassava planting	(28.3)
Yam planting	(17.3)
Weeding root crops	22.3 to 77.6 (36.7)
Weeding (general)	(40)
Cassava harvesting	(28.5)
Yam harvesting	(32.0)

*Average values in parenthesis

Source: Anazode (1976).

Men can serve as a source of power and/or as a control device but the extent to which they may be used depends on the degree of

mechanisation. Thus human power is still important as it remains a source of supplementary power, in conjunction with other power sources.

Animal power: Animal power is still widely used in several countries, and may be derived from oxen, buffalo, donkeys, camels or horses. Stationary or mobile operations are possible through special harnesses and yokes used to hitch various equipment to the animal.

Animals generally have a capacity to be overloaded for short periods of time and they provide good grip even in difficult conditions. The output available from animals is dependent on

1. the food intake
2. the breed of the animal
3. the training given
4. the yoke used for hitching.

Table 5 shows the power capabilities of draft animals over long period of time

Table 5: Power capacities of draft animals

Animal type and number	Weight (kg)	Average effort (N)	Maximum effort (N)	Effective daily working period (hrs)
Donkey (one)	160	460	880	3.5
Oxen (one pair) N'Dama	657	900	1700	5.5
Zebu bullocks (two pairs)	1300	1600	4000	5.4
Zebu bullocks (one pair)	650	800	1500	4.4
Oxen (half Brahma) (one pair)	1060	1470	3100	4.4

Odigboh (1991) explained the serious major limitations of animal power and concluded that animal power is not likely to play a significant role in the Nigerian agriculture of tomorrow.

2.6.2 Tractor Power

The tractor is generally referred to as a 'central power station' in that it provides power for many activities, both mobile and stationary.

Today's farm tractor can be used to do the following:

1. Pull machines behind it;
2. Push machines in front of it;
3. Operate machines mounted upon it;
4. Transmits power to machines through its power-take off;
5. Raise, lower and control machines and attachments by hydraulic power from the tractor;
6. Drive machines by belt power;
7. Transmit power through flexible shafts;
8. Furnish power for fast highway transportation and hauling.

The tractor when compared with non-tractor power available for tillage operations, is more reliable and effective. Though the initial cost of investment is high, it requires less money to maintain especially during idle time. The tractor can work longer period without getting tired unlike other sources of power. It is not susceptible to diseases nor affected by slight weather changes. Odigboh (1990) concluded that for efficient and intensification programmes in Nigerian agriculture, tractor power will be the appropriate power source.

2.6.2.1 Trend of development in Tractors

Tractors have been in existence for over a century. The evolution of tractors was due to enormous increase in demand for food and fibre.

The early steam engines furnished belt power but had to be pushed from place to place by horses or oxen. This was later converted into a self-propelled traction engine. Successful steam ploughs were developed in the decade of the 1850s and continuous development occurred until 1900. Traction was a serious problem to the inventors of the early tractors, however this led to the development of track-type agricultural tractors about 1900. Otto patents expired in 1890, but before then it was discovered that gasoline could be used to generate power in internal-combustion engines.

The first Winnipeg tractor trials were held in 1908, giving the public the opportunity to compare the field operations of steam and gas tractors. There were various tests after this leading to world standards to evaluate performance of tractors. These tests speeded improvement of tractors and inferior ones thus become obsolete. Some of the important highlights in tractor development are:-

1858 - Steam plowing engine by J.W. Fawkes drew 8 ploughs at 4.8km/hr in virgin sod.

1873 - The parvins steamer was probably the first American attempt at a tract-laying device, although the United States patent office records crawler tractor developments in the early 1950s.

1876 - Otto patents were issued for an internal combustion engine.

1889 - At least one company built a tractor with an internal combustion engine.

1908 - The first Winnipeg tractor trials were held.

1910-1914 1. The first tractor demonstration was held in the United States at Omaha, Nebraska, in 1911.

2. Smaller, light weight tractors were introduced.

3. The frameless type tractor was introduced.

1915-1919 - 1. The power take off was introduced

2. The Nebraska tractor test law was passed.

1920-1924 - A highly successful all-purpose farm tractor was developed.

1925-1929 - The power take-off was gradually adopted.

1930-1937 - 1. The diesel engine was applied to larger tractors.

2. Pneumatic tires and higher speeds were introduced.

3. Full electrical equipment was adopted.

4. Interests in high compression engines increased.

5. The all-purpose tractor was generally accepted.

1937-1941 - 1. Standardized ASAE and SAE power take off and hitch locations were generally accepted.

2. Pressurized cooling systems were introduced.

3. Liquid fill was widely used in tires to add ballast for traction.

4. Three-point implement hitch and linkage were introduced.

5. Automatic hydraulic draft control were introduced.

1941-1949 - 1. Live power take off was introduced.

2. Hydraulic controls for drawn implements were adopted.
3. Tractors for burning liquified petroleum gases were introduced.
4. Number of lawn and garden tractors expanded rapidly.

1950-1960 - 1. Power of tractors increased rapidly.

2. Percentage of diesel tractors increased.
3. Refinements such as power steering, automatic transmission and transmissions with greater speed selections became widely available.

1961-1970 - 1. Power of tractors continued to increase.

2. Except for smaller tractors in the United States, all tractors now have diesel engines.
3. Much more emphasis placed on operator's comfort and safety.
4. Full power-shift transmissions available.
5. Radial-ply tractor tires available.

1970-1978 - 1. Turbo charger and intercoolers added to diesel engines.

2. Roll-over protectives structures (ROPS) became available.
3. Most large tractors were equipped with cabs.
4. Nebraska tractor tests include sound level measurements.
5. Four-wheel drive increases in popularity.
6. Percentage of tractors over 75kw continues to increase. (John et al, 1979).

2.6.2.2 Types and Sizes of Farm Tractors

The different types of farm tractors (Figure 10) are classified in a number of ways, depending on their conformation and general use. One major method is based on the manner in which traction is achieved. Three types of tractors may be identified

under this classification.

1. Wheel type: A tractor that generally has rubber-tyred wheels at the front and rear.
2. Crawler type: A tractor that has a crawler chain running practically the full length of the machine on both sides.
3. Half-track type: A tractor that is the combination of both the above types. That is the front part has wheels and the rear part has tracks (Figure 10).

The track or crawler type of tractor is preferred where heavier powered machines are required. They are usually used for:

- i) land clearing and land forming;
- ii) soil conservation operation, such as pond building, irrigation ditches and so on;
- iii) deep tillage operations;
- (iv) work in soft and swampy ground.

The large area of contact between the tracks and the ground reduces slips provides better traction and allows the tractor to be used even on soft ground. However, crawler tractors do not usually have adjustable tread or adequate clearance for row crop operation.

The wheel type tractor, on the other hand is more of a general-purpose machine especially for row-crop use. There are four wheels mounted in pairs on front and rear axles and generally the spacing between the wheels is adjustable to suit row-crop spacing. (Kaul and Egbo, 1989).

Another means of classification is the type of drive. We have rear wheel drive (two wheel drive) and four wheel drive. Many types of four-wheel drive unit are available. They have advantages over rear-wheel drive for heavy cultivation or transport in difficult conditions or for work on filling silage clamps, but do not necessarily give a better performance on medium-powered tractors where conditions for adhesion are good. Wheeled tractors are able when conditions are good, to work at higher forward speeds than crawlers; but when conditions are difficult their weight and excessive wheel slip may cause physical damage to certain soils. (Culpin, 1981).

There are also differences in basic configuration of the tractor chassis, including overall dimensions, and several terms are used to define a particular type as described in the table 6 below

Table 6: Distinguishing features of different tractor types

Tractor type	Major or distinguishing feature
Row crop	The implement can become an integral part of the tractor, and can be mounted front or rear. High clearance and adjustable wheel tread (spacing) to suit different crops. Attachments may be easily fixed
Standard	Ideal for general work but not for row crop cultivation. Less vertical clearance
Utility	A type between a row crop and a standard wheel tractor. A general purpose machine.
Orchard	Possesses narrow tread and short wheel-base. Operator seat low. All projecting parts covered to prevent damage by tree branches.
Garden	Small wheel, compact machine with low centre of gravity.
Industrial	Suitable for heavy duty loading and other industrial operations
Tool Carrier	Provides versatility, simplicity and ease of tools attachment.
Two wheel	For small operations. Steered by walking operator.

Source:- (Kaul and Egbo, 1989)



ROW-CROP TRACTOR, WITH HIGH
CLEARANCE



ORCHARD TRACTOR



TOOL CARRIER



STANDARD TRACTOR



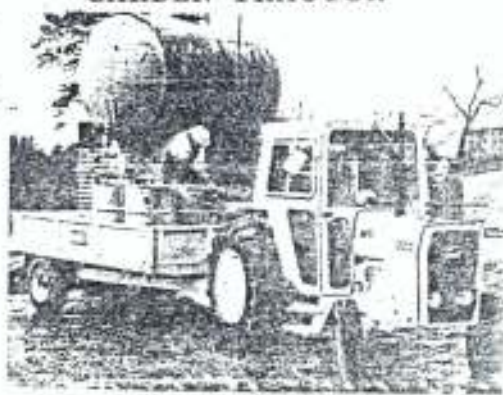
GARDEN TRACTOR



TWO-WHEEL TRACTOR



UTILITY TRACTOR



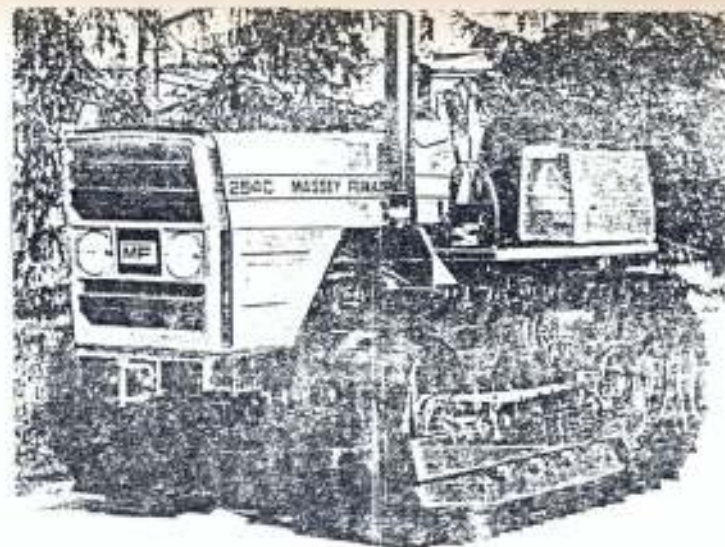
INDUSTIRAL TRACTOR

FIGURE 10:

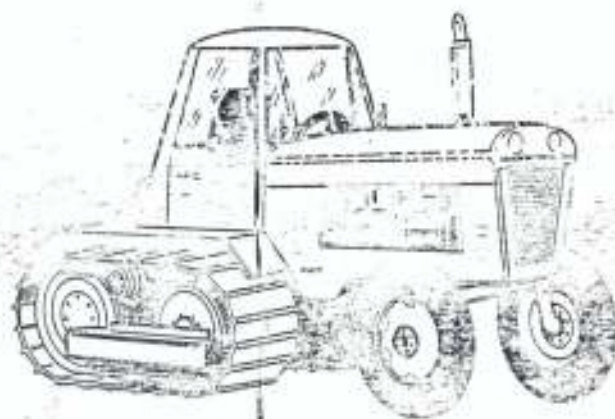
TYPES OF FARM TRACTORS.



RUBBER-WHEELED TRACTOR



CRAWLER TRACTOR, WITH TRACKS INSTEAD OF WHEELS



HALF-TRACK TRACTOR, HAVING WHEELS AT THE FRONT
AND TRACKS AT THE REAR

Size of Tractors

The size of a tractor can be expressed by (1) weight, (2) power, or (3) implement capacity. Capacity may also be expressed by the number of rows a tractor can cultivate, that is, single row, six row, eight row tractors and so on.

Rating capacity by the number of ploughs a tractor can operate is a common and convenient method, though not very accurate. Power required for ploughing varies greatly; in some soils a tractor can pull three ploughs easily, but in a different soil it might pull only one. The power needed for average conditions is shown in table 7 below

Table 7: Plough capacity of tractors

Engine Horsepower	Mould board plough bottoms
8 to 12	one - 30cm
15 to 20	one 41cm or two - 25cm
25 to 30	two - 36cm
35 to 45	three - 36cm / 41cm
50 to 60	four - 36cm
65 to 75	five - 41cm
80 to 130	six - 41cm

(Stone and Gulvin, 1977)

2.6.2.3 Tractor Operation and Maintenance

In modern agriculture, the tractor has been accepted as a symbol of mechanised farming. Knowledge regarding the farm tractors and maintenance has been getting increasing popularity on farms.

The cost of repairs and wear can be reduced with a good maintenance programme. Timeliness of operation can also be achieved with a good maintenance schedule. (Bukhari and Khan, 1982).

Good tractor operation and maintenance start from the purchase of the tractor and implement. The operator's manual and dealer provide special features and also explain what the owner must do for proper operation and care of the tractor.

Good tractor operation requires operator's safety, efficiency, timeliness and economy. Stone and Gulvin (1977) stated the rules for safe tractor operations and also evaluated the causes of accident during tractor operation. It is clear therefore that the operator should have a thorough knowledge of the tractor controls, to enhance safety of operator and others. The accuracy, efficiency and economy of your work also depend to a great extent on the level of the operator's knowledge of the tractor use and maintenance.

For optimal use of the tractor, maintenance is an essential tool that can reduce time loss during operation. Farmers should be able to make minor repairs on the farm, and proceed also to do the routine servicing of the tractor.

Periodic maintenance of the tractor should be performed everyday, and every 50 hours, 100 hours, 250 hours, 500 hours and 1000 hours as reported by Ademosun (1991).

1. Daily maintenance

1. Check and service the air cleaner
2. Check the crank case oil level
3. Check that the radiator is full of water
4. Lubricate grease fittings

5. Check the fuel sediment bowl for dirt, rust and water deposits.
 6. Make sure that all controls function properly.
 7. Tighten any loose nuts and bolts.
 8. Check inflation and condition of tyres.
2. Each 50 hours of operation (weekly)
- (i) Check the electrolyte level in the battery.
 - (ii) Check the fluid level in the hydraulic system.
 - (iii) Check the lubricant level in the power train.
 - (iv) Clean the dry-type air cleaner.
 - (v) Clean the crank case breather.
 - (vi) Perform daily maintenance.
3. Each 100 hours of operation (two weeks)
- (i) Change the crankcase oil and filter.
 - (ii) Perform 10 and 50-hour maintenance.
4. Every 250 hours of operation
- (i) Clean and regap, or replace spark plugs.
 - (ii) Clean the battery.
 - (iii) Clean the fuel sediment bowl.
 - (iv) Adjust the carburetor on spark ignition engine.
 - (v) Adjust the clutch-pedal free travel.
 - (vi) Check tension of drive belts.
 - (vii) Lubricate the clutch release bearing.
 - (viii) Adjust the steering free play on manual steering equipped tractors.
 - (ix) Perform 10, 50, and 100-hour maintenance.

5. Every 500 hours of operation (every two months)

- (i) Service the distributor on spark ignition engines.
- (ii) Check ignition timing on spark ignition engines.
- (iii) Service the starter and generator.
- (iv) Replace or clean diesel fuel filters.
- (v) Perform 10, 50, 100 and 250-hour maintenance.

6. Every 1000 hours of operation

- (i) Service the oil-bath air cleaner
- (ii) Drain and refill the power train with lubricant.
- (iii) Drain and refill the hydraulic system with hydraulic fluid.
- (iv) Adjust the engine governor if recommended by manufacturers.
- (v) Clean and repack front wheel bearings.
- (vi) Drain, clean and refill cooling system.
- (vii) Check air conditioning components.
- (viii) Perform 10, 50, 100, 250 and 500-hour maintenance.

Proper operation of the tractor will reduce the level of trouble-shooting encountered on the tractor. The following rules for proper tractor operation must be obeyed in order to ensure personal safety and the safety of the tractor.

- 1. Be sure gear-shift lever is in neutral before starting the engine.
- 2. Always engage clutch gently, especially when going up a hill or pulling out of a ditch.
- 3. When driving on highways, or to and from the fields, be sure that both wheels are braked simultaneously when making an emergency stop. Use the slow moving emblem on your machine.
- 4. When driving on the highway after dark, make sure your equipment is well lighted and use reflecting tape on the rear of the

trailed implement.

5. Always ride on the seat or stand on the platform of tractor.
Never ride on drawbar of tractor or drawn implement.
6. When tractor is hitched to a stump or heavy load, always hitch to drawbar; never take up slack of the chain with a jerk.
7. Be extra careful when working on hillsides. Watch out for holes or ditches into which a wheel may drop, causing tractor to overturn.
8. Always keep tractor at speeds slow enough to ensure safety, especially over rough ground or near ditches.
9. Always drive the tractor in gear when going down steep hills or grades.
10. Reduce speed before making a turn or applying the brakes.
11. Always stop PTO before dismounting from tractor.
12. Never permit persons other than driver to ride on tractor when it is in operation.
13. Never dismount from tractor when it is in motion. Wait until it stops.
14. Never stand between tractor and drawn implement when hitching.
15. Do not put on or remove belt from belt pulley while pulley is in motion.
16. Should engine overheat, be careful when refilling radiator.
17. Never refuel tractor while motor is running or is still extremely hot.

18. When tractor is attached to a power implement, be sure that all power-line shielding is in place.

Stone and Gulvin (1977) and Ademosun (1991).

2.6.2.4 Consumption of Tractor power

The sole source of power for a tractor is the internal combustion engine with which it is fitted, but losses occur before the power can be utilized. The loss varies according to the outlet point from which the power is taken.

The power generated by the internal combustion engine is called the indicated power of the tractor. This is the power obtainable at the engine, but in practice this power is not utilized directly. Other terms useful in the consumption of tractor power are:

Drawbar horsepower: This is the power available at the drawbar for pulling purposes.

PTO power: This is the power available at the take off shaft. This is usually more than the drawbar power, because of the loss between the PTO shaft and the drawbar.

Belt horse power: This is the power available at the belt pulley. Thus there is a difference between the indicated power of a tractor and that available at the drawbar. It is therefore important that when stating the power of a tractor, the type of power should be clearly stated. (Kaul and Egbo, 1989).

A considerable amount of power generated by the internal combustion engine gets lost before it can be utilized. Kaul and Egbo (1989) gave an estimate of the consumption pattern of tractor power, as shown below.

Indicated power	----	100%
1. Lost in exhaust gases and other heat losses	----	31%
2. Lost in cooling water, (in radiator)	---	40%
3. Lost in engine friction		5.5%
<u>Subtotal</u>		76.5%

Amount of power available

at the PTO $(100 - 76.5\%) = 23.5\%$

4. Lost in transmission and traction	---	4.5%
<u>Subtotal</u>		81%



Therefore, the total amount of power available at drawbar
 $(100 - 81) = 19\%$.

From the estimate, it can be inferred that, much of the power generated is consumed due to losses. Thus a fraction of the indicated power is obtainable at the PTO or at the drawbar. A true knowledge of the different power available on the tractor and the outlet point is necessary in the selection of a suitable tractor for farm operations.

Thus, the power of the tractor are available for consumption at the following point:

1. Drawbar (single hitch point). For coupling trailed implements, which are only pulled, such as trailer and mulcher.
2. 3-point hitch: For coupling semi-mounted and fully mounted

implements, which are pulled when in operation and lifted during transportation, such as mould board plough and disc plough.

To couple the implement to the tractor, the left link is coupled first, followed by the right link and the top link is coupled last, since the position of the top link and the right link is adjustable.

3. Power take off (P.T.O.) shaft: For transmitting power from the tractor engine to implements to provide rotary motion e.g. rotary mower and manure spreader.

4. Hydraulic system: For providing power required to lift or lower the implements e.g. tipping trailer and foragil harvester.

5. Electrical system: Electrical power is supplied by the battery and alternator to the implements e.g. electric fans on some airtype row crop planter and electric agitator.

2.7 TRACTOR AND TILLAGE IMPLEMENT MANAGEMENT

Tractor and tillage implements are very important particularly in agricultural production. The burden and drudgery of farm work have been greatly reduced, through the use of tractors and tillage implements. To ensure continuity of efficient output however, proper management becomes important.

Management involves consideration of many factors which include determining the costs for performing a particular operation, selecting the best size and type of equipment for each application, establishment of an efficient maintenance programme, matching machinery components in a complete system, determining the optimum age for replacing a

particular machine and scheduling farm operations for optimum utilisation of machines. Management also involves decisions on the type of machines to be purchased, its size, the source of money to be utilized and the age of equipment to be purchased. Essentially, tractors and tillage implements must be seen as instruments of management.

2.7.1 Old and new machines

It is important to consider every necessary factor before purchasing a new or an old machine. Such factors include, the source of cash, the amount of cash available, the amount of this cash that could be used for the purchase of the machine, the nature of the job, the quantity of the job and its duration.

The fixed cost and the operating costs of old and new machines must also be compared. The fixed costs of new machines is generally higher than that of its old equivalent, while the maintenance and operating costs of old machines are higher due to frequent breakdowns.

The cost of owning a machine varies with the extent of use and the efficiency of the maintenance programme. A farmer making less use of a machine may opt for an old machine to take advantage of smaller fixed cost and little operating cost resulting from occasional use of the machine.

According to Stone and Gulvin (1977), old tractors are more adaptable to open field work such as ploughing, harrowing, drilling and harvesting operations unlike newer ones. However, new models of machines may have special features which make them perform better in service. For instance, new models of tractors with huge tyres

gives added traction with excellent flotation, prevents slippage in loose soils and facilitates work on steep hills. Old machines may also incur higher repair and maintenance costs due to the fact that the spare parts are outdated and difficult to find.

Larson (1955) developed the analyses presented in Figure 11, depicting the annual costs and replacement times for tractors purchased new and at ages 1 through 7, his findings were summarized as follows:

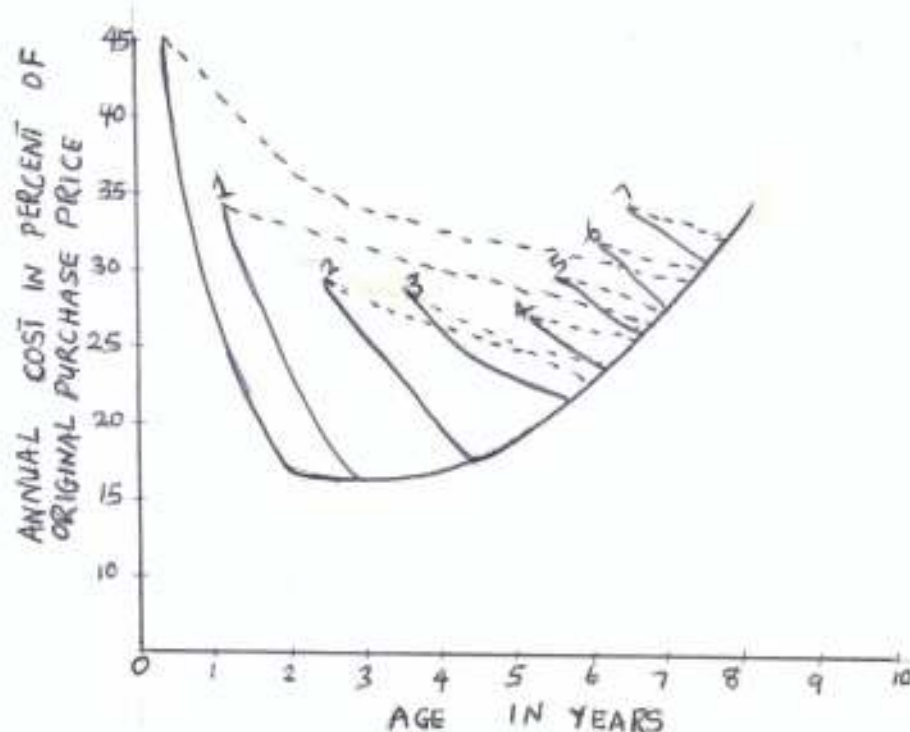


Figure 11 : Cost comparison for new and used machines (Adapted from Hunt, 1974)

1. A new tractor should be replaced at the end of 7 years.
2. Used tractors purchased as late as 6 years of age can have lower operating costs than a new tractor.
3. A tractor purchased at the age of 3 and sold at the age of 6

has the lowest cost.

The ability of a manager to recognise a discrepancy between price and value is all important. The effect of wear, adequacy of prior maintenance, extent of deterioration must be well evaluated before purchasing old machines.

The occurrence of economic and functional used machines is a matter of chance, managers of large commercial farm should not purchase them, especially when the following points are considered:

1. The probable greater reliability of new machines.
2. The improved design of new machines resulting in greater capacity, more efficiency and less labour requirement.
3. Personal preference, because of ease of operation, increased bodily comfort and prestige.

An individual farmer however, should not overlook the potential cost reductions possible with old machines.

2.7.2 Effect of age on Tractor cost

According to Khan (1981), the older tractors had higher repair and maintenance cost per hour due to the reasons that older tractors had frequent breakdowns which were blamed on poor workmanship. The repair and maintenance cost of tractors was found to be higher during the age of 4 to 6 and increased beyond 8 years. Two things were responsible for this, first, the first and second general overhauls of the tractors and second, the high prices of some parts.

ASAE (1970) published the tractor repair costs according to age records in the United States. It was found that the total amount

of repairs on a machine were proportional to the total use. New tractors had less repair costs than the old ones.

Rahmoo et al (1979) found that the owning cost per hour decreased as age increased because old tractors were purchased at lower prices than the new ones. The operating cost, excluding repairs also showed a decreasing trend as tractor age increased.

Moses and Frost (1965), reported that the season's use and age were both important in explaining the difference in cost per hour of operating tractors. The season's use appear to be much more important than age.

2.7.3 Effect of Tractor size on cost

There is the need to match the tractor size with the amount of work to be done depending on timeliness and cost. The cost of owning and operating a tractor is directly proportional to its size.

According to Sanrictores (1978), the steep rise in sales of the versatile compact four-wheel tractor which suit medium size farms of 10 to 25 ha is being experienced, which comprise a major portion of all farms and its price is much lower than the big 4-wheel tractors.

Chandhry (1976) reviewing the state of mechanisation reported that the big tractors of 40 to 60hp have benefitted only the big farmers owning farms which are 50ha and above. He suggested that multipurpose power tillers on a massive scale should be introduced to ensure 98% benefit on the part of small land holders with farm

sizes of 2 to 25 acres.

According to Hunt (1974), the 70hp range tractors produced a minimum cost but the selection was not very sensitive to power level. The reason was that there was less than \$70 annual difference among the power levels from 60hp to 90hp.

Chancellor (1968), concluded that small tractors are more appropriate for small size of farms. However, considering the cost on the basis of work done, the big tractors were more economical than the smaller tractors as cost per rated horsepower for the latter was higher.

2.7.4 Effect of farm size on Tractor costs

The size of a farm determines the number and size of machines needed for a profitable agricultural venture. The use of tractors is not feasible by way of ownership on small farms, except by way of hiring. Large farm sizes permits the tractor to cover an appreciable area of land per annum. Thus, it is implied that the annual cost of operating a tractor reduces with increasing farm size.

Rahmoo et al (1970) found that the smallest farm having a tractor was about 40ha in size and the largest farm was about 400ha. The tractors were employed for operations such as ploughing, harrowing, levelling, transporting and operating threshers. Tractor owners have discovered how beneficial it is to have increased annual use and therefore small farmers used their tractors frequently for hired work.

According to the United States Department of Agriculture (1973), large tractors were commonly used on farms which averaged 25ha. The

minimum size of farm land on which large tractors are economically feasible is 10ha.

Kaneda (1969), reported that for farms between 25 and 30ha, the cost of use of a 35hp tractor was equal to that of 15hp tractor. For larger acreages the cost of use of 35hp declined more and rapidly than smaller ones. It was also discovered that the use of 35hp tractor gave greater returns than using power tillers when the operating area was more than 30ha.

2.7.5 Hiring versus owning machines

Agricultural machines such as tractors and implements are very expensive, thus it may not be economically practical for individual ownership on small farms especially in developing countries. This is one of the major retarding factors affecting mechanisation. Hiring or joint ownership are two methods that could be employed to solve this problem. However, on large farms, ownership of these machines become inevitable to meet the demand for timeliness in agricultural production. According to Kaul and Egbo (1991), the decision of whether to hire or to buy can be made on the basis of the break-even cost, which is given approximately by the following equation.

$$\text{Break-even cost} = \frac{\text{Total annual fixed cost}}{\text{Hiring rate} - \text{variable cost per unit.}}$$

According to Rahmoo et al (1970), tractor owners realised the benefits of increased annual use and therefore small farmers used their tractors frequently for hired work. This realization was based on the fact that the more you use the machine for

productive work, the lower the cost per acre. The idea is to keep the machine busy at productive work as much as possible.

Stone and Gulvin (1977) stated that hiring is a way of enabling the machine owner to work his machine more and hence reduce the hourly costs. It should however be decided whether the owner can spare the time and the equipment from his own work (farm) and whether hiring work will be profitable, considering all the opportunity costs. This is dependent on how well the owner analyse and control his costs and what price he charges for the work. However, hiring may prove cheaper and more convenient than owning.

According to Singh (1972), the cost of production was low and income was more on large and medium farms where tractors were owned as compared with small farms which depended on hired tractors. This confirms the necessity of economy of scale.

2.8 FACTORS AND PARAMETERS AFFECTING THE DURATION OF TILLAGE OPERATIONS

The duration of each tillage operation includes the time spent on the operation, which is referred to as the 'theoretical time' and the time loss. The faster the speed of a machine, the less the duration of the operation, however there is a specific range of speed at which each operation can be efficiently performed. (Kepner et al., 1975; Culpin, 1981).

The duration of tillage operation can also be affected by the nature of soil, the type of crop, the width of the field, the speed of operation and the time loss. Effective time management is a useful tool in optimising tractor utilization since agricultural operations are time specific.

2.8.1 Soil Factor

The reaction of soils to forces applied by tillage tools are affected by the resistance of the soil to compression, the resistance to shear, adhesion and frictional resistance. (Nichols, 1931). Nichols has shown that reactive forces of all classes of soils are dominated by the film moisture on the colloidal particles, and thus directly related to the soil moisture and colloidal content.

Soils may be classed as plastic and nonplastic, the term plastic implying that the soil is moldable within a certain range of moisture contents and that it will retain its molded shape after drying. Sands or other soils containing less than 15 to 20% colloids or clay are generally considered as nonplastic. If a plastic soil is saturated with water and then allowed to dry, it passes through the following stages, in order: sticky, friable and hard. The friable stage represents optimum conditions for tillage. Time loss due to slippage and soil compaction which are serious problems in some cases, is often caused by working on the soil when too wet. (Kepner et al, 1978). The shearing of soils is considerably different from the shearing of most solids, in that the reaction may extend for a considerable distance on either side of the shear plane because of the internal friction and the cohesive action of moisture films. Cohesion and internal friction affects the level of impact of tillage on soils and are known as real physical properties of the soil. Their relationship is given as:

$$\tau = C + \sigma \tan \phi$$

where τ = shearing stress at soil failure

C = cohesion

σ = stress normal to plane of shear failure.

ϕ = angle of internal friction. ' τ ' the shear strength has an important influence on the draft of tillage tool.

Failure of a soil by compression is generally associated with a reduction in volume. Failure by shear and failure by compression occur as a combined action. (Gill and Vanden Berg, 1967). Soil strength therefore affects the duration of tillage operation by offering an appreciable amount of resistance to tillage implement. Nichols (1931) used the figure below to explain the relationship between the soil-metal friction and soil moisture content.

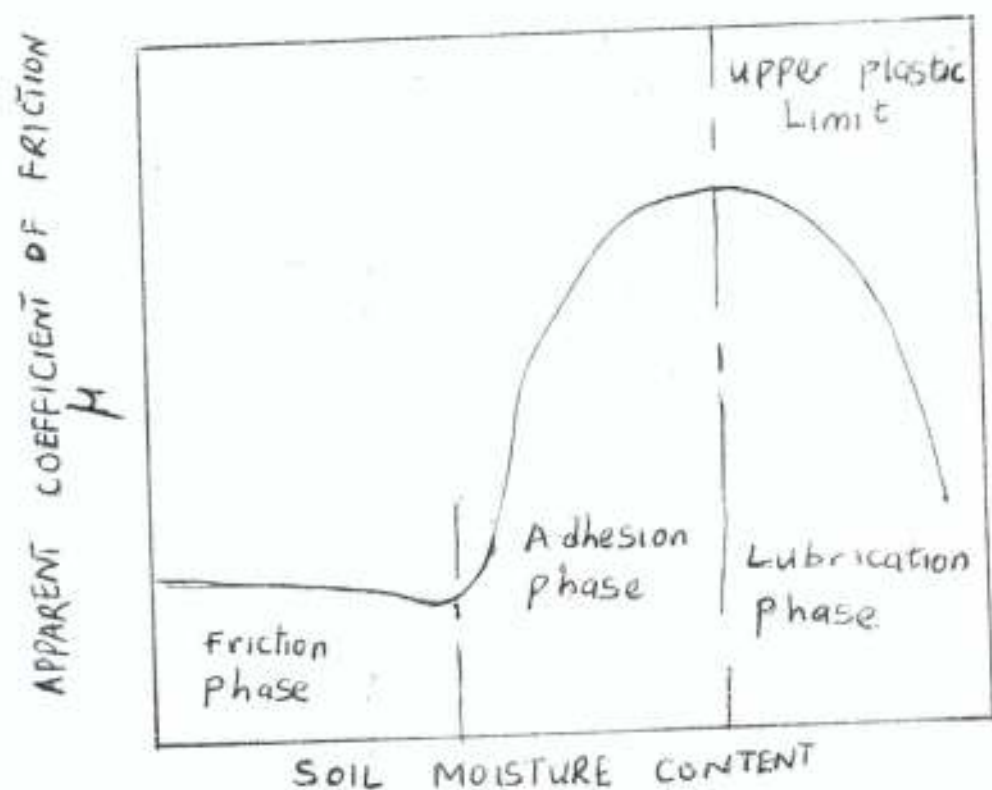


Figure 12: Relationship between soil-metal friction and moisture content.

2.8.2 Implement Factor

The shape of implements, size, design, materials or composition, angle of tilth and so on, have significant effect on the duration of production operations.

Soeline (1959) studied the effect of high speed during tillage operation on plough bottom design, he recommended that for high speed, plough bottom must be relatively flat, elongated and pointed so that vertical and lateral soil velocity components will not be much greater than for conventional bottoms at lower speeds. Reed (1941) found distinct differences in specific draft for different types of plough bottoms and even among various bottoms within the general-purpose classification. In general shapes that give the best trash coverage or the greatest degree of pulverization tend to have the highest drafts. The depth and width of cut of implements have significant impact on the duration of tillage operation. Most available evidence indicates that the specific draft of plough generally decreases as depth is increased to some optimum depth/width ratio and then increases as the depth is increased further. (Kepner et al, 1978). The sharpness of cutting edges have significant effect on the draft, for instance, worn shares have substantially greater draft than new shares. (Nichols et al, 1958).

The size of implements is another predominant factor that affects the duration of tillage operation. It is obvious that the larger the implement size the lower the duration of tillage operation for a given plot of land. The overall effect is the requirement of a tractor with a larger horsepower, this may be desirable, since tillage operations are time specific. Ademosun (1986) used

simulation and network analysis to determine the optimum size of implements to adapt for a medium-scale multi-crop production.

2.8.2.1 Field capacity of Implements

Field capacity is the rate of work that can be achieved by a machine. This can be classified into two based on the expected and actual rate of work.

Theoretical field capacity: This is the rate of work that would be achieved if the machine were performing its function at full rated speed for 100 percent of the time.

Effective field capacity: Actual average rate of work achieved usually expressed in acres (or ha) per hour.

Field efficiency is the ratio of the effective field capacity to the theoretical field capacity

$$\therefore \text{Field efficiency} = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100\%$$

Field efficiency varies with type of implements, for tillage operations it ranges between 75 - 90 percent (Culpin, 1981).

The actual rate of work accomplished by field machines is influenced by factors such as:

1. Width of machine; as affected by
 - (a) Total measured working width of machine
 - (b) Percentage of this width actually used.

$$\text{Number of trips } n_t = \frac{L}{W}$$

$$\text{The time spent during one trip} = L/v$$

Therefore:

$$\text{The total theoretical time } t_t = \frac{L}{v} n_t$$

2. Speed of travel as affected by:

- (a) Draft of machine
- (b) Operating limitations on speed
- (c) Drawbar horsepower available
- (d) Variations in grade and rolling resistance
- (e) Traction of power loss.

It is desirable to keep the speed of the tractor high but the above factors pose notable constraints to increasing speed. The faster the speed the higher the field efficiency. It is therefore necessary to keep the tractor's speed at an optimum value.

3. Time loss

A large amount of time loss is due to interruptions when performing farming operations. This can be classified as follows:

(i) Interruptions proportional to area of the farm

- (1) Refuelling and greasing
- (2) Marking of the field
- (3) Turning at the headlands
- (4) Resting
- (5) Repair or reset of machine parts.

Ademosun (1986) concluded that the total time loss by each of the interruptions is a product of the pre-determined time loss per unit area and the area of the farm.

(ii) Interruptions independent of the area of the farm

- (1) Travelling to and from the farm
- (2) Opening and closing the gate
- (3) Repair if there is a breakdown.

Considering the three field patterns - Circuitous, alternation and headland - the circuitous pattern does not involve any time loss in turning but it can only be used efficiently on a farm with round edges. Hunt (1974) found that, using an alternation pattern a two-row tractor mounted cultivator takes 14 to 18s for one turning in a wide headland, 21 to 27s in a narrow headland and at least 28s on a farm with no headland. The total time for turning with the headland pattern is given as

$$T = T_t \frac{L}{W}$$

It is necessary to clear the headland as a pre-tillage operation, and this is considered as time loss. The number of trips while working at the headlands is given as $n_h = \frac{L-1}{W}$

Time spent during one trip = b/v

Total time spent while working at the headlands

$$t_t = (b/v) n_h$$

Total time for turning while working at headlands

$$T = T_t \left(\frac{L-1}{W} \right)$$

It is possible to reduce the time loss in certain of the factors mentioned above. Good field layout will lessen idle travel, equipping the tractor with appropriate weights or ballast will reduce slippage and careful adjustment and maintenance of machines before taking them to the field means fewer stoppages in the field. It is desirable to reduce the time loss in tillage operation as it is a dominant factor affecting the field efficiency.

2.8.3 Soil - Implement - Tractor interactions

The duration of production operation is also affected by the soil-implement-tractor interactions. There is travel reduction

(slip) as the tractor goes over the soil during operation. The nature of soil, the moisture content and the amount of load affects the slip considerably, both tyre efficiency and dynamic ratio are a direct function of the amount of slip of drive wheels. Slip increases with increasing load. (Bulkhari et al, 1991). Slip is calculated by the following formula:

$$\text{Slip} = 100 \frac{(1 - A_s)}{S_0} \quad \text{where } A_s = \text{actual travel speed in km/hr} \\ S_0 = \text{no load travel speed.}$$

Frank (1972) as reported by Baloch et al (1991) concluded that maximum tractive efficiency occurs at 10% slip.

Pull increases with increasing width and depth of cut of implements. Table 8 shows the relationship between tractor pull, width and depth of cut

Table 8: Tractor pull, width and depth of cut

Gear	Cm Depth of cut	Cm width of cut	M/s speed	pull kg
1	14.8	86.6	0.543	568
2	13.3	88.6	0.725	568
3	16.0	87.6	0.96	613

(Bulkhari et al 1991 AMA Vol. 22 No. 4 1991)

Pull is the total force exerted by the power unit on the implement. With tillage implements it is generally at some angle above the horizontal. The pull is affected by the depth of cut, width of cut, tool shape, tool arrangement, type of soil, moisture content and travel speed.

The speed of operation has profound effect on tractor implement performance. The maximum permissible forward speed is related to such factors as the nature of operations (primary or secondary or

tertiary tillage), the condition of the field and the amount of power available. Increased forward speed increases the draft with most tillage implements. (Bukhari et al, 1991). McKibben and Reed (1952) consolidated the many speed-versus-draft test results reported between 1919 and 1949. They concluded that there was an appreciable percentage increase in draft as speed increases. Soil breakup may increase as speed increases but this is not a general phenomenon. Soeline (1960) compared 4 general types of plough bottoms in 2 soils at 4.35 km/hr and 12.2 km/hr. In one soil there was little difference in clod size distribution, in the other the differences were not significant. Therefore different designs are needed for high speeds to obtain optimum performance without excessive draft.

Bukhari et al (1991) concluded with the following suggestions. On firm soils the rear wheel drive tractor should be operated at 10% slip to obtain maximum horsepower. Graphical solution based on tyre performance criteria may be used to determine the expected drawbar pull, drawbar horsepower, travel speed and slip of any tractor under various implement-soil-conditions.

2.9 COST ANALYSIS

The management of agricultural machinery is very important and of particular concern to the users. One important aspect of managing agricultural machinery is determining the cost for performing a particular operation. Jacobs et al (1983) stated that the management of agricultural machinery includes an important aspect of finance. This element of finance is more than how much it

costs to purchase a machine, rather it is how much it costs to own and operate the machine over its useful life.

According to Witney (1988), the operating costs, either directly or indirectly are linked to the list price of the machinery. An estimation of the capital cost of different sizes of equipment is useful when matching various tractor power outputs and machine capacities to provide the optimum machinery complement for whole farm operation. A large price surcharge for a marginal increase in machine size has little market appeal because extra cost would not be justified by the small improvement in output.

2.9.1. Marginal cost of extra Machine capacity

The list price of various categories of machinery is closely determined by the manufacturing costs for the design specification, plus a realistic profit margin. Thus the price of the two-wheel drive tractors, all basically of the same design, are linearly affected by the engine power ratings. Witney (1988) outlined the relationship as follows:

$$PP_{2wd} = 2000 + 190 \times P_{max} \quad 1$$

Purchase price of 2WD tractor, N x maximum P.T.O. power, KW.

A substantial change to the specification not only alters the production costs but also affects consumer demand and marketing strategy. The purchase prices of four-wheel drive tractors and for crawlers follow a similar pattern to those for two-wheel drive tractors but the price trends are increasingly affected by the engine power rating as shown below:

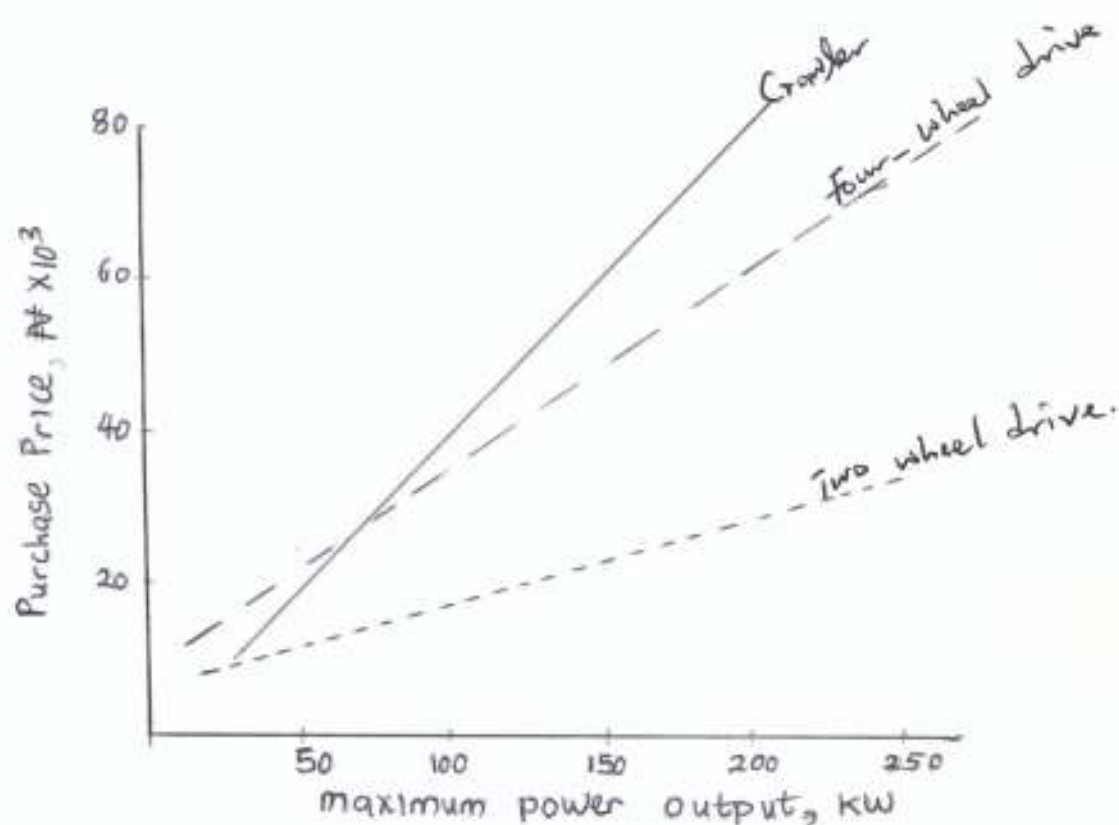


Figure 13: Effect of output power on purchase price of tractors.

In tillage operations however, tractors are not the only set of equipment required. Machinery which include ploughs, harrows and such like are each used to form a single unit with the tractor during tillage operations. Purchase price trends can be established for these machinery in the same way. The major cost elements for a plough are the main frame per furrow (or implement width) and the number of plough bodies. Witney (1988) linked these cost elements in a linear equation with three coefficients, q , r and s as shown below:

$$PP_p = q + r \times W_f + s \times N_b \dots \dots \dots .2$$

Purchase price of plough, N x furrow width, m + Number of plough bodies

A change in frame design from mounted to either semi-mounted or trailed versions and from conventional to reversible specifications jointly affects the independent coefficient and the machine width coefficient. The addition of accessories affects the plough body coefficients only.

A slightly different form of price equation is used for power driven cultivators as shown below:

$$PP_C = q + r + W + s \times N_t \dots \dots \dots 2.9.3$$

Purchase price of cultivator, ₦ x machine width, n + number of tines.

The purchase price coefficients for various machine types as

recorded by Witney (1988) are listed in table 9 below:

Table 9: Values of price coefficients, q, r, and s for different types of machines

Machine	Purchase price coefficients		
	q	r	s
Tractors 1983			
Two-wheel drive	2000	190	-
Four-wheel drive	-320	310	-
Crawler	-9400	450	-
Ploughs 1983			
Conventional, mounted, fixed leg	-250	370	490
Reversible, mounted, fixed leg	-1800	5800	940
Conventional, semi mounted, auto-reset	-20,000	58000	740
Reversible, semi-mounted, auto-reset	-130,000	360000	1500
Cultivators (power driven) 1984			
Rotary, L blade	-400	350	31
Rotary, tine	-820	1300	6
Harrow	-2600	2000	-

2.9.2 Machinery Operating Costs

According to Kepner et al (1978) machinery operating costs are divided into two categories, fixed costs and variable costs. Fixed costs are dependent on the duration of ownership of a machine and occur regardless of whether or not the machine is used. Fixed costs of machinery include:

- Depreciation
- Interest
- Tax and Insurance
- Shelter.

Variable costs are the expenses which occur as a result of actually using the machine. They are directly related to the amount of use and comprise:

- Fuel and Lubricant
- Repair and Maintenance
- Labour.

2.9.3 Fixed Costs

Fixed costs occur normally in the ownership of a machine, regardless of the extent of use. Thus fixed costs are constant per annum and will decrease per hectare or per tonne as the annual use of the machine increases. This is illustrated in figure 14

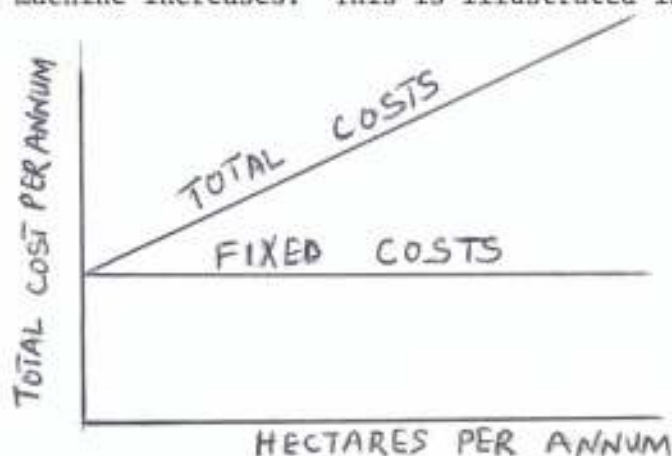


Figure 14: Effect of annual use on operating cost.

Fixed costs often represent a large part of the total cost of the machine. This is due to the limited annual use, particularly for the more expensive types of equipment

2.9.3.1 Depreciation

Micheal et al (1989) stated that depreciation is the largest single item in the fixed costs. It is referred to as the loss in value of a machine due to time and use. Machines depreciate as a result of age, wear and tear and obsolescence.

The rate of actual depreciation depends on the useful life of the machine. This in turn depends on the rate of use, the operating conditions and the care given by the operator for adjustment, lubrication and repairs.

There are several methods for calculating depreciation but the three most relevant are:

- straight-line depreciation,
- declining balance depreciation,
- decremental depreciation.

Straight-line depreciation:

The straight line depreciation is widely used because of its simplicity. It reduces the value of a machine by an equal amount each year during its useful life. The annual average depreciation is obtained by deducting the resale value of the machine, s , from the purchase price, PP , and dividing by the period of ownership, N

$$D = \frac{(PP - S)}{N} \quad \text{-----} \quad 4$$

The purchase price relates to machines bought either new or second hand, and the resale values after a long period of ownership may

become the scrap value. The straight line method can be illustrated by the figure 15 below:

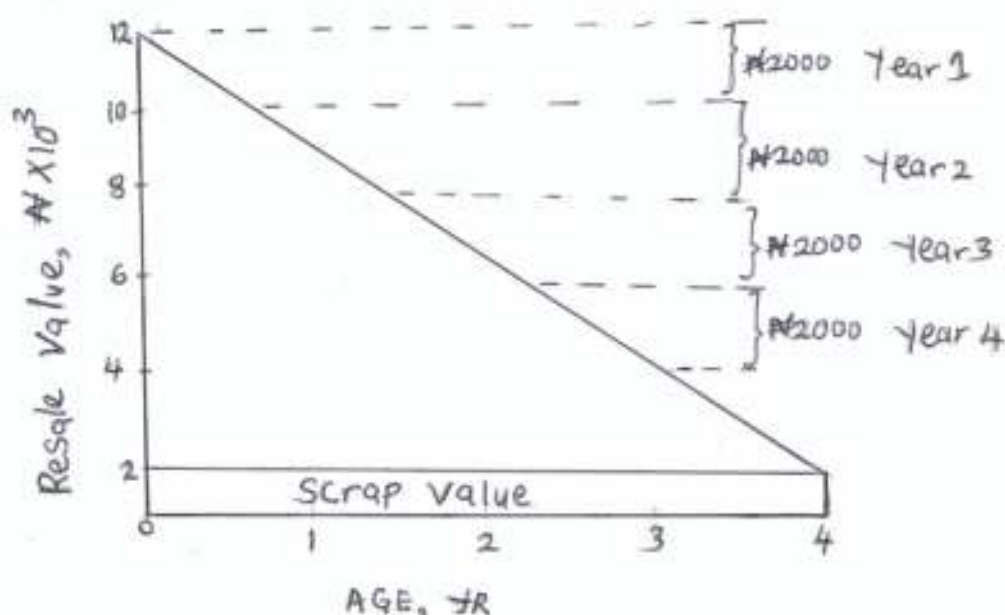


Figure 15: Straight-line Depreciation.

Straight-line depreciation is most suitable for estimating costs for the entire life of the machine. Thus the annual depreciation charged can be considered as the sum which must be set aside each year in order to replace the machine with an identical model at the end of the period of ownership. Straight-line depreciation however, is an over simplification and ignores the more rapid depreciation in the early life of the machine.

Declining balance depreciation;

This method depreciates a machine by a different amount each year, but the decimal rate of annual depreciation remain constant. Witney (1988) gave the formula relating the depreciation and salvage value as:

$$S = PP \times (1 - d)^n \quad \text{---} \quad .5$$

Thus the annual depreciation cost for any year is obtained by multiplying the written down value of a machine at the beginning of the year by the decimal rate (d) of annual depreciation. This method gives a better estimate of the actual price of a machine at a specific age. This is important in the calculation of assets in a balance sheet. Declining balance method does not account for the first year depreciation, but by introducing a first year correction factor to the resale value, the method becomes more accurate.

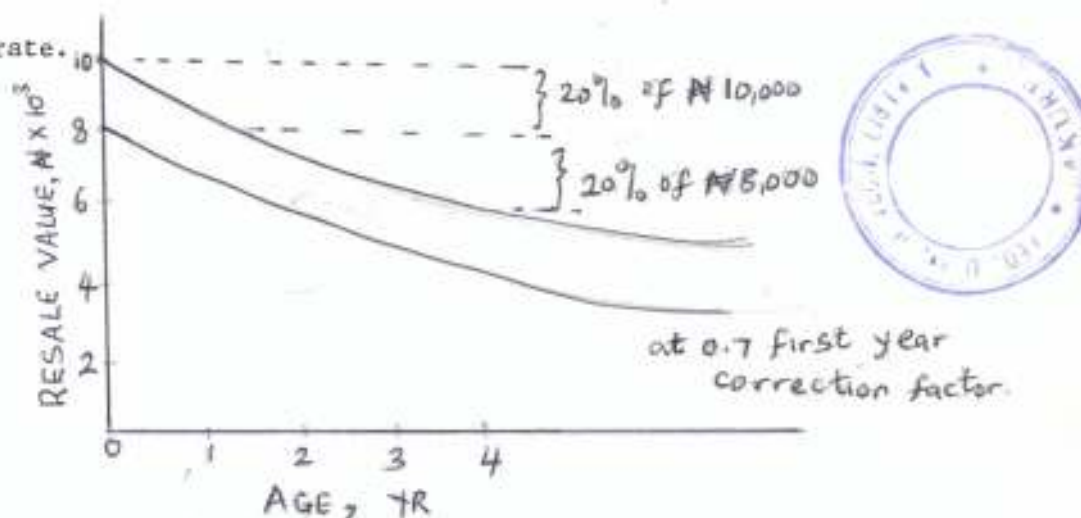


Figure 16: Declining Balance Depreciation.

Declining balance method is not as simple as the straight line method. However, it provides a more accurate estimate for depreciation.

Decremental Depreciation:

Witney (1988) gave the relationship between the initial purchase price and the resale value as an exponential function

$$S/PP = e^{(-0.2 \times n + 0.008 \times n^2)} \quad \text{---} \quad .6$$

e is the base of natural logarithms and n is the depreciation age of the tractor. The advantage of this method is that the resale value of the tractor when new, at the age of zero, is identical with

the current purchase price. The age of the tractor therefore affects the ratio of the resale value to the initial purchase value as shown in the figure below:

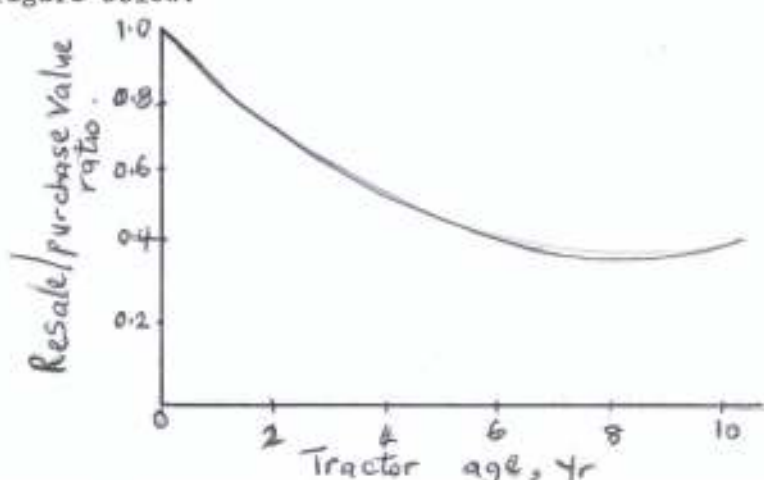


Figure 17 : Effect of tractor age on the ratio of the resale value to the initial purchase price in equivalent monetary terms.

2.9.3.2 Interest

There must be a charge for interest on the capital invested in a machine, while calculating the cost of owning and operating machines. This should be done regardless of the source of capital for the purchase (either the money is borrowed or owned).

Jacobs et al (1983) stated that the amount of interest charged includes financing charges and can be determined by taking one-half the purchase price minus 10 percent investment credit plus the salvage value times the interest charge. According to Witney (1988), the real interest rate, using identical monetary values, is the total repayment related to the purchasing power of the loan and is expressed as

$$i_r = \left[\frac{1 + i_1/100}{1 + j/100} - 1 \right] \times 100 \quad \text{---} \quad .7$$

$$\text{i.e. Real interest rate, } \% = \left[\frac{1 + \text{investment rate, \%}/100}{1 + \text{inflation rate, \%}/100} \right] - 1 \times 100$$

where i is the investment interest rate and j is the inflation rate. For straight-line depreciation, the interest charge is obtained from the average investment over the whole period of ownership multiplied by the net rate of interest.

$$\therefore I = i_n \times (PP \times S)/200 \quad \text{-----} \quad .8$$

Average investment over the life of a machine is half the sum of the purchase price and resale value as shown below:

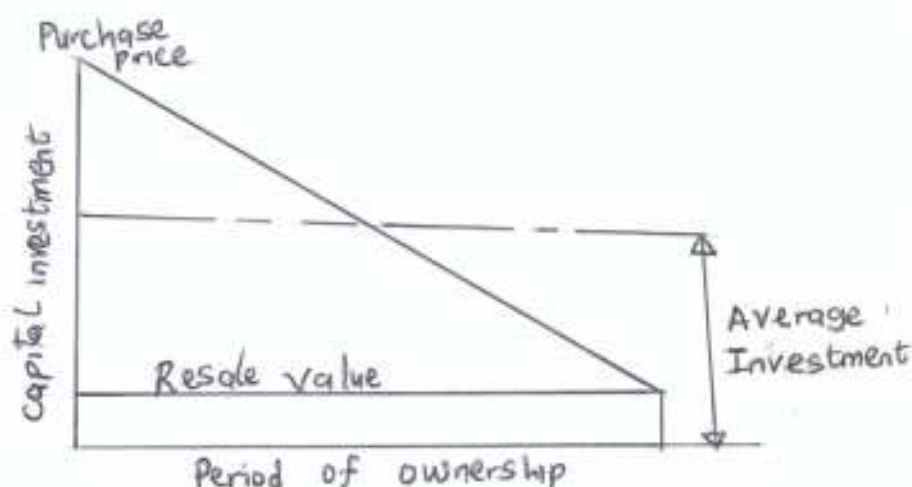


Figure 18 : Average investment when straight-line depreciation is used.

2.9.3.3 Tax and Insurance

Agricultural tractors and machines are considered as personal properties and are taxed according to state and local laws. The registration of tractors and self-propelled machinery for use on the highway involves an annual payment of vehicle excise duty (vehicle licence). Tax and excise duty for equipment vary depending on the existing laws of a locality. An accurate value of tax for a

machine therefore depends on the use of the actual rate on the local or state charts.

Insurance policy may not be carried on some of the older and less costly machines, it is however, necessary for new and costly ones. Insurance for tractors should cover third party liability, fire and theft. It could also include free cover for attached trailer and implement. The cost of insurance varies with localities. Insurance could be taken at a lower premium of 0.25 percent and an higher premium of 0.5 percent.

2.9.3.4 Shelter

The financial benefit of shelter for farm equipment is difficult to evaluate, however, most valuable machinery should be kept under cover for at least a part of the year. A good and tidy machinery shed, apart from facilitating repair and maintenance, demonstrates managerial commitment to good machine care. The need for machinery housing is a function of the climatic condition of a country. It is desirable to erect machinery housing suitable enough to protect the machine from ambient weather conditions. The shelter could be a purpose-built structure. Tractors could also be housed in existing barns, cart sheds and ware houses especially when these are out of use. Brian (1988) estimated the shelter charge to range between 0.5 percent and 1 percent of the initial purchase price of the machinery stored inside the building.

2.9.4 Variable costs

Variable costs are those costs that vary with the extent of use. They are directly related to the extent of use of the machine.

Operator labour, engine fuel and oil and schedule maintenance costs are associated directly with machine use and are called variable costs. The cost of repair is not directly related with use as part failures, and labour required to make the repair does not occur at regular intervals.

2.9.4.1 Fuel and Oil

The fuel consumption of a tractor is directly related to the extent of use. The age of the tractor and its size also affects the quantity of fuel consumed per unit time. The fuel consumption however, regardless of age and size, is related to the extent of use.

According to Witney (1988), the fuel consumption of a tractor is governed by the amount of energy demanded at the drawbar, or through the power take-off. The net energy requirements for typical farm operations are shown in Table 10.

Table 10: Net energy requirement at the tractor drawbar or through the p.t.o. for typical farm operations

Operation	Draught power Kw	p.t.o. power Kw	Net energy requirement MJ/ha
Ploughing (3 furrows, 20cm deep)	32	-	222
(7 furrows, 10cm deep)	38	-	108
Rotary cultivation	4	38	82
Grain drilling (15 row)	9	-	13
Direct drilling (15 row)	14	-	22
Forage harvesting	8	28	10
Potato harvesting	15	5	280

Source: Witney (1988)

Fuel consumption varies considerably over the duty cycle, even for heavy work such as ploughing. Therefore the average consumption is generally considered. Brian (1988) gave the average loading throughout the year for a tractor as 55 percent. The fuel consumption per unit of power output is called specific fuel consumption and is shown in table 11 for different diesel engine loadings.

Table 11: Percentage of time tractors operate at various engine loading

Engine loading, % of max. power	Operating time % of annual use
Over 80	16.8
60-80	23.9
40-60	22.6
20-40	17.5
Under 20	19.2

Source: Bowers, 1975)

According to Jacobs et al (1983), the annual cost for fuel can be estimated by using the performance factor in table 12 and equation 2.9.9:

Table 12: Performance factor for fuel consumption

Fuel	Average performance maximum PTO hp (kw) Kw.h/L
Gasoline	1.8
Diesel	2.6
L.P gas	1.44

Source:

$$\text{Annual fuel cost} = \frac{\text{Price per litre} \times \text{P.T.O. power} \times \frac{\text{maximum}}{\text{Kw.h/L}} \times \frac{\text{total hr}}{\text{used}} \times 0.6}{--}$$

where 0.6 = 60% of maximum P.T.O. power for average load on an annual basis.

2.9.2.4 Maintenance and Repairs

Maintenance and repairs are essential in an effort to guarantee a high standard of machine performance and reliability. The parts of machines tend to wear and fail after prolong use. Excessive wear adversely affects output and increases the likelihood of random failures.

Witney (1988) gave four major ways of maintaining a useful machine:

- routine replacement of wearing parts
- repair of accidental damage
- repairs through operator's neglect
- routine overhauls.

Routine replacement of wearing parts:

Tillage implements requires routine replacement of all wearing parts which may include tines, discs, shares and mouldboards. Although the wear rate is governed by soil characteristics, by crop flow, by engine hours and natural deterioration, good maintenance can extend the servicesable life of the machine.

Repair of accidental damage:

Accidents may occur naturally with any operator, but carelessness, rushing to finish a job and excessive overtime are the major causes

of accident. Thus farm operations need good planning as to the beginning and ending of a job. Damages from accidents may include twisting a frame, cracking an axle housing etc. The solution to accidents on the farm is sound management to ensure that neither the operator nor the machine is overstretched. Competence of the operator is the key to minimizing accidental damage.

Repairs through operator's neglect:

Neglecting regular maintenance or minor repairs can be expensive. Engine oil starvation leads to overheating and bearing failure for lack of timely oil check. Tyres can be quickly destroyed by underinflation. Thus good timely maintenance, with a rigid daily inspection and servicing schedule makes a machine more reliable in service.

Routine overhauls:

Machines are overhauled to replace worn or defective parts before total failure occurs. The service life of various groups of component is reasonably predictable. It is necessary therefore, to organise routine overhauls during slack times when machine downtime is unimportant compared with the potential benefits from restoring the performance to the original level.

Machinery repair cost is however part of the expected cost of owning and operating a machine. It should therefore be properly accounted for to include both the on-farm repairs and contract repairs. In some well organised farms, it includes the cost of inventory, the depreciation cost on workshop building, cost of routine services, depreciation costs on tools and equipments.

2.9.4.3 Labour Costs

There is some hesitation to charge the cost of labour to operating costs when doing a personal job, however, labour is a major operating cost and should be assigned its value. The rate equal to the wage should be used to determine the labour cost when machine is operated by the owner/manager. But for hired labour, the actual hourly rate is used to figure labour costs.

According to Witney (1988), the calculation for labour charge infers that labour is available by the hour, on a casual basis, whereas the real value of labour may be higher at the time required because of its opportunity cost. Thus considering all managerial factors, it may be necessary to hire permanent staff to ensure their availability at the critical time of the year. The annual cost of hiring a permanent staff is used in such cases as the labour cost instead of the hourly labour charge.

CHAPTER THREE

3.0 METHODOLOGY

3.1 THE STUDY AREA

3.1.1 Location

The south-western part of Nigeria was considered as the study area. This area lies between 5° to 7° north of the equator and 4° to 14° east of the Greenwich meridian.

The area is located in the tropical rain forest which experiences two rainy seasons per annum. Rainfall in this area ranges from 1250mm to 2000mm per annum and starts in March or April and continues until July ending. The latter is known as the first tillage period. The second rainy season starts in September after the August break, and continues until November. The only dry season starts in November and ends in March. Tillage could be done during the second rainy season (second tillage period) also. However with adequate irrigation facilities, tillage could be done any time of the year.

The study area is naturally drained by major rivers such as Owena, Ogun, Osun and Ala rivers. The selected farms are however drained by gullies and perennial streams. Artificial drainage channels and irrigation facilities were absent.

Two farms, the Teaching and Research Farm of the Federal University of Technology (FUTA), Akure and Little by Little Farm, Ijare, were selected. These farms were selected within the study area to evaluate tractor field performance under varying soil and implement conditions. They were selected based on their proximity and availability of necessary facilities for the research work.

The results of experiments performed in this two test stations are as shown from tables 14 to 30.

Two research stations, International Institute of Tropical Agriculture (I.I.T.A.) Ibadan and Institute of Agricultural Research and Training (I.A.R.&T.) also at Ibadan were selected to compare the extent of mechanization, machinery maintenance culture and general management of machines with private profit-oriented farms.

The power required for tillage operations was determined by a set of experiments performed at the Agricultural Mechanics and Machinery Operators Training Centre (AMMOTRAC), Federal Department of Agriculture, Akure.

FUTA farm and Little by Little farm where most of the experiments were performed, had similar soil and weather conditions. The farms provided two major agricultural soils. These were clayey loam soil and sandy loam soil. The test plots were fairly levelled due to preceding clearing and tillage operations, but the land became steep towards river valleys and streams. Occasional rock outcrops and some other obstacles were found on the test plots. These obstacles constitute one of the time-loss items. The rock - outcrops are believed to be the remains of the parent rocks from which the soils were formed.

3.1.2 Soil and Vegetation

The type of soil and the nature of its vegetal cover has a predominant effect on tillage efficiency. The soils in the test plots were typical agricultural soils of the tropics with good depth

which permits high plough and root penetration. The two types of soils, clayey loam soil and sandy loam soil have varying degree of water retention and infiltration rate, were found in the test stations.

The natural vegetation is made up of three storeys, the top storey is characterized by high, scattered and emergent trees of about 30 meters. The middle storey has trees of about 15 to 25 meters high and tends to form a continuous canopy. The lower storey (ground storey) is made up of evergreen grasses and seedlings. This natural vegetation has an important impact on the cost of clearing agricultural lands and tillage efficiency. In the study area, when virgin land is cleared, stumps of tall trees which could penetrate up to 6.5 meters into the soil hinders smooth tillage operations. Disc-implements should be used in areas with such vegetal cover to improve tillage efficiency. On farms where rotational cropping is not practised, grasses could grow up to 1.5 meters or more when the land is left uncultivated.

3.2 DATA COLLECTION

3.2.0 General Description

Tractors and implements have huge initial costs. This makes tractor management and tractor field performance of great importance to users.

To evaluate tractor field performance, it is imperative that the parameters pertaining to the performance must be determined. These parameters include, drawbar pull, fuel consumption, initial soil conditions, final soil conditions desired, implement and tractor types, operational parameters and field parameters.

The effect of these parameters as they affect the field capacity and field efficiency and indeed the overall tillage effectiveness were studied. These parameters were varied one at a time to show their individual effect on tillage effectiveness.

The instruments and machines used in the research work were:

(1) Tractors as the power source

- (i) Ford 70 hp
- (ii) 375E MF 60 hp
- (iii) Steyr 768 59 hp
- (iv) Steyr 8075 70 hp

(2) Tillage implements

- (i) Disc ploughs
- (ii) Disc harrows

(3) Measuring instruments:

- (i) Spring dynamometer
- (ii) Speedy moisture Tester (meter)
- (iii) Stop watch
- (iv) Wrist watch
- (v) Measuring tape
- (vi) Steel rule
- (vii) Meter rule
- (viii) Sieves
- (ix) Sieve shaker
- (x) Measuring cylinder

3.2.1 Soil type and moisture content

The soil type was analysed using particle size mechanical analysis. Soil samples were collected from the test stations for this experiment. The mineral matters higher than 2mm were first removed by screening the sample through the 2mm diameter sieve before analysis. The remaining sample was then weighed and placed on the 2mm sieve, and the other sieves, 0.05, 0.002, and the collector were placed below the 2mm sieve in descending order. The set was placed on the sieve shaker and the sizes were separated into different ranges.

The samples were collected separately from the sieves and weighed. The percentage of each size range compared to the sample

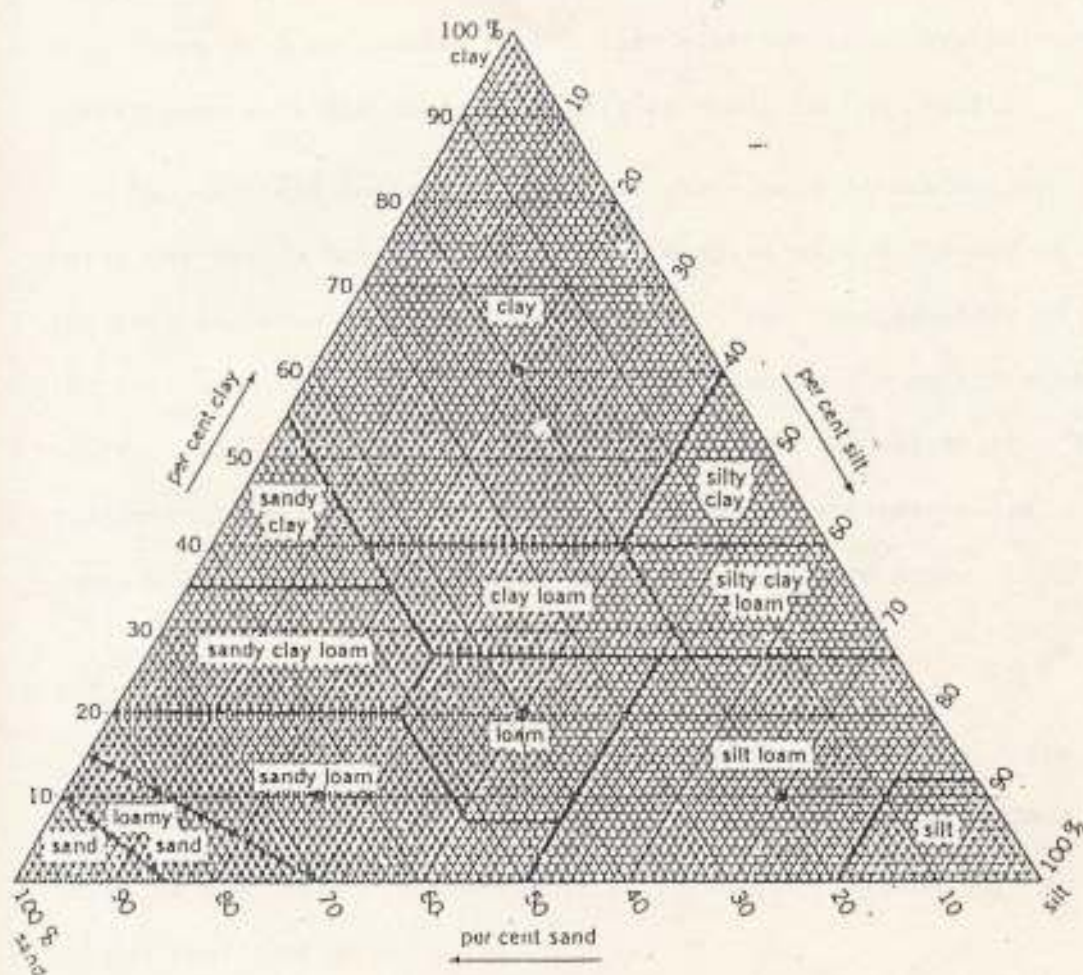


FIGURE 19: TEXTURAL TRIANGLE.
ADAPTED FROM DONAHUE ET AL (1990).

weight was evaluated. These percentages were used to determine the textural class on the textural triangle (Fig 19). Two major soil types were discovered on the test stations after analysis, clayey loam soil and sandy loam soil as shown in the results.

The moisture content of the test plots were determined by using the speedy moisture meter, soil samples were collected on the test stations at an average depth of 15cm. The quantity of the soil used for analysis was as recommended on the moisture meter chart. Calcium carbide (powdered) was used as the absorbent. The moisture content in percentage was read on the moisture meter gauge after shaking the content inside the moisture meter.

3.2.2 Working Depth and Width

The working depth was measured with the steel rule. The depth was measured from the bottom of the furrow to the surface level of the soil. This was done at different selected places on the test plot.

The effective working width of the implements (disc plough and disc harrow) was determined by using a steel tape to measure four passes of tilled area and dividing by 4 to get the average effective working width at four randomly selected places on the test plots. The maximum width was obtained by measuring the width of the implement before operation. The maximum width and the effective width were compared as shown in the results.

3.2.3 Speed of Operation

In order to evaluate the speed of operation, a distance of 50 meters was measured, the time taken by the tractor to cover

this distance from the relation :

$$\text{speed(m/s)} = \frac{50\text{m test run}}{\text{time taken (s)}}$$

The speed of operation was however varied from 6.0 to 8.0 km/hr to evaluate its effect on tillage efficiency.

3.2.4 Slippage

The slippage of the rear wheel drive tractors were evaluated during the research work by measuring 50m on the different location on the farm, and the tractor with load and without load was operated over the distance. The slip was calculated from the following formula:

$$\text{Slip \%} = 100 \frac{(1 - A_s)}{S_o}$$

A_s = Actual travel speed in km/hr

S_o = No load travel speed (km/hr).

3.2.5 Evaluation of the effect of shape of farmland

To study the effect of shape of farm plots on tillage efficiency, the land was divided into three, one hectare plots with varying shape. The productive time was noted for each plot shape. The total non-productive time was also noted. The field capacity and field efficiency were obtained at varying speed for each plot shape as shown in table 14.

3.2.6 Primary Tillage and Tillage effectiveness

The land was marked out before the commencement of the tillage operations. The headland was also cleared as a pre-tillage operation.

There were no irrigation facilities on the test stations, so the operation was performed during the raining season from March to June. The height of the existing vegetation on each farmland was noted for all primary tillage operations performed. This ranged from 0.2m to above 2.5m. The moisture of content of each farm plot was also determined.

The primary tillage operation was performed using three different tractors, 70 hp Ford, 60 hp MF and 59 hp Steyr. The productive and non-productive time consumed were recorded as shown in tables 14 to 22. The operation was performed twice for farmlands with vegetation higher than 1.8 meters especially where the elephant grass constituted the vegetal cover.

The operation was repeated at various soil type, moisture content, tractor type, speed of operation and farm size. The data obtained were used to estimate the costs of tillage operations as shown in tables 14 to 22 (Appendix 1).

The time loss items were identified as follows:

- Turning at the headland
- Idle travel
- Time loss due to presence of obstacles
- Repair and reset
- Cleaning the blades
- Refuelling
- Resting.

The following precautions were observed during the tillage operations:

Tillage operations were not performed immediately after a heavy storm. This is to avoid excessive wheel slippage. Although sandy loam soil has higher infiltration rate compared to clayey loam soil, tillage operation was not done after a heavy storm to avoid sinkage.

The operator only was allowed on the tractor during operation to avoid accident or distractions.

The tractors were kept in good working conditions before the tests began, hence there were no major breakdowns during operations.

Time loss at the headland was minimized by adopting rectangular farm shape during operations.

The implements were properly hitched during the test because of its notable effect on draught and speed of operation.

The experiment was controlled to avoid speed fluctuation except occasionally at the headlands.

Some farmers plant their crops immediately after primary tillage operations, thus the degree of pulverization and the amount of trash coverage were noted at various speed, moisture content and soil type.

3.2.7 Secondary Tillage and Tillage effectiveness

The implement used during this operation was a disc harrow with 2.0m rated width. This operation was performed between 5 and 7 days after primary tillage operations. However, the interval between primary and secondary tillage operations can be more than

the latter depending on the initial farm conditions.

The operation was performed and the time taken by the productive and non-productive items were recorded. Tillage effectiveness was evaluated as the following soil, implement and operational parameters were varied; soil type, moisture content, implement type, implement size, farm size and speed of operation.

The time loss items during secondary tillage operations were similar to the time loss items during primary tillage operations. The same set of precautions observed during primary tillage operations were observed. The data obtained was used to compute field capacities and to estimate tillage costs as shown in tables 14 to 30 (Appendix 1 and 2).

3.2.8 Determination of Fuel Consumption Rate

Three tractors of different make, having 52.22kw, 44.76kw and 44.01kw were used to evaluate the fuel consumption rate at various forward speed.

The fuel tank of each tractor used during the study was filled to capacity before the commencement of the primary tillage operation. At the interval of 1 hour, 2 hours, 3 hours and 4 hours, the fuel tank was refilled to capacity using a measuring cylinder. The number of litres required to refill the fuel tank to capacity after each interval represented the fuel consumed per unit time. The average values of fuel consumed by each tractor per hour are as shown in table 35 (Appendix 4). The procedure was repeated for secondary tillage operations and the results are also shown in table 35.

3.2.9 Determination of the Power Requirement for Tillage Operations

The power required to operate tillage machines could be measured by drawbar dynamometer, hydraulic type dynamometer or spring dynamometer.

There was no dynamometer available for use during the study, thus a calibrated spring device Fig 20 (spring dynamometer) was used.

The spring rate (k) was first determined from the relation $F = kx$. This was done to ensure that the spring obeyed Hooke's law. Thus an experiment to measure the extension of the spring per unit force was performed. The result is shown in table 32 (Appendix 3).

To measure the draught required for primary tillage operation, the spring dynamometer was attached to the front of 44.76kw tractor on which a disc plough was mounted. Another auxiliary 52.22kw tractor was used to pull the implement mounted tractor through the spring dynamometer. The auxiliary tractor pulled the implement mounted tractor with the latter tractor in neutral gear but with the implement in operating position. The draught was measured. The draught was also measured when the implement was raised. The implement was dropped and the draught required by the tractor alone was measured. This was done on sandy loam soil and on clayey loam soil. The procedure above was repeated using the disc harrow. The results of the experiment are shown in tables 33 and 34 (Appendix 3).

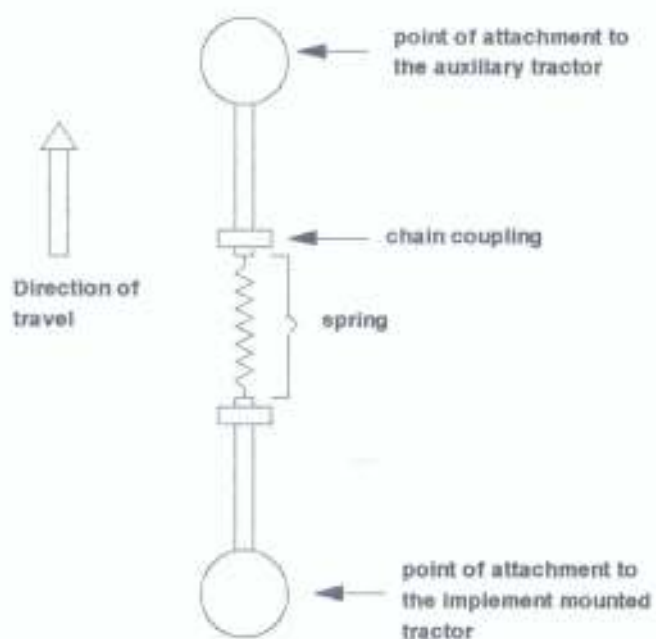


Fig. 20 SPRING DYNAMOMETER

3.3.1 Determination of Field Capacity and Field Efficiency

On a farmland of length l , of 200m and breadth b , of 50m, a disc plough of width w , of 1.3m was used during primary tillage operation. The following parameters affect the duration of the operation.

$$(i) \quad n_t = b/w$$

$$(ii) \quad t_t = \frac{1}{v} n_t$$

where n_t = Number of trips over the farmland

t_t = theoretical time taken to complete the operation.

for (200 x 50) m² farmland

$$n_t = 50/1.3 \quad 39 \text{ trips}$$

$$\text{At } 6 \text{ km/hr} = 1.67 \text{ m/s}$$

$$t_t = \frac{(200)(39)}{1.67}$$

$$t_t = 77 \text{ min/ha.}$$

Theoretical field capacity $C_t = \frac{1}{t_t} wv$

$$C_t = (1.3)(1.67) \text{ m}^2/\text{s}$$

$$C_t = 0.78 \text{ ha/hr.}$$

The effective field capacity = C_a

$$C_a = \frac{\text{Area covered}}{\text{+ time loss}}$$

$$C_a = \frac{1 \text{ ha}}{(77 + 24)/60}$$

24 mins is the time loss at 6.0km/hr from table 21.

$$= \frac{60}{77+24} = 0.59 \text{ ha/hr}$$

The field efficiency is the ratio of C_a to C_t

$$= \frac{0.59}{0.78} = 0.76$$

At other forward speed of operation, a similar approach was used to calculate the theoretical time, theoretical field capacity and effective field capacity.

- Secondary tillage

The same equation holds as in primary tillage, but the rated width was bigger (2m).

The number of trips per hectare

$$n_t = b/w$$

The implement used was disc harrow

Implement width -- 2.0m

$$\text{Number of trips} = 50/2$$

$$25 \text{ trips / ha}$$

The speed (v) was varied from 6 km/hr to 8 km/hr

$$\text{at } 6 \text{ km/hr} = 1.67 \text{ m/s}$$

$$t_t = \frac{L}{v} (n_t) = \frac{200}{1.67} \quad (25)$$

$$= 2994.0 \text{ sec/ha}$$

$$t_t = 50 \text{ min/ha.}$$

Theoretical time was calculated for other speeds in a similar way.

All the time loss items considered in primary tillage were noted also during secondary tillage operations. The total time taken was recorded. The difference between the total time taken (actual)

and the theoretical time form the time loss for the operation.

$$\text{Theoretical field capacity} = \frac{60}{50} = 1.2 \text{ ha/hr}$$

$$\text{Effective field capacity} = \frac{60}{t_t + \text{total time loss}}$$

$$= \frac{60}{50} + 20 = 0.86 \text{ ha/hr}$$

$$\text{The field efficiency} = 0.86/1.2 = 0.72$$

3.3.2 Determination of Tractor-Implement Match

According to Hunt (1974) and Kepner et al 1975, the power measurements of various tractors showed that no drawbar power is less than 50 percent of the indicated power of the tractor. The specific draught on clayey soil with a factor of safety of 1.5 are 8.585 kN/m and 6.098 kN/m for primary tillage operation and secondary tillage operation respectively.

Therefore, at 7 kmh^{-1} the maximum width of implement for the three tractors would be:

$$P = Fv$$

(i) for 52.22 kw Ford

$$(a) \quad 52220 = 8585 (1.944) \quad \text{where } F = \text{draught (n/m)}$$

$$\text{width (m)} = 3.13\text{m.}$$

$$P = \text{power (kw)}$$

$$v = \text{speed (m/s)}$$

50% of indicated power available at drawbar

$$\therefore \text{maximum width (0.5) (3.13)m}$$

$$\text{maximum width of disc plough} = 1.56\text{m.}$$

(b) disc harrow

$$0.5 (52220) = 6098 (1.944)$$

$$\text{maximum width} = 2.20\text{m.}$$

(ii) 44.76 kw MF

(a) Disc plough

$$0.5 (44760) = 8585 (1.944)$$

$$\therefore \text{maximum width} = 1.34\text{m}$$

(b) disc harrow

$$0.5 (44760) = 6098 (1.944)$$

$$\text{maximum width} = 1.90\text{m}$$

(iii) 44.01 kw Steyr

(a) disc plough

$$0.5 (44010) = 8585 (1.944)$$

$$\text{maximum width} = 1.32\text{m}$$

(b) disc harrow

$$0.5 (44010) = 6098 (1.944)$$

$$\text{maximum width} = 1.90\text{m}.$$

3.3.2 Determination of the Cost of Tillage Operations

Fixed Costs

Table 13: Annual depreciation of three tractors

Tractor type	Total fixed cost N	Year or purchase	Salvage value N	Depreciation N	Tractor Age
Steyr 59 hp	80,000	1988	8,000	4,800	6
MF 60 hp	150,000	1990	15,000	9,000	4
Ford 70 hp	220,000	1991	22,000	13,200	3

New tractors could be expected to operate for 15 years with good maintenance culture.

Taking 10% of the cost price as salvage value, we obtain

the value in table 23.

(a) Depreciation: using the straight line method due to its simplicity and convenience

$$D = \frac{P - S}{L}$$

(b) Interest: Depending on the source of money, interest varies from one bank to the other.

$$I = \text{Rate} \left(\frac{\text{Purchase cost} + \text{salvage value}}{200 (15)} \right)$$

According to Kepner et al (1978)

(c) shelter, taxes, insurance = 0.02

1. Steyr 59 hp at N80,000

The salvage value = 10% of N80,000 = N8,000

$$(a) \text{ Depreciation} = \frac{80,000 - 8,000}{15} = \text{N}4,800$$

$$(b) \text{ Interest} = \frac{20(80,000 + \text{N}8,000)}{200 (15)}$$

$$= \text{N}587.00$$

(c) Shelter, taxes and insurance can be estimated as 2% of the purchase price

$$\therefore 2/100 \times 80,000 = \text{N}1,600$$

$$\text{Total fixed cost} = 4,800 + \text{N}587 + \text{N}1600$$

$$= \text{N}6987$$

$$\text{Total annual fixed cost} = \text{N}6987$$

For a farmer making use of his tractor for 1000 hours of productive work per annum.

The total fixed cost for Steyr 59 hp becomes N6.987 or N7.00 per hour.

Variable cost

(i) According to Kepner et al (1978)

repair cost can be estimated as 25% of purchased price

$$25\% \text{ of } 80,000 = \text{N}2,000 \text{ per annum}$$

$$= \text{N}2.00 \text{ per hour.}$$

(ii) Fuel Cost

The fuel cost per hour from table 22 at the maximum speed 8.0km/hr is 12.07 litre/hr for Steyr 59 hp. The present rate of diesel is N3.00 per litre.

$$\therefore \text{Fuel cost} = \text{N}3.00/\text{L} \times 12.07 \text{ L/hr}$$

$$= \text{N}36.21 \text{ per hour}$$

(iii) Taking 15% of fuel cost as lubricant cost

$$15\% \text{ of } 36.21 = \text{N}5.43 \text{ per hour}$$

(iv) The cheapest labour is obtainable by employing an operator on full time basis. For an operator receiving N25,000 total package per annum. The labour cost/hr = N25.00 per hour.

$$\text{Total variable cost} = ((i) + (ii) + (iii) + (iv))$$

$$= (2.00 + 36.21 + 5.43 + 25)$$

$$= \text{N}68.64$$

$\therefore$ with 59 hp Steyr

$$\text{Total cost of tillage operation per hour}$$

$$= 7.00 + 68.64 = \text{N}75.64 \text{ per hour}$$

$$\text{or } \text{N}75,640 \text{ per annum.}$$

A similar approach was used to determine the annual cost of MF 60 hp and Ford 70 hp.

2. MF 60 hp at N150,000

(a) Depreciation = N9,000

(b) Interest = $20 \frac{(150,000 + 15,000)}{200 (15)}$

N1,100

(c) shelter, tax and insurance

$2/100 \times 150,000$

= N3,000

Total fixed cost = (9,000 + 1,100 + 3,000)

= N13,100 per annum

The cost per hour = N13.10

Variable cost

(i) repair cost

$2.5/100 \times 150,000 = \text{N}3,750$

(ii) Fuel cost

at 8.0 km/hr fuel consumption = 12.18 L/h

at the rate of N3 per litre

Fuel cost = $3 \times 12.18 = \text{N}36.54$

= N36,540 per annum

(iii) lubricants cost

$15\% \times 36,540 = \text{N}5481$ per annum

(iv) Labour cost = N25,000 per annum

Total variable cost = $3,750 + 36,540 + 5,481 + 25,000$

= N70,771 per annum or N70.771 per hour.

Total operating cost = fixed cost + variable cost

= $13,100 + 70,771$

N83,871 per annum

Total cost per hour = N83.871

(3) 70 hp (operating cost)

(a) Depreciation = 13200 per annum

(b) Interest = $20 \frac{(220000 + 22000)}{200 (15)}$

= N1613.33 per annum

(c) shelter, tax and insurance

$2/100 \times 220000 = \text{N}4400$

Total fixed cost = $13200 + 1613.33 + 4400$

= N19213.33

= N19.21 per hour.

Variable cost

(i) repair cost

$2.5/100 \times 220000 = \text{N}5500$

(ii) Fuel cost at 12.90 l/hr

at the rate of N3 per litre

Fuel cost = $3 \times 12.90 = \text{N}38.70$ per hour

= N38700 per annum

(iii) Lubricants cost = $15\% \times 38700$

= N5.81 per hour

or N5810 per annum

(iv) Labour cost = N25,000 per annum

= N25 per hour

Total cost (variable cost)

= $5500 + 38700 + 5810 + 25000$

$$= \text{N}75010 \text{ per annum}$$

$$\text{variable cost} = \text{N}75.01 \text{ per hour}$$

Total operating cost

$$= \text{N}19213.33 + \text{N}75010$$

$$= \text{N}94223.33 \text{ per annum}$$

$$\therefore \text{Total cost} = \text{N}94.22 \text{ per hour.}$$

3.3.3 Determination of costs at varying hours of use per annum

(i) 59 hp Steyr

Fixed cost per annum is not affected by time of use

$$= \text{N}7000 \text{ per annum}$$

$$\text{at 400 hours per annum} = \text{N}17.50/\text{hr}$$

$$\text{at 600 hours per annum} = \text{N}11.67/\text{hr}$$

$$\text{at 800 hours per annum} = \text{N}8.75/\text{hr}$$

$$\text{at 1000 hours per annum} = \text{N}7.00/\text{hr}$$

Variable cost however is directly related to the amount of use

59 hp Steyr

$$\text{cost per hour} = \text{N}68.64$$

$$\text{for 1000 hours} = \text{N}68,640$$

$$\text{for 800 hours} = \text{N}54912 = \text{N}68.64 \text{ per hour}$$

cost per hour is constant but cost per annum increases with increasing use

$\therefore$

cost per hour at varying length of use

$$(i) \text{ 1000 hours} = 7 + 68.64 = \text{N}75.64$$

$$\text{800 hours} = 8.75 + 68.64 = \text{N}77.39$$

$$600 \text{ hours} = 11.67 + 68.64 = \text{N}80.30$$

$$400 \text{ hours} = 17.50 + 68.64 = \text{N}86.14$$

(2) MF 60 hp

Fixed cost

$$\text{at } 1000 \text{ hours} = \text{N}13.10 \text{ per hour}$$

$$\text{at } 800 \text{ hours} = \text{N}16.38$$

$$\text{at } 600 \text{ hours} = \text{N}21.83$$

$$\text{at } 400 \text{ hours} = \text{N}32.75$$

Variable cost per hour is constant i.e. N70.77

$$\therefore \text{ at } 1000 \text{ hours of annual use, total cost/hr} = (13.10 + 70.77) = 83.87$$

$$\text{at } 800 \text{ hours of annual use, total cost} = (16.38 + 70.71) = \text{N}87.09$$

$$\text{at } 600 \text{ hours of annual use, total cost} = (21.83 + 70.71) = \text{N}92.54$$

$$\text{at } 400 \text{ hours of annual use, total cost} = (32.75 + 70.71) = \text{N}103.46$$

(3) Ford 70 hp

Fixed cost

$$\text{at } 1000 \text{ hours per annum} = \text{N}19.21 \text{ per hr}$$

$$\text{at } 800 \text{ hours per annum} = \text{N}24.01 \text{ per hr}$$

$$\text{at } 600 \text{ hours per annum} = \text{N}32.01 \text{ per hr}$$

$$\text{at } 400 \text{ hours per annum} = \text{N}48.02 \text{ per hr}$$

Variable cost per hour is constant = N75.01

$$\therefore \text{ at } 1000 \text{ hours of annual use, total cost/hr} = (19.21 + 75.01) = \text{N}94.22$$

$$\text{at } 800 \text{ hours of annual use, total cost/hr} = (24.01 + 75.01) = \text{N}99.02$$

$$\text{at } 600 \text{ hours of annual use, total cost/hr} = (32.01 + 75.01) = \text{N}107.02$$

$$\text{at } 400 \text{ hours of annual use, total cost/hr} = (48.02 + 75.01) = \text{N}123.03$$

3.3.4 Comparison between the cost of hiring and owning

7km/hr is the mean between 8km/hr and 6km/hr range of forward speed. Therefore the mean cost per hectare for primary and secondary tillage operations are considered

∴ primary tillage, the mean cost on both clayey and sandy loam is: (Tables 17 and 18)

$$\frac{140.57 + 112.38 + 124.31 + 143.11 + 115.16 + 127.55}{6} \\ = \text{N}127.35$$

∴ secondary tillage (Tables 25 and 26)

$$\text{mean} = \frac{95.73 + 78.06 + 86.43 + 96.77 + 78.14 + 86.79}{6} \\ = \text{N}86.98$$

Hiring cost:

ploughing = N600

Cost of fuel = $\frac{88\text{mins}}{60}$ per hectare $\times 10.83\text{L/hr} \times \text{N}3/\text{L}$

Tables (17 and 18) and Table 35

$$= \text{N}47.68 \text{ per hectare}$$

∴ cost of ploughing per hectare from the tractor hiring service = N600 + N47.68 = N647.68

Fuel cost of harrowing = $\frac{61}{60}$ per ha $\times 9.09\text{L/hr} \times \text{N}3/\text{L}$

$$= \text{N}27.72$$

∴ total average cost = N500 + 27.72
= N527.72

CHAPTER FOUR

4. RESULTS AND DISCUSSION

The results of the tests performed during the study are shown in tables 14 to 37 (see appendices) and figures 21 to 27.

4.1 SOIL TYPE AND MOISTURE CONTENT

The results of the particle size analysis (table 31 Appendix 3) showed that there were two agricultural soils, clayey loam and sandy loam soils in the study area. As shown in tables 14 to 30 (Appendix 1 and 2) the values of field efficiencies obtained during tillage operations was higher in sandy loam soils than in clayey loam soils. However this difference was notably reduced at low forward speeds. Figure 22 also shows that the effective field capacities are the same on both soils at low forward speeds, but higher on sandy loam than clayey loam soils beyond 6.5km/hr.

The moisture content of soils on the test stations at an average depth of 15cm on sandy loam and clayey loam soils was 12 to 18% and 14 - 21% respectively. The field efficiency and effectiveness of tillage operations reduced drastically below this range of moisture content. Below the range, the resistance to tillage implements was very high due to cementation effect among the soil particles. Beyond the range, however, sinkage increased on sandy loam soils while slippage and clogging increased on clayey loam soils.

4.2 FIELD CONDITION, SIZE AND SHAPE

Table 14 shows the effect on varying the shape of field on field capacity and field efficiency. It was observed that the adoption of

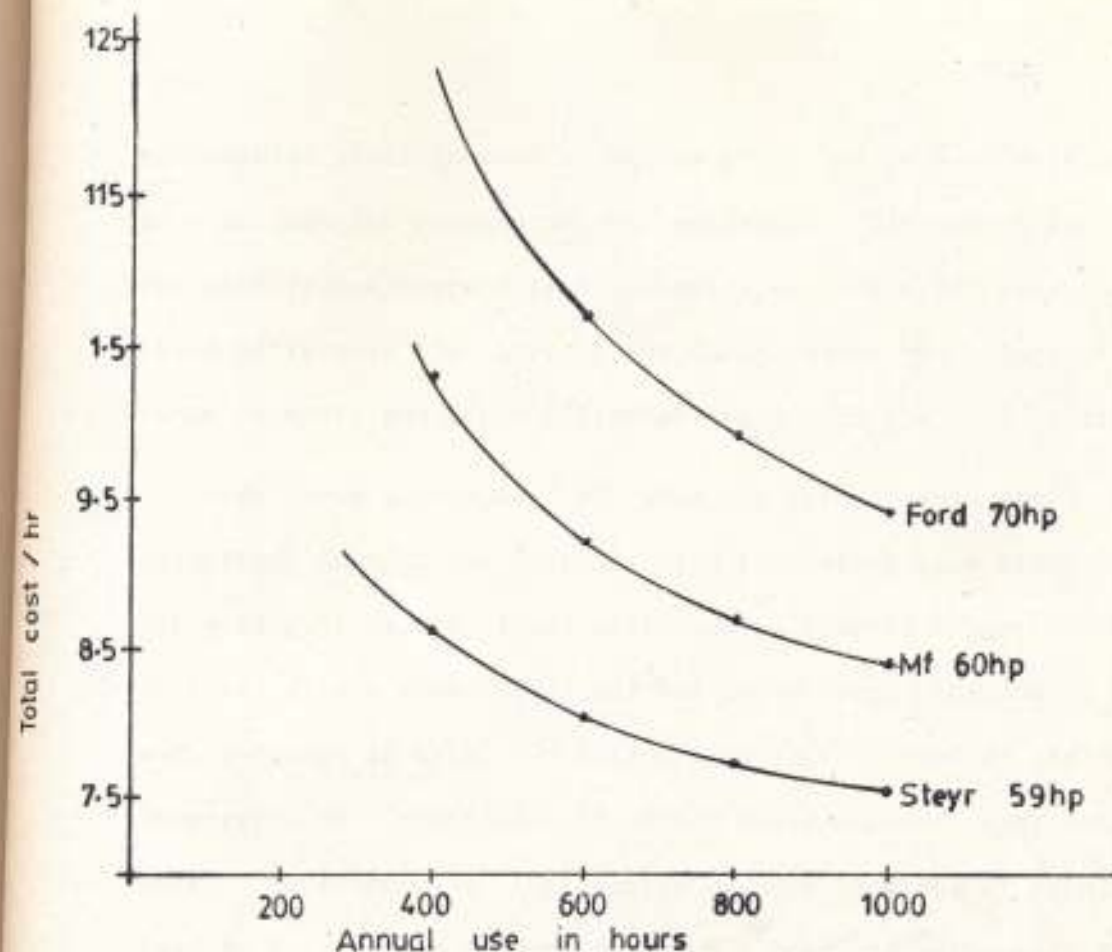


Fig. 21 The total cost per hour for tillage operations at varying annual tractor usage.

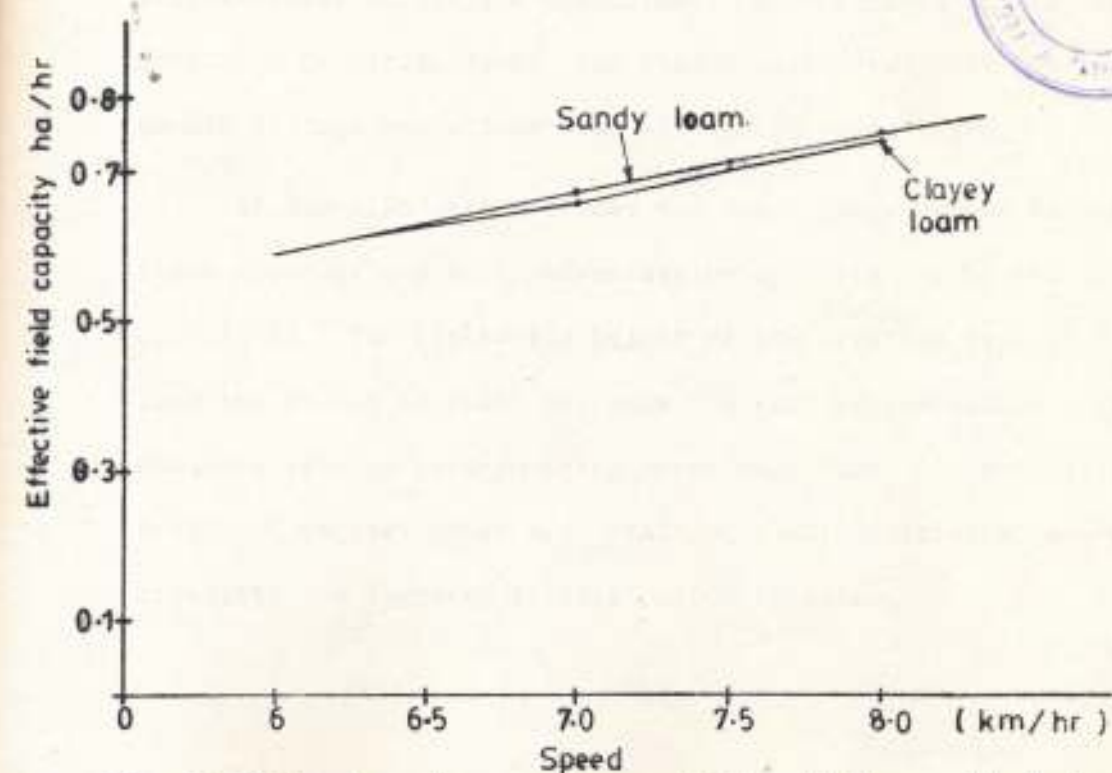


Fig. 22 Effect of varying speed on effective field capacity during primary tillage operations.

rectangular plots instead of square plots led to a notable reduction in time loss for turning at the headlands. This result agrees with the established concept that the major criterium for selecting a field pattern is the shape of the field, since the values of the field capacity and field efficiency vary with the field pattern used.

As shown in figure 27, when the farm size is small, the field efficiency increaseses notably with increasing farm size. However, for a large farm, the field efficiency decreased slightly with increasing farm size. This was due to varying condition of the field with increase in area. On a farm with fairly levelled fields and less interruptions - the field efficiency would increase with increase in area. Therefore, the cultivation of more hectares of farmland should lead to a reduction in unit production cost and agree with the theory of economies of scale, Witney (1988).

It was observed that the initial field condition affects the effectiveness of tillage operations. High forward speeds are not adoptable on virgin lands, but fields cultivated over the years enhanced smooth tillage operations even at high forward speed.

It was also observed that the two tillage output factors, trash coverage and soil pulverization are affected by the initial field conditions. The higher the height of the existing vegetal cover, the less the amount of trash coverage and soil pulverization. Thus an adequate farming pattern (crop rotation), aimed at controlling the height of vegetal cover and retaining plant nutrients is a pre-requisite to improved tillage output factors.

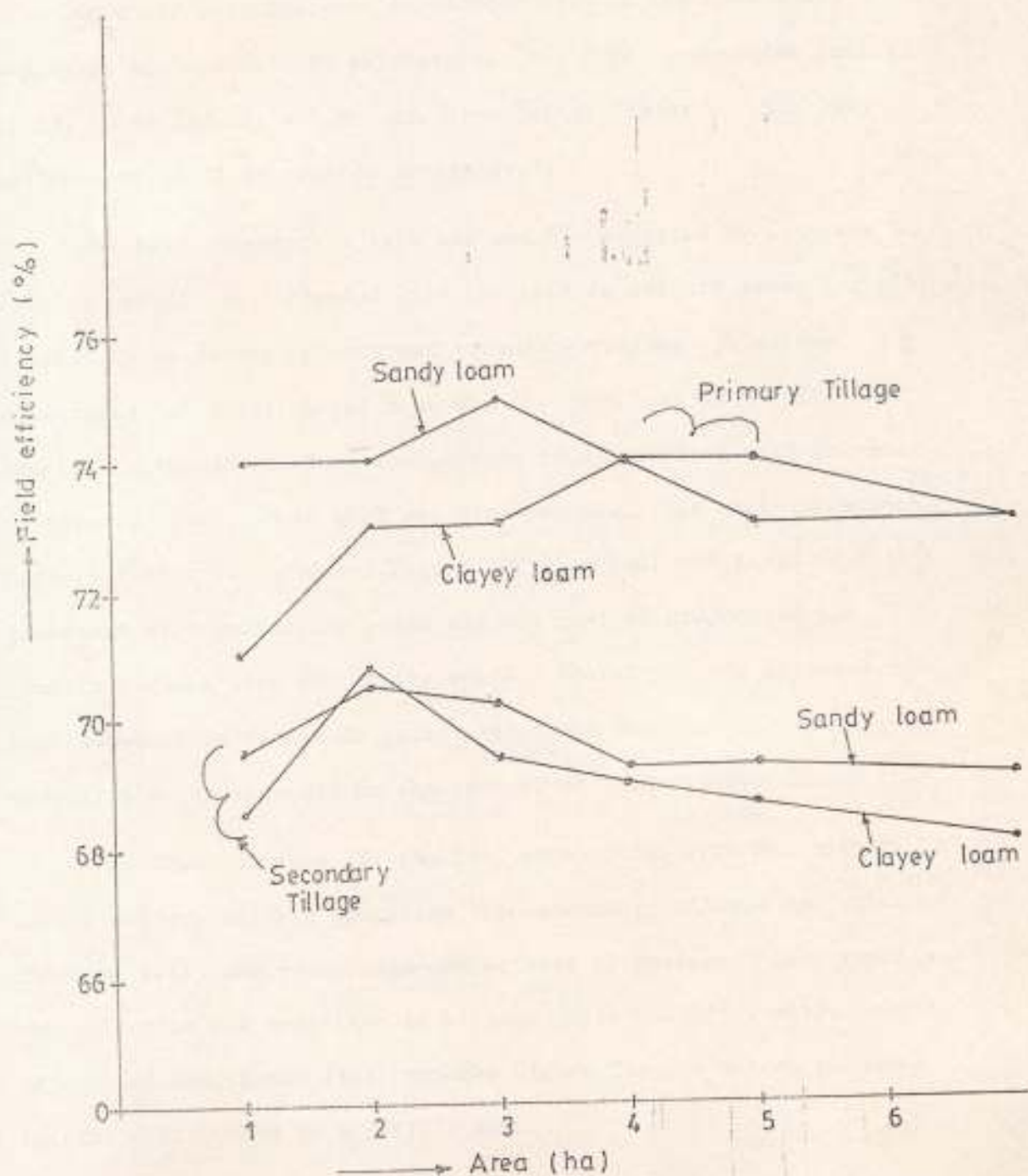


Fig- 27 The effect of increasing area of farmland on field efficiency.

4.3 FUEL CONSUMPTION RATE

The average fuel consumption rate of three tractors are shown in table 35 (Appendix 4). It was observed that the fuel consumption rate increased with increase in tractor size at the same soil, implement and operational parameters. The fuel consumption rate of 11.29, 10.66 and 10.56 L/hr were recorded at 7km/hr for 52.22kw, 44.76kw and 44.01 kw tractor respectively.

The fuel consumption rate was notably affected by increase in forward speed. It increased with increase in forward speed for all tractor types during primary and secondary tillage operations. A difference of 3 litres per hour was observed between 8 km/hr and 6km/hr. Although the fuel consumption rate increased with increase in forward speed. More work was done per unit time with increase in speed. Tables 14 to 30 and figure 22 show that the field capacity increased with increasing speed and the cost of production per hectare reduces with increasing speed. Therefore, the increase in fuel consumption rate with increasing speed does not have any undesirable consequence on the economy of production.

As shown in table 35, the fuel consumption rate was higher during primary tillage operation than secondary tillage operation at the same soil, implement and operational parameters. This results not only from the variation in tillage implement size, shape, depth of cut and length but also from the higher draught needed to cause initial disturbance to a soil in situ.

4.4 POWER CONSUMPTION RATE

Table 34 (Appendix 3) shows the power consumed by tillage implements during primary and secondary tillage operations. The power consumed per meter length of the implement was greater during primary tillage operation than in secondary tillage operation at the same forward speed. At 7.0km/hr the power required was 9.95kw/m and 6.95 kw/m for the 1.3m disc plough and 2.0m double action tandem disc harrow respectively.

As shown in table 34, the power requirement increased with increase in forward speed, thus the maximum permissible forward speed should be considered in determining tractor size. The power requirements for both primary and secondary tillage operations was higher in clayey loam soil than in sandy loam soil. This results not only because clayey loam soil retain more water but also because clayey loam soil is heavier than sandy loam soil. Thus the type of soil had a notable influence on the power consumed during tillage operations.

According to Arno Dego (1986), there is no general answer to the question of tractor size. The minimum tractor size should be determined according to the operation for which the highest power requirement is needed. Thus appropriate tractor - implement matching is the bedrock of a successful tillage optimisation technique. The power required by tillage implements from the foregoing is influenced by soil, implement and operational parameters.

4.5 FIELD CAPACITY AND FIELD EFFICIENCY

The values of field efficiencies obtained during primary and secondary tillage operations are shown in tables 14 to 30. The maximum

value of field efficiency obtained on clayey loam soils during primary tillage operation was 76% at 6km/hr. The minimum value obtained was 72% at 8km/hr. On sandy loam soils, the efficiency was slightly higher, 76.5% and 73% were obtained at 6km/hr and 8km/hr respectively. Thus field efficiency decreased with increasing speed as shown in figure 4.6 because the effect of non-productive time was higher at increasing speed.

The field capacity increased with increasing speed on both soils. Figure 22 shows similar values of effective field capacity on both soils below 6.5km/hr. The field capacity was higher in sandy loam soils than clayey loam soils beyond 6.5km/hr.

Figure 27 shows the effect of increasing area of field on field efficiency. The values of field efficiencies on both soils increased initially with increase in area but drops slightly with further increase in area. This was due to the variation in soil conditions, increasing interruptions and other time loss items with increase in area.

The values of field efficiencies obtained during secondary tillage operations on clayey loam soils were 70% and 68% at 6km/hr and 8km/hr respectively. While working on sandy loam soils during secondary tillage operations, the values of field efficiencies were 71% and 69% at 6km/hr and 8km/hr respectively.

The width of disc harrow used was bigger than that of the disc plough, thus the field capacity was higher with the disc harrow than the disc plough. However, the field efficiency obtained with the disc plough was higher at the same soil and operational parameters.

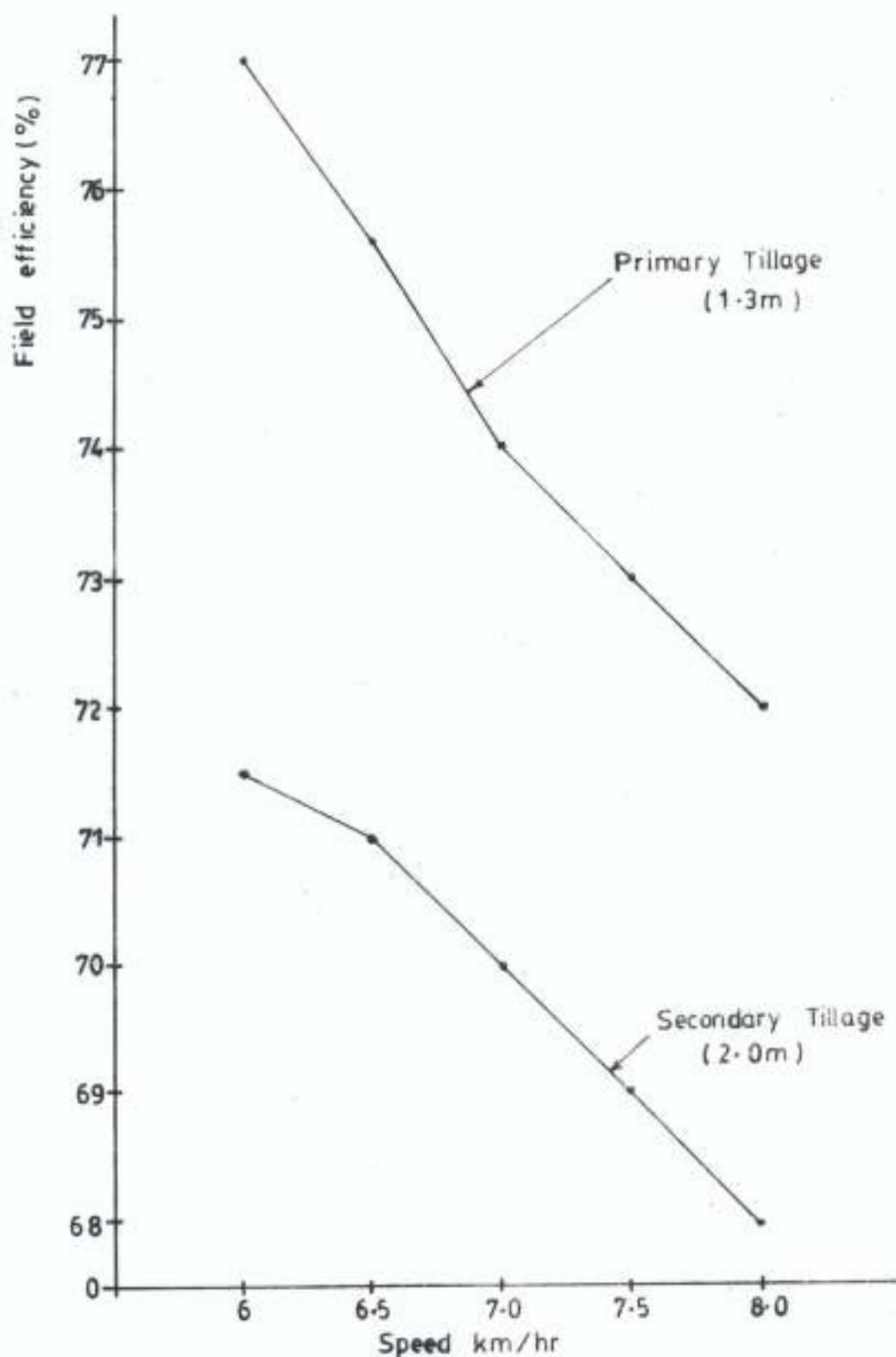


Fig.26 The effect of increasing speed on field efficiency.

4.6 COST OF OPERATION

Figure 21 shows the relationship between increasing annual use and total production cost. The greater the duration of use per annum, the less the total production cost per hour for all types of tractor. The 52.22kw Ford had a total cost of N94 per annum at 1000 hours annual use. As shown in figure 25, the total cost per hectare was not only affected by tractor type, but also affected by soil type. The smaller the soil particles making up a soil type, the greater the power required for tillage, the less the field efficiency and the greater the cost of production (figures 25 and 27).

The mean cost per hectare for three tractors are shown in tables 15 to 30 (Appendix 1 and 2). It decreases with increasing speed for both primary and secondary tillage operations. Thus it is profitable to make use of higher forward speed ^{within} the acceptable range. Witney and Sardoun (1989), gave 5.5 to 10km/hr and 5 to 10 km/hr for primary and secondary tillage operations respectively as an acceptable range. On a farm with specific annual use, the total cost increases as shown in figures 23 and 24. But when increase in hectarage means increasing annual use, the total cost increases at a decreasing rate with increase in area.

The mean cost of operating the tractor per hectare was ₦127.35 and ₦86.98 for primary and secondary tillage operations respectively. This values were obtained in this study. However the cost of hiring from the governments hiring unit was ₦600 and ₦500 per hectare for primary and secondary tillage operations respectively. The commercial hiring unit releases the tractor at ₦1,000 for both primary and secondary tillages operations.

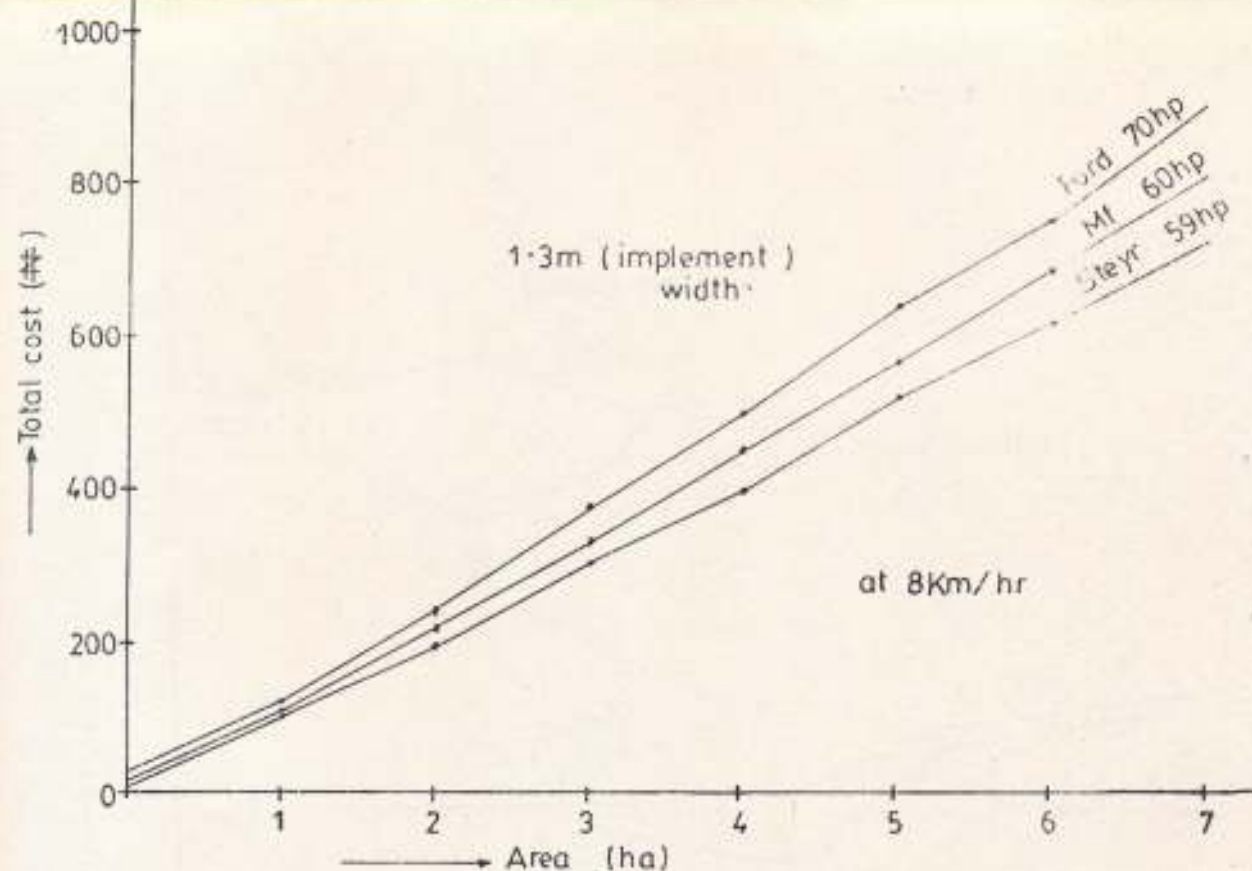


Fig-23 The effect of increasing area of farmland on total cost of primary tillage operations

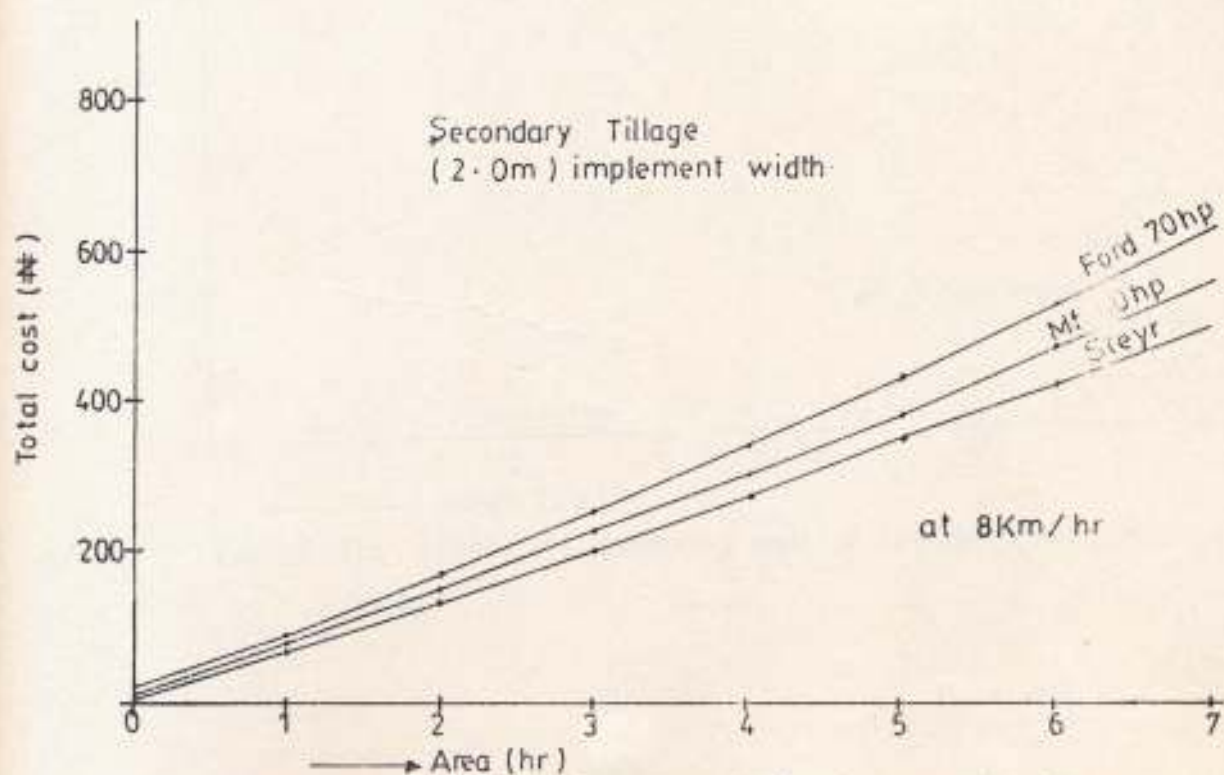


Fig-24 The effect of increasing area of farmland on total cost of secondary tillage operations

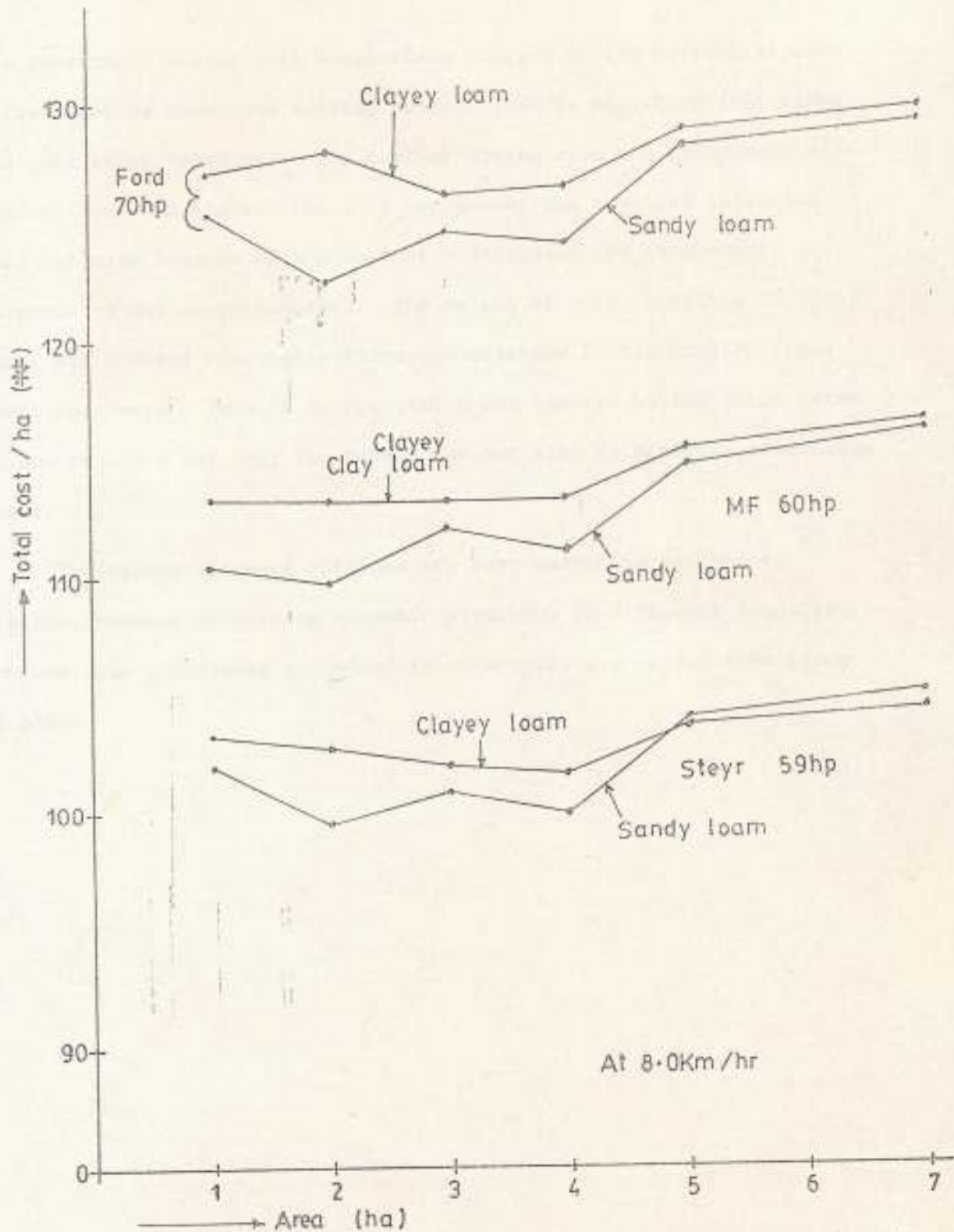


Fig. 25 The effect of increasing area of farmland on total cost per hectare .

The government hiring unit based their charges on the current tractor price which is about one million naira. This is more than four times the cost three years ago. The cost of hiring from the government hiring unit was the highest not only because of the supposed inflation rate but also because of the cost of maintaining the management, maintenance and operating crew. The values of costs obtained in this study are however reasonable since old tractors having smaller fixed costs were used. Thus it is profitable for farmers having large farms to own tractors not only for timely use but also to minimize production costs.

The values of costs obtained are most useful in south-west Nigeria, because of varying economic situation in different countries. However, the principles contained in this study are useful from place to place.

CHAPTER FIVE

5.0 CONCLUSION

In this study, an investigation into the parameters affecting tillage operations was carried out. It was found that soil parameters such as soil type, soil moisture content; implement parameters such as Implement type, Implement size and operational parameter such as forward speed had notable effects on field efficiency and the cost of tillage operations.

The moisture content of 12 to 18% on sandy loam soil and 14 to 21% on clayey loam soil is adjudged optimum during tillage operations in South-west Nigeria. This is due to minimum clogging and slippage obtainable within this range of moisture content.

The maximum value of field efficiency obtained during primary tillage operation was 76.5% and 76% on sandy loam and clayey loam soils respectively. However, 71% and 70% were recorded during secondary tillage operation on Sandy loam and clayey loam soils respectively. Thus the value of field efficiency obtained while working on sandy loam soil is higher than the value obtained on clayey loam soil.

The fuel consumption rate not only increases from 9.70 L/hr to 12.70 L/hr as the speed increases from 6.0 km/hr to 8.0 km/hr, but also increases from 9.05 to 9.70 L/hr as the tractor power increases from 44kw to 52kw at the same forward speed (6.0 km/hr). The power consumed during tillage operations on clayey loam soil is 1.5 to 2.0kw higher than the power consumed while working on sandy loam soil.

The result from this study shows that 44kw to 52kw tractor can be used successfully to pull 1.3m disc plough or 2.0m disc harrow. This result confirms the importance of appropriate tractor-implement matching.

The cost of tillage is directly influenced by the annual usage of tractors. As the annual use increases from 200 to 1000 hours, the cost of tillage operation decreases from ₦125.00 to ₦94.00 per hectare with a 52 kw tractor. The mean cost of tillage operation also decreases from ₦157.81 to ₦125.56 per hectare as the speed increases from 6.0km/hr to 8.0km/hr with the 52kw tractor. Thus high forward speeds are profitable within the acceptable range. The cost of production is generally higher during primary tillage operation than during secondary tillage operations. The tractors used for this project were purchased between 1988 and 1991, thus tractors between the age of 3 and 6 years are more economical to operate than never ones in south-west Nigeria. This is due to the alarming rate of inflation in the sub-region.

It could be inferred from the above study that with good planning and adequate maintenance of tractors and accessories, the operational cost is not only minimized, high field efficiencies are also obtainable in south-west Nigeria. Since the data in this study provides a way of combining soil, implement and operational parameters for optimum tillage, it could serve as a good check-list for tractor owners to know the cost of tillage operations at various conditions.

The maintenance culture in south-west Nigeria is gradually improving. However the following recommendations are noteworthy:

1. Appropriate tractor-impliment matching should be adopted by tractor owners.
2. The soil type and its moisture contents should be determined before tillage operations are performed. This will aid the use of suitable values of operational parameters for optimum tillage.
3. High forward speeds should be encouraged within the acceptable range to reduce tillage costs.
4. The annual usage of tractors should be increased to about 1000 hours to reduce tractor costs during tillage operations.
5. Adequate tillage records should be kept by tractor owners to aid the determination of tractor costs.

APPENDIX 1

RESULTS OF PRIMARY TILLAGE OPERATION
(Tables 14 to 22)

Table 14: The effect of shape of farmland and speed on field efficiency

Primary Tillage Shape of farmland (m)	Implement Width Disc Plough	Area (ha)	Tract- or Type	Soil Type	Speed km/hr	Theoretical time (min)	Time loss (min)	Theoretical field capacity (ha/hr)	Effective field capacity (ha/hr)	Field Efficiency	Productive cost N	Non-Productive cost N	Total cost/ha	Mean cost/ha
200 x 50	1.3	1	Ford 70hp	Sandy loam	8.0	58.00	18	1.03	0.79	0.77	91.08	28.27	119.35	125.64
150 x 66.7	1.3	1			8.0	58.00	22	1.03	0.75	0.73	91.08	34.57	125.65	
117 x 85.5	1.3	1			8.0	58.00	26	1.03	0.71	0.69	91.08	40.83	131.91	
200 x 50	1.3	1			7.0	66.06	19	0.90	0.70	0.78	103.64	29.84	133.48	140.81
150 x 66.7	1.3	1			7.0	66.06	24	0.90	0.67	0.74	103.64	37.69	141.33	
117 x 85.5	1.3	1			7.0	66.06	28	0.90	0.64	0.71	103.64	43.97	147.61	
200 x 50	1.3	1			6.5	71.00	19.8	0.84	0.66	0.79	111.49	31.09	142.58	150.01
150 x 66.7	1.3	1			6.5	71.00	24.8	0.84	0.65	0.75	111.49	38.94	150.43	
117 x 85.5	1.3	1			6.5	71.00	29.0	0.84	0.60	0.71	111.49	45.54	157.03	
200 x 50	1.3	1			6.0	77.00	20.7	0.78	0.61	0.79	120.92	32.51	153.43	160.18
150 x 66.7	1.3	1			6.0	77.00	25.2	0.78	0.59	0.75	120.92	39.57	160.49	
117 x 85.5	1.3	1			6.0	77.00	29.1	0.78	0.57	0.73	120.92	45.70	166.62	

Table 15: The effect of tractor type and area on sandy loam soil at 8 km/hr.

Primary Tillage	Implement Width (m)	Area (ha)	Speed (km/hr)	Tractor Type	Soil Type/Moisture Content	Theoretical time (min)	Time loss (min)	Theoretical field capacity (ha/hr)	Effective field capacity (ha/hr)	Field Efficiency	Productive cost (N)	Non-Productive cost (N)	Total cost (N)	Total cost/ha (N)	Mean cost per hour (N)
200 x 50	1.3	1	8	Ford 70hp	Sandy loam	58	22	1.03	0.75	0.73	91.08	34.55	125.35	125.35	125.56
	1.3	2	8			116	40	1.03	0.77	0.75	182.16	62.81	244.97	122.49	
	1.3	3	8			174	64	1.03	0.75	0.73	273.24	100.50	373.74	124.58	
	1.3	4	8			232	84	1.03	0.76	0.74	364.32	131.91	496.23	124.06	
	1.3	5	8			290	118	1.03	0.73	0.71	455.40	185.30	640.69	128.14	
	1.3	7	8			406	168	1.03	0.73	0.71	637.58	263.82	901.40	128.77	
LITTLE BY LITTLE FARM	1.3	1	8	MF 60hp	Sandy loam	58	21	1.03	0.76	0.74	81.08	29.35	110.43	110.43	112.37
	1.3	2	8			116	41	1.03	0.76	0.74	162.14	57.31	219.45	109.73	
	1.3	3	8			174	67	1.03	0.75	0.73	243.24	93.65	336.89	112.30	
	1.3	4	8			232	86	1.03	0.75	0.73	324.20	120.21	444.41	111.10	
	1.3	5	8			290	120	1.03	0.73	0.71	405.40	167.74	573.14	114.63	
	1.3	7	8			406	175	1.03	0.72	0.70	567.52	224.62	812.14	116.02	
	1.3	1	8	Steyr 59hp	Sandy loam	58	23	1.03	0.74	0.72	73.12	29.00	102.11	102.11	101.96
	1.3	2	8			116	42	1.03	0.76	0.74	146.24	52.95	199.19	99.59	
	1.3	3	8			174	67	1.03	0.75	0.73	219.36	84.46	303.82	101.27	
	1.3	4	8			232	85	1.03	0.76	0.74	292.46	107.16	399.62	99.90	
	1.3	5	8			290	122	1.03	0.73	0.71	365.60	153.80	519.40	103.88	
	1.3	7	8			406	177	1.03	0.72	0.70	511.83	223.14	734.97	104.99	

Table 16: The effect of tractor type and area on clayey loam soil at 8 km/hr.

Primary Tillage	Implement Width (m)	Area ha	Speed km/hr	Tractor Type	Soil Type/Moisture Content %	Theoretical time (min)	Time loss (min)	Theoretical field capacity ha/hr	Effective field capacity ha/hr	Field Efficiency	Productive cost N	Non-Productive cost N	Total cost N	Total cost/ha N	Mean cost per ha N
200 x 50	1.3	1	8	Ford 70hp	Clayey loam 18.5	58	23	1.03	0.74	0.72	91.08	36.12	127.20	127.20	127.62
	1.3	2	8			116	47	1.03	0.74	0.72	182.16	73.81	255.97	127.98	
	1.3	3	8			174	67	1.03	0.75	0.73	273.24	105.21	378.45	126.15	
	1.3	4	8			232	90	1.03	0.75	0.73	364.32	141.33	505.65	126.41	
	1.3	5	8			290	120	1.03	0.73	0.71	455.40	188.44	643.84	128.77	
	1.3	7	8			406	170	1.03	0.73	0.71	637.55	266.96	904.52	129.22	
LITTLE BY LITTLE FARM	1.3	1	8	MF 60hp	Clayey loam 19.3	58	23	1.03	0.74	0.72	81.08	32.15	113.23	113.23	113.92
	1.3	2	8			116	46	1.03	0.74	0.72	162.14	64.30	226.44	113.22	
	1.3	3	8			174	69	1.03	0.74	0.72	243.24	96.45	339.69	113.23	
	1.3	4	8			232	91	1.03	0.74	0.72	324.20	128.60	452.80	113.20	
	1.3	5	8			290	122	1.03	0.73	0.71	405.40	170.54	575.94	115.19	
	1.3	7	8			406	172	1.03	0.73	0.71	567.52	240.43	807.95	115.42	
	1.3	1	8	Steyr 59hp	Clayey loam 19.8	58	24	1.03	0.73	0.71	73.12	30.26	103.38	103.38	102.86
	1.3	2	8			116	47	1.03	0.74	0.72	146.24	59.25	205.49	102.75	
	1.3	3	8			174	69	1.03	0.74	0.72	219.36	86.99	306.34	102.11	
	1.3	4	8			232	91	1.03	0.74	0.72	292.46	114.72	407.18	101.79	
	1.3	5	8			290	122	1.03	0.73	0.71	365.60	153.80	519.40	103.88	
	1.3	7	8			406	173	1.03	0.72	0.70	511.83	218.09	729.93	104.28	

Table 17: The effect of tractor type, and area on sandy loam soil at 7 km/hr.

Primary Tillage	Implement Width (m) Disc Plough	Area (ha)	Speed km/hr	Tractor Type	Soil Type/ Moisture Content %	Theoretical Time (min)	Time loss (min)	Theoretical field capacity ha/hr	Effective field capacity ha/hr	Field efficiency	Productive cost N	Non-Productive cost N	Total cost per ha	Mean cost per ha
200 x 50														
FUTA FARM	1.3	1	7	Ford 70hp	Sandy loam	66	24	0.91	0.67	0.74	103.64	37.69	141.33	140.57
	1.3	2	7			132	46	0.91	0.67	0.74	207.28	72.23	139.76	
	1.3	3	7		15.90	198	67	0.91	0.68	0.75	310.92	105.21	138.71	
	1.3	4	7			264	94	0.91	0.67	0.74	414.56	147.61	140.54	
	1.3	5	7			330	120	0.91	0.67	0.74	518.20	188.44	141.33	
	1.3	7	7			462	170	0.91	0.66	0.73	725.48	266.96	141.78	
LITTLE BY LITTLE FARM	1.3	1	7	Steyr 59hp	Sandy loam	66	23	0.91	0.67	0.74	83.20	29.00	112.20	112.38
	1.3	2	7			132	47	0.91	0.67	0.74	166.41	59.25	112.83	
	1.3	3	7		16.35	198	69	0.91	0.67	0.74	239.62	86.99	108.87	
	1.3	4	7			264	91	0.91	0.68	0.75	332.82	114.72	111.89	
	1.3	5	7			330	122	0.91	0.66	0.73	416.02	153.80	113.96	
	1.3	7	7			462	174	0.91	0.66	0.73	582.43	219.36	114.54	
LITTLE BY LITTLE FARM	1.3	1	7	MF 60hp	Sandy loam	66	22	0.91	0.68	0.75	92.26	30.75	123.01	124.31
	1.3	2	7			132	45	0.91	0.68	0.75	184.51	62.90	123.71	
	1.3	3	7		16.50	198	65	0.91	0.68	0.75	276.77	90.86	122.54	
	1.3	4	7			264	93	0.91	0.67	0.74	369.03	130.00	124.76	
	1.3	5	7			330	120	0.91	0.67	0.74	461.29	167.74	125.81	
	1.3	7	7			462	169	0.91	0.66	0.73	645.80	236.23	126.00	

Table 18: The effect of tractor type and area in clayey loam soil at 7 km/hr.

Primary Tillage Shape of farmland (m)	Implement Width (m) (1.2)	Area (ha)	Speed km/hr	Tractor Type	Soil Type/Moisture Content %	Theoretical Time (min)	Time loss (min)	Theoretical field capacity ha/hr	Effective field capacity ha/hr	Field Efficiency	Productive cost N	Non-Productive cost N	Total cost/ha	Mean cost/ha
200 x 50 FUTA FARM														
	1.3	1	7	Ford 70hp	Clayey loam 19.80	66	27	0.91	0.65	0.71	103.64	42.40	146.04	143.11
	1.3	2	7			132	50	0.91	0.66	0.73	207.28	78.52	142.90	
	1.3	3	7			198	75	0.91	0.66	0.73	310.92	117.77	142.90	
	1.3	4	7			264	96	0.91	0.67	0.74	414.56	150.75	141.33	
	1.3	5	7			330	124	0.91	0.66	0.73	518.20	194.72	142.58	
	1.3	7	7			462	175	0.91	0.66	0.73	725.48	274.81	142.90	
	1.3	1	7	Steyr 59hp	Clayey loam 18.96	66	27	0.91	0.65	0.71	83.20	34.04	117.24	115.16
	1.3	2	7			132	53	0.91	0.65	0.71	166.41	66.82	116.62	
	1.3	3	7			198	77	0.91	0.65	0.71	239.62	97.07	112.23	
	1.3	4	7			264	101	0.91	0.66	0.73	332.82	127.33	115.04	
	1.3	5	7			330	125	0.91	0.66	0.73	416.02	157.58	114.72	
	1.3	7	7			462	177	0.91	0.66	0.73	582.43	223.14	115.08	
	1.3	1	7	MF 60hp	Clayey loam 19.50	66	26	0.91	0.65	0.71	92.26	36.34	128.60	127.55
	1.3	2	7			132	52	0.91	0.65	0.71	184.51	72.68	128.60	
	1.3	3	7			198	75	0.91	0.66	0.73	276.77	104.84	127.20	
	1.3	4	7			264	98	0.91	0.66	0.73	369.03	137.00	126.51	
	1.3	5	7			330	125	0.91	0.66	0.73	461.29	174.73	127.20	
	1.3	7	7			462	175	0.91	0.66	0.73	645.80	244.62	127.20	

Table 19: The effect of tractor type and area on sandy loam soil at 6.5 km/hr.

Primary Tillage Shape of farmland (m)	Implement Width (m) (1.2)	Area ha	Speed km/hr	Tractor Type	Soil Type/Moisture content %	Theoretical Time (min)	Time loss (min)	Theoretical field capacity ha/hr	Effective field capacity ha/hr	Field Efficiency	Productive cost N	Non-Productive cost N	Total cost/ha	Mean cost/ha
200 x 50														
FUTA FARM	1.3	1	6.5	Ford 70hp	Sandy loam	71	24	0.84	0.63	0.75	111.49	37.69	149.18	148.41
	1.3	2	6.5			142	47	0.84	0.63	0.75	222.99	73.81	148.40	
	1.3	3	6.5		16.28	213	66	0.84	0.65	0.77	334.48	103.64	146.04	
	1.3	4	6.5			284	92	0.84	0.64	0.76	445.97	144.47	147.61	
	1.3	5	6.5			355	120	0.84	0.63	0.75	557.47	188.44	149.18	
	1.3	7	6.5			497	172	0.84	0.63	0.75	780.46	270.10	150.08	
LITTLE BY FARM	1.3	1	6.5	Steyr 59hp	Sandy loam	71	24	0.84	0.63	0.75	89.51	30.26	119.77	119.07
	1.3	2	6.5			142	46	0.84	0.64	0.76	179.01	58.00	118.51	
	1.3	3	6.5		17.00	213	67	0.84	0.64	0.76	268.52	84.46	117.66	
	1.3	4	6.5			284	91	0.84	0.64	0.76	358.03	114.72	118.19	
	1.3	5	6.5			355	121	0.84	0.63	0.75	447.53	152.54	120.01	
	1.3	7	6.5			497	171	0.84	0.63	0.75	626.54	215.57	120.30	
LITTLE BY FARM	1.3	1	6.5	MF 60hp	Sandy loam	71	23	0.84	0.64	0.76	99.25	32.15	131.40	129.80
	1.3	2	6.5			142	46	0.84	0.64	0.76	198.49	64.30	131.39	
	1.3	3	6.5		16.96	213	67	0.84	0.64	0.76	297.73	93.65	130.46	
	1.3	4	6.5			284	94	0.84	0.63	0.75	396.98	131.40	119.59	
	1.3	5	6.5			355	120	0.84	0.63	0.75	496.22	167.74	132.79	
	1.3	7	6.5			497	170	0.84	0.63	0.75	694.71	237.63	133.19	

Table 20: The effect of tractor type and area on clayey loam soil at 6.5 km/hr.

Primary Tillage	Implement Width (m) Disc Plough	Area ha	Speed km/hr	Tractor Type	Soil Type	Theoretical time (min)	Time loss (min)	Theoretical field capacity ha/hr	Effective field capacity (ha/hr)	Field Efficiency	Productive cost N	Non-Productive cost N	Total cost/ha	Mean cost/ha
200 x 50														
FUTA FARM	1.3	1	6.5	Ford	Clayey loam	71	25	0.84	0.62	0.74	111.49	39.26	150.75	149.46
	1.3	2	6.5	70hp		142	47	0.84	0.63	0.75	222.99	73.80	148.40	
	1.3	3	6.5		20.25	213	69	0.84	0.64	0.76	334.48	108.35	147.61	
	1.3	4	6.5			284	97	0.84	0.63	0.74	445.97	152.32	149.57	
	1.3	5	6.5			355	123	0.84	0.63	0.74	557.47	193.15	150.12	
	1.3	7	6.5			477	173	0.84	0.64	0.74	780.46	271.66	150.30	
LITTLE BY FARM	1.3	1	6.5	Steyr	Clayey loam	71	26	0.84	0.62	0.74	89.51	32.77	122.28	120.59
	1.3	2	6.5	59hp		142	49	0.84	0.63	0.75	179.01	61.77	120.39	
	1.3	3	6.5		19.59	213	74	0.84	0.63	0.75	268.52	93.29	120.60	
	1.3	4	6.5			284	96	0.84	0.63	0.75	358.03	121.02	119.76	
	1.3	5	6.5			355	121	0.84	0.63	0.75	447.53	152.54	120.01	
	1.3	7	6.5			477	172	0.84	0.64	0.76	626.54	216.83	120.48	
LITTLE BY FARM	1.3	1	6.5	MF	Clayey loam	71	25	0.84	0.62	0.74	99.25	34.94	134.19	133.68
	1.3	2	6.5	60hp		142	50	0.84	0.62	0.74	198.49	69.89	134.19	
	1.3	3	6.5		20.75	213	70	0.84	0.64	0.76	297.73	97.85	131.86	
	1.3	4	6.5			284	99	0.84	0.63	0.75	396.98	138.39	133.84	
	1.3	5	6.5			355	124	0.84	0.63	0.75	496.22	173.33	133.91	
	1.3	7	6.5			477	175	0.84	0.64	0.76	694.71	244.58	134.11	

Table 21: The effect of tractor type and area on sandy loam soil at 6.0 km/hr.

Primary Tillage	Implement Width	Area (ha)	Speed km/hr	Tractor Type	Soil Type	Theoretical time (min)	Time loss (min)	Theoretical field capacity (ha/hr)	Effective field capacity (ha/hr)	Field Efficiency	Productive cost N	Non-Productive cost N	Total cost/ha N	Mean cost/ha N
200 x 50														
FUTA FARM	1.3	1	6	Ford 70hp	Sandy loam	77	24	0.78	0.59	0.76	120.92	37.69	158.61	157.81
	1.3	2	6			154	46	0.78	0.60	0.77	241.83	72.23	157.03	
	1.3	3	6			231	67	0.78	0.60	0.77	362.74	105.21	155.98	
	1.3	4	6			308	92	0.78	0.60	0.77	483.66	144.47	157.03	
	1.3	5	6			385	121	0.78	0.59	0.76	604.57	190.01	158.92	
	1.3	7	6			539	171	0.78	0.59	0.76	846.40	268.52	159.27	
LITTLE BY FARM	1.3	1	6	Steyr 59hp	Sandy loam	77	23	0.78	0.60	0.77	97.07	29.00	126.07	126.52
	1.3	2	6			154	47	0.78	0.60	0.77	194.14	59.25	126.70	
	1.3	3	6			231	67	0.78	0.60	0.77	291.22	84.46	125.23	
	1.3	4	6			308	93	0.78	0.60	0.77	388.29	117.24	126.38	
	1.3	5	6			385	119	0.78	0.59	0.76	485.36	150.02	127.08	
	1.3	7	6			539	170	0.78	0.59	0.76	679.50	214.31	127.69	
LITTLE BY FARM	1.3	1	6	MF 60hp	Sandy loam	77	24	0.78	0.59	0.76	107.63	33.55	141.18	140.53
	1.3	2	6			154	46	0.78	0.6	0.77	215.27	64.30	139.79	
	1.3	3	6			231	69	0.78	0.6	0.77	322.90	96.45	139.78	
	1.3	4	6			308	92	0.78	0.60	0.77	430.53	128.60	139.28	
	1.3	5	6			385	119	0.78	0.59	0.76	538.17	166.34	140.90	
	1.3	7	6			539	171	0.78	0.59	0.76	753.44	239.03	141.78	

Table 22: The effect of tractor type and area in clayey loam soil at 6.0 km/hr.

Primary Tillage	Implement Width (m)	Area (ha)	Speed km/hr	Tractor Type	Soil Type/ moisture content %	Theoretical Time (min)	Time loss (min)	Theoretical field capacity (ha/hr)	Effective field capacity (ha/hr)	Field Efficiency	Productive cost N	Non-Productive cost N	Total cost/ ha N	Mean cost/ ha N
200 x 50 FUTA FARM	1.3	1	6	Ford 70hp	Clayey loam 18.89	77	26	0.78	0.58	0.75	120.92	40.83	161.75	159.33
	1.3	2	6			154	48	0.78	0.59	0.76	241.88	75.38	158.61	
	1.3	3	6			231	70	0.78	0.60	0.77	362.74	109.92	157.55	
	1.3	4	6			308	96	0.78	0.59	0.76	483.66	150.75	158.60	
	1.3	5	6			385	123	0.78	0.59	0.76	604.57	193.15	159.54	
	1.3	7	6			539	174	0.78	0.59	0.76	846.40	273.24	159.95	
LITTLE BY LITTLE FARM	1.3	1	6	Steyr 59hp	Clayey loam 20.90	77	27	0.78	0.58	0.75	97.07	34.04	131.11	128.45
	1.3	2	6			154	50	0.78	0.59	0.76	194.14	63.03	128.59	
	1.3	3	6			231	72	0.78	0.59	0.76	291.22	90.77	127.33	
	1.3	4	6			308	96	0.78	0.59	0.76	388.29	121.02	127.33	
	1.3	5	6			385	121	0.78	0.59	0.76	485.36	152.54	127.58	
	1.3	7	6			539	176	0.78	0.59	0.76	679.30	221.88	128.74	
	1.3	1	6	MF 60hp	Clayey loam 19.78	77	26	0.78	0.58	0.75	107.63	36.34	143.97	142.15
	1.3	2	6			154	49	0.78	0.59	0.76	215.27	68.49	141.88	
	1.3	3	6			231	70	0.78	0.60	0.77	322.90	97.85	140.25	
	1.3	4	6			308	97	0.78	0.59	0.76	430.53	135.59	141.53	
	1.3	5	6			385	124	0.78	0.59	0.76	538.17	173.33	142.30	
	1.3	7	6			539	177	0.78	0.59	0.76	753.44	247.42	142.95	

APPENDIX 2

THE RESULTS OF SECONDARY TILLAGE
OPERATION
(Tables 23 - 30)

Table 23: The effect of tractor type and area in sandy loam soil at 8.0 km/hr.



Secondary Tillage	Implement Width (m)	Area ha	Speed km/hr	Tractor Type	Soil Type/Moisture content %	Theoretical Time	Time loss	Theoretical field capacity (ha/hr)	Effective field capacity (ha/hr)	Field Efficiency	Productive cost N	Non-Productive cost N	Total cost/ha	Mean cost/ha
200 x 50														
FUTA FARM	2	1	8	Ford 70hp	Sandy loam 12.05	38	15	1.6	1.13	0.71	59.67	23.56	83.23	85.59
	2	2	8			76	31	1.6	1.12	0.70	119.34	48.68	84.01	
	2	3	8			114	48	1.6	1.07	0.66	179.02	75.38	84.80	
	2	4	8			152	65	1.6	1.11	0.69	238.69	102.07	85.19	
	2	5	8			190	85	1.6	1.10	0.68	298.36	133.48	86.37	
	2	7	8			266	135	1.6	1.05	0.66	417.70	212.00	89.96	
LITTLE BY LITTLE FARM	2	1	8	Steyr 59hp	Sandy loam 13.12	38	16	1.6	1.11	0.69	47.90	20.17	68.07	68.72
	2	2	8			76	30	1.6	1.13	0.71	95.81	37.80	66.81	
	2	3	8			114	46	1.6	1.13	0.71	143.70	58.00	67.23	
	2	4	8			152	66	1.6	1.10	0.68	191.60	83.20	68.70	
	2	5	8			190	87	1.6	1.08	0.68	239.51	109.67	69.84	
	2	7	8			266	132	1.6	1.06	0.66	335.32	166.41	71.68	
LITTLE BY LITTLE FARM	2	1	8	MF 60hp	Sandy loam 12.75	38	15	1.6	1.13	0.71	53.12	20.96	74.08	75.63
	2	2	8			76	29	1.6	1.14	0.71	106.23	40.54	73.39	
	2	3	8			114	46	1.6	1.12	0.70	159.35	64.30	74.55	
	2	4	8			152	64	1.6	1.11	0.69	212.47	89.46	75.48	
	2	5	8			190	84	1.6	1.09	0.68	265.58	117.42	76.60	
	2	7	8			266	133	1.6	1.05	0.66	371.81	185.91	79.67	

Table 24: The effect of tractor type and area in clayey loam soil at 8.0 km/hr.

Secondary Tillage	Implement width (m)	Area ha	Speed km/hr	Tractor Type	Soil Type/Moisture content %	Theoretical time	Time loss	Theoretical field capacity (ha/hr)	Effective field capacity (ha/hr)	Field efficiency	Productive cost N	Non-Productive cost N	Total cost/ha N	Mean cost/ha N
200 x 50														
FUTA FARM	2	1	8	Ford 70hp	Clayey loam	38	17	1.6	1.09	0.68	59.67	26.70	86.37	86.57
	2	2	8			76	31	1.6	1.12	0.70	119.34	48.68	84.01	
	2	3	8			114	50	1.6	1.10	0.69	179.02	78.52	85.85	
	2	4	8		14.20	152	66	1.6	1.10	0.69	238.69	103.64	85.58	
	2	5	8			190	87	1.6	1.08	0.68	298.36	136.62	86.96	
	2	7	8			266	138	1.6	1.04	0.65	417.70	216.71	90.63	
LITTLE BY LITTLE FARM	2	1	8	Steyr 59hp	Clayey loam	38	18	1.6	1.07	0.67	47.90	22.69	70.59	68.78
	2	2	8			76	33	1.6	1.10	0.69	95.81	41.60	68.71	
	2	3	8		14.00	114	50	1.6	1.10	0.69	143.70	63.03	68.91	
	2	4	8			152	66	1.6	1.10	0.69	191.60	83.20	68.70	
	2	5	8			190	86	1.6	1.09	0.68	239.51	108.42	69.59	
	2	7	8			266	137	1.6	1.04	0.65	335.32	127.71	66.15	
LITTLE BY LITTLE FARM	2	1	8	MF 60hp		38	18	1.6	1.07	0.67	53.12	25.16	78.28	77.45
	2	2	8			76	33	1.6	1.10	0.69	106.23	46.13	76.18	
	2	3	8		15.05	114	50	1.6	1.10	0.69	159.35	69.89	76.41	
	2	4	8			152	67	1.6	1.10	0.69	212.47	93.65	76.53	
	2	5	8			190	84	1.6	1.09	0.68	265.58	117.42	76.60	
	2	7	8			266	138	1.6	1.04	0.65	371.81	192.90	80.67	

Table 25: The effect of tractor type and area on sandy loam soil at 7 km/hr.

Secondary Tillage	Implement Width (m)	Area ha	Speed km/hr	Tractor Type	Soil Type/moisture content %	Theoretical time	Time loss	Theoretical field capacity	Effective field capacity	Field Efficiency	Productive cost N	Non-Productive cost N	Total cost/ha N	Mean cost/ha N
200 x 50														
FUTA FARM	2	1	7	Ford 70hp	Sandy loam 12.51	43	17	1.4	1.0	0.71	67.52	26.70	94.22	95.73
	2	2	7			86	34	1.4	1.0	0.71	135.05	53.40	94.23	
	2	3	7			129	53	1.4	0.99	0.72	202.58	83.23	95.27	
	2	4	7			172	73	1.4	0.98	0.70	270.10	114.63	96.18	
	2	5	7			215	92	1.4	0.98	0.69	337.63	144.47	96.42	
	2	7	7			301	136	1.4	0.96	0.69	472.68	213.56	98.03	
LITTLE BY LITTLE FARM	2	1	7	Steyr 59hp	Sandy loam 12.05	43	20	1.4	0.95	0.68	54.21	25.21	79.42	78.06
	2	2	7			86	36	1.4	0.98	0.70	108.42	45.38	76.90	
	2	3	7			129	56	1.4	0.97	0.69	162.62	70.60	77.74	
	2	4	7			172	75	1.4	0.97	0.69	216.83	94.55	77.85	
	2	5	7			215	94	1.4	0.97	0.69	271.04	118.50	77.91	
	2	7	7			301	135	1.4	0.96	0.69	379.46	170.19	78.52	
LITTLE BY LITTLE FARM	2	1	7	MF 60hp	Sandy loam 13.54	43	20	1.4	0.95	0.68	60.10	27.96	88.06	86.43
	2	2	7			86	34	1.4	1.0	0.71	120.21	47.53	83.87	
	2	3	7			129	55	1.4	0.98	0.70	180.32	76.88	85.73	
	2	4	7			172	75	1.4	0.97	0.69	240.43	104.84	86.32	
	2	5	7			215	96	1.4	0.96	0.69	300.54	134.19	86.95	
	2	7	7			301	138	1.4	0.96	0.69	420.75	192.90	87.66	

Table 26: The effect of tractor type and area on clayey loam soil at 7 km/hr.

Secondary Tillage	Implement width (m)	Area ha	Speed km/hr	Tractor Type	Soil Type/ moisture content %	Theoretical time	Time loss	Theoretical field capacity	Effective field capacity	Field Efficiency	Productive cost N	Non-Productive cost N	Total cost/ha N	Mean cost/ha N
FUTA FARM	2	1	7	Ford 70hp	Clayey loam 14.50	43	19	1.4	0.97	0.69	67.52	29.83	97.35	96.77
	2	2	7			86	35	1.4	0.99	0.71	135.05	54.96	95.01	
	2	3	7			129	55	1.4	0.98	0.70	202.58	86.37	96.32	
	2	4	7			172	73	1.4	0.98	0.70	270.10	114.63	96.18	
	2	5	7			215	94	1.4	0.97	0.69	337.63	147.61	97.05	
	2	7	7			301	139	1.4	0.95	0.69	472.68	218.28	98.71	
LITTLE BY LITTLE FARM	2	1	7	Steyr 59hp	Clayey loam 15.05	43	20	1.4	0.95	0.68	54.21	25.21	79.42	78.14
	2	2	7			86	35	1.4	0.99	0.71	108.42	44.12	76.77	
	2	3	7			129	56	1.4	0.97	0.69	162.62	70.60	77.74	
	2	4	7			172	75	1.4	0.97	0.69	216.83	94.55	77.85	
	2	5	7			215	95	1.4	0.97	0.69	271.04	119.76	78.16	
	2	7	7			301	140	1.4	0.95	0.68	379.46	176.49	79.42	
LITTLE BY LITTLE FARM	2	1	7	MF 60hp	Clayey loam 14.75	43	19	1.4	0.97	0.69	60.01	26.56	86.57	86.79
	2	2	7			86	36	1.4	0.98	0.70	120.21	50.32	85.27	
	2	3	7			129	57	1.4	0.97	0.69	180.32	79.68	86.67	
	2	4	7			172	76	1.4	0.97	0.69	240.43	106.23	86.67	
	2	5	7			215	98	1.4	0.96	0.68	300.54	137.00	87.51	
	2	7	7			301	140	1.4	0.95	0.68	420.75	195.70	88.06	

Table 27: The effect of tractor type and area in sandy loam soil at 6.5 km/hr.

Secondary Tillage	Implement width (m)	Area ha	Speed km/hr	Tractor type	Soil Type/ moisture content %	Theoretical time	Time loss	Theoretical field capacity	Effective field capacity	Field Efficiency	Productive cost N	Non-Productive cost N	Total cost/ ha N	Mean cost/ ha N
200 x 50														
FUTA FARM	2	1	6.5	Ford 70hp	Sandy loam	46	19	1.3	0.92	0.71	72.24	29.84	102.08	102.21
	2	2	6.5			92	36	1.3	0.94	0.72	144.47	56.53	100.50	
	2	3	6.5			138	57	1.3	0.92	0.71	216.70	89.51	102.07	
	2	4	6.5		14.21	184	75	1.3	0.93	0.71	288.89	117.78	101.67	
	2	5	6.5			230	96	1.3	0.92	0.71	361.17	150.75	102.38	
	2	7	6.5			322	144	1.3	0.90	0.69	505.64	226.13	104.54	
LITTLE BY LITTLE FARM	2	1	6.5	Steyr 59hp	Sandy loam	46	20	1.3	0.91	0.70	58.00	25.21	83.21	82.33
	2	2	6.5			92	35	1.3	0.94	0.73	115.98	44.12	80.05	
	2	3	6.5			138	58	1.3	0.92	0.71	173.96	73.12	82.36	
	2	4	6.5		13.50	184	76	1.3	0.92	0.71	231.96	95.81	81.94	
	2	5	6.5			230	98	1.3	0.91	0.70	289.94	123.54	82.70	
	2	7	6.5			322	143	1.3	0.90	0.69	405.92	180.28	83.74	
LITTLE BY LITTLE FARM	2	1	6.5	MF 60hp	Sandy loam	46	18	1.3	0.94	0.73	64.30	25.16	89.46	91.00
	2	2	6.5			92	35	1.3	0.94	0.73	128.60	48.92	88.76	
	2	3	6.5			138	58	1.3	0.92	0.71	192.90	81.07	91.32	
	2	4	6.5		12.90	184	77	1.3	0.92	0.71	257.20	107.63	91.21	
	2	5	6.5			230	99	1.3	0.91	0.70	321.50	138.39	91.98	
	2	7	6.5			322	145	1.3	0.90	0.69	450.10	202.68	93.25	

Table 28: The effect of tractor type and area in clayey loam soil at 6.5 km/hr.

Secondary Tillage	Implement Width (m)	Area ha	Speed km/hr	Tractor Type	Soil Type/ Moisture content %	Theoretical time (min)	Time loss (min)	Theoretical field capacity (ha/hr)	Effective field capacity (ha/hr)	Field Efficiency	Productive cost N	Non-Productive cost N	Total cost/ha	Mean cost/ha
200 x 50														
FUTA FARM	2	1	6.5	Ford 70hp	Clayey loam 15.02	46	20	1.3	0.91	0.70	72.24	31.41	103.65	103.30
	2	2	6.5			92	38	1.3	0.92	0.71	144.47	59.67	102.07	
	2	3	6.5			138	59	1.3	0.91	0.70	216.70	92.65	103.12	
	2	4	6.5			184	78	1.3	0.92	0.71	288.89	122.49	102.85	
	2	5	6.5			230	97	1.3	0.92	0.71	361.17	152.32	102.69	
	2	7	6.5			322	148	1.3	0.89	0.69	505.64	232.41	105.44	
LITTLE BY LITTLE FARM	2	1	6.5	Steyr 59hp	Clayey loam 14.57	46	22	1.3	0.88	0.68	58.00	27.73	85.73	83.80
	2	2	6.5			92	41	1.3	0.90	0.69	115.98	51.68	83.83	
	2	3	6.5			138	60	1.3	0.91	0.70	173.96	75.64	83.20	
	2	4	6.5			184	77	1.3	0.92	0.71	231.96	97.07	82.26	
	2	5	6.5			230	99	1.3	0.91	0.70	289.94	124.81	82.95	
	2	7	6.5			322	149	1.3	0.89	0.69	405.92	187.84	84.82	
LITTLE BY LITTLE FARM	2	1	6.5	MF 60hp	Clayey loam 13.90	46	20	1.3	0.91	0.70	64.30	27.96	92.26	92.14
	2	2	6.5			92	39	1.3	0.92	0.71	128.60	54.51	91.56	
	2	3	6.5			138	60	1.3	0.91	0.70	192.90	83.87	92.26	
	2	4	6.5			184	77	1.3	0.92	0.71	257.20	107.63	91.21	
	2	5	6.5			230	98	1.3	0.91	0.70	321.50	136.99	91.70	
	2	7	6.5			322	148	1.3	0.89	0.69	450.10	206.88	93.85	

Table 29: The effect of tractor type and area on sandy loam soil at 6.0 km/hr.

Secondary Tillage	Implement width (m)	Area ha	Speed km/hr	Tractor Type	Soil Type/ moisture content %	Theoretical time (min)	Time loss (min)	Theoretical field capacity (ha/hr)	Effective field capacity (ha/hr)	Field Efficiency	Productive cost N	Non-Productive cost N	Total cost/ha N	Mean cost/ha
200 x 50														
FUTA FARM	2	1	6	Ford 70hp	Sandy loam 12.80	50	20	1.2	0.86	0.71	78.52	31.41	109.93	109.60
	2	2	6			100	39	1.2	0.86	0.71	157.03	61.24	109.90	
	2	3	6			150	58	1.2	0.87	0.72	235.55	91.08	108.88	
	2	4	6			200	77	1.2	0.87	0.72	314.07	120.91	108.75	
	2	5	6			250	97	1.2	0.86	0.71	392.58	152.32	108.98	
	2	7	6			350	149	1.2	0.84	0.70	549.61	233.98	111.94	
LITTLE BY LITTLE FARM	2	1	6	Steyr 59hp	Sandy loam 13.20	50	21	1.2	0.85	0.70	63.03	26.47	89.50	88.78
	2	2	6			100	42	1.2	0.85	0.70	126.07	52.94	89.51	
	2	3	6			150	60	1.2	0.86	0.71	189.10	75.64	88.25	
	2	4	6			200	78	1.2	0.86	0.71	252.13	98.33	87.62	
	2	5	6			250	98	1.2	0.86	0.71	315.17	123.54	87.74	
	2	7	6			350	150	1.2	0.84	0.70	441.24	189.10	90.05	
LITTLE BY LITTLE FARM	2	1	6	MF 60hp	Sandy loam 13.45	50	21	1.2	0.85	0.70	69.89	29.35	99.24	98.22
	2	2	6			100	40	1.2	0.86	0.71	139.78	55.91	97.85	
	2	3	6			150	60	1.2	0.86	0.71	209.68	83.87	97.85	
	2	4	6			200	78	1.2	0.86	0.71	279.57	109.03	97.15	
	2	5	6			250	99	1.2	0.86	0.71	349.46	138.38	97.57	
	2	7	6			350	149	1.2	0.84	0.70	489.24	208.28	99.65	

Table 30: The effect of tractor type and area on clayey loam soil at 6.0 km/hr.

Secondary Tillage	Implement width (m)	Area ha	Speed km/hr	Tractor type	Soil Type/ moisture content %	Theoretical time (min)	Time loss (min)	Theoretical field capacity (ha/hr)	Effective field capacity (ha/hr)	Field efficiency	Productive cost N	Non-Productive cost N	Total cost/ ha N	Mean cost/ ha N
200 x 50														
FUTA FARM	2	1	6	Ford 70hp	Clayey loam 16.25	50	22	1.2	0.83	0.69	78.52	34.55	113.07	110.84
	2	2	6			100	41	1.2	0.85	0.71	157.03	64.38	110.71	
	2	3	6			150	60	1.2	0.86	0.71	235.55	94.22	109.92	
	2	4	6			200	79	1.2	0.86	0.71	314.07	124.06	109.53	
	2	5	6			250	99	1.2	0.86	0.71	392.58	155.46	109.61	
	2	7	6			350	150	1.2	0.84	0.70	549.61	235.55	112.17	
LITTLE BY LITTLE FARM	2	1	6	Steyr 59hp	Clayey loam 15.90	50	22	1.2	0.83	0.69	63.03	27.73	90.76	89.49
	2	2	6			100	43	1.2	0.84	0.70	126.07	54.21	90.14	
	2	3	6			150	61	1.2	0.85	0.71	189.10	76.90	88.67	
	2	4	6			200	80	1.2	0.86	0.71	252.13	100.85	88.26	
	2	5	6			250	101	1.2	0.85	0.71	315.17	127.33	88.50	
	2	7	6			350	153	1.2	0.84	0.70	441.24	192.88	90.59	
LITTLE BY LITTLE FARM	2	1	6	MF 60hp	Clayey loam 15.75	50	22	1.2	0.83	0.69	69.89	30.75	100.64	98.91
	2	2	6			100	42	1.2	0.84	0.70	139.78	58.71	99.25	
	2	3	6			150	60	1.2	0.86	0.71	209.68	83.87	97.85	
	2	4	6			200	80	1.2	0.86	0.71	279.57	111.83	97.85	
	2	5	6			250	100	1.2	0.86	0.71	349.46	139.78	97.85	
	2	7	6			350	151	1.2	0.84	0.70	489.24	216.07	100.04	

APPENDIX 3 : POWER REQUIREMENT OF TILLAGE IMPLEMENTS
ON SANDY AND CLAYEY LOAM SOILS

Tables (31 - 34)

Table 31: Mechanical Analysis of Soil Types

Soil type	Sand 0.05mm %	Silt 0.05-0.002mm %	Clay 0.002mm %
Sandy loam)	62	37	1
Sandy loam) FUTA	60	29.6	10.4
Mean) FARM	61	33.3	5.7
Clayey loam)	40.3	23.9	35.8
Sandy loam)	54.5	39.8	5.7
Sandy loam) LITTLE	56	35.2	8.8
Sandy loam) BY	24.4	46	29.6
Clayey loam) LITTLE			
Clayey loam) FARM			
Slippage ==> 16 -	27%		

Table 32: Determination of average spring
rate (k)

Weight kg	Extension x (cm)	K (kg/cm	Average K
20	0.10	200.00	197.0kg/cm
25	0.12	208.33	
30	0.15	200.00	
35	0.18	194.44	
40	0.21	190.50	
45	0.23	195.65	
50	0.26	192.31	

Table 33: Draught required for tillage operations

	Clayey loam			Sandy loam	
	Extension cm	Pull (KN)	k kg/cm	Extension	Pull
(a) Tractor only	0.91	1.76	197	0.80	1.554
(b) Tractor + plough	3.02	5.84	197	2.65	5.12
(c) Tractor + plough + soil	4.76	9.20	197	4.25	8.21
(d) Tractor + harrow + soil	5.12	9.89	197	4.50	8.70
(e) Plough + soil		7.44			6.656
(f) Harrow + soil		8.13			7.146

Table 34: Power requirement of tillage implements

Tillage Implement	Depth of cut	Speed km/hr (m/s)	Draught (K/N)	Power (kw)	Power (hp)	Power kw/m
Disc plough (1.3m)	(soil type)	6.0 (1.67)	6.656	11.12	14.90	8.55
	18cm	6.5 (1.805)	6.656	12.01	16.10	9.23
		7.0 (1.944)	6.656	12.94	17.34	9.95
		8.0 (2.222)	6.656	14.79	19.82	11.38
	(sandy loam)					
Disc harrow (2.0m)	11cm	6.0	7.146	11.93	16.00	5.97
		6.5	7.146	12.90	17.29	6.45
		7.0	7.146	13.89	18.62	6.95
		8.0	7.146	15.88	21.28	7.94
Disc plough (1.3m)	(Clayey loam) 18cm	6.0	7.44	12.42	16.65	9.56
		6.5	7.44	13.43	18.00	10.33
		7.0	7.44	14.46	19.38	11.12
		8.0	7.44	16.53	22.16	12.72
Disc harrow (2.0m)	(Clayey loam) 11cm	6.0	8.13	13.58	18.20	6.79
		6.5	8.13	14.67	19.67	7.33
		7.0	8.13	15.80	21.18	7.90
		8.0	8.13	18.06	24.21	9.03

APPENDIX 4: FUEL CONSUMPTION RATE OF TRACTORS

Table 35: Average fuel consumption rate of three tractors at varying speed

Tractor Type	Horsepower	Speed km/hr	Primary Tillage Fuel Consumption L/hr	Secondary Tillage Fuel Consumption L/hr
Ford	70hp	8.0	12.90	10.82
	"	7.0	11.29	9.48
	"	6.5	10.48	8.80
	"	6.0	9.70	8.14
Steyr	59hp	8.0	12.07	10.13
		7.0	10.56	8.86
		6.5	9.81	8.23
		6.0	9.05	7.59
MF	60hp	8.0	12.18	10.22
		7.0	10.66	8.95
		6.5	9.90	8.31
		6.0	9.20	7.72

APPENDIX 5 : TRACTOR COSTS

Table 36: (At 1000 hours annual use) Cost of operating tractors per hour or per annum

Tractor type	Cost per annum N	Cost per hour N	Tractor Age yrs
Ford 70hp	94,223.33	94.22	3
MF 60hp	83,871.00	83.87	4
Steyr 59hp	75,640.00	75.64	6

Table 37: Hourly cost of tractors at varying hours of use per annum

Hours of annual use	Tractor Type/Cost of use per hour		
	Steyr 59hp N	MF 60hp N	Ford 70hp N
1000	75.64	83.87	94.22
800	77.39	87.09	99.02
600	80.30	92.54	107.02
400	86.14	103.46	123.03



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