EFFECT OF TILLAGE TOOL GEOMETRY ON SOIL STRUCTURE: CASE STUDY OF DISC PLOUGH

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DEDICATION

This work is dedicated to the Almighty God.

DECLARATION

I hereby declare that this thesis is a record of my research work. It has neither been presented nor accepted in my previous application for a higher degree. All sources of information have been specifically acknowledged.

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ABSTRACT

A field study of the effects of the microshape of a disc plough on the draught requirement and the final soil tilth was conducted on a tropical agricultural soil. Three factor-factorial experiment with three replicates were conducted with three levels of tilt angle. Soil data were acquired to help support the findings of the study. The disc blades used were of uniform radius of curvature (concavity) size (diameter) and edge sharpness to eliminate their effects on the performance of the tools. The magnitude of the angle of soil-metal friction (which was used as an index of surface roughness) of the three different blade surfaces are 19^0, 14^0 and 21.6^0 respectively. The disk surface with the greatest surface roughness gave the highest draught and highest Mean Weight Diameter (MWD). An advantage of the disk plough, with revolving discs revealed that it requires less effort and is highly efficient while working on soils having adhesion.

A mathematical relationship was established between MWD and other tillage parameters under study. From the analysis, speed is the most strongly linearly related variable to MWD. Also, there are no significant differences in the interaction of the three input factors of tillage study namely. (Tool's surface roughness, tilt angle and speed). Hence these factors are independent.

CHAPTER ONE

INTRODUCTION

1.1 General Introduction

Increased food and fibre production is a major concern to the government of most countries, particularly in the third world countries where the population is increasing faster than the rate of agricultural growth (FAO, 1993). Various constraints militate against rapid growth in the food production sector. One of such constraints is the lack of judicious and effective management of our natural resources, particularly soils. Also, it is an accepted fact that soil structure is of prime importance in maintaining soil productivity and increasing crop yield.

Tillage practices are a major factor that have a significant effect on soil productivity. Although the concept of no tillage and minimum tillage have been introduced in some parts of the world for the growth of crops, primary and secondary tillage operations are still performed in order to ensure maximum crop yield (Lal, 1980). In order to be able to control the tillage operations, there exist a range of values of tillage determining features or parameters which are required to achieve optimum operating conditions. The knowledge of these values is also essential for the proper design and selection of the implement for appropriate matching of the implements with their power sources and estimating soil characteristics under tillage operation (Ademosun, 1990 and Carter, 1981). The tillage parameters consist of the operational parameters such as forward speed, soil parameters (such as moisture content) and implement parameters (such as type and shape of implement). Different types and geometry of tillage implements are in existence for tillage operations. In the Southern part of Nigeria which is the study area, the disk implements are the common tillage implements in use . The reason is because of its operational suitability in wet, dry, sticky soils and adverse soil conditions. The level of tillage mechanization in South West Nigeria is low because of the high cost - benefit ratio of tillage machinery. This is not only due to few hours of implement utilization per annum but also due to lack of good management of the implement.

Research has shown that forces on tillage implements are altered by wear depending on soil type and condition (Fielke 1996). Also harrow design are influenced by disk blade geometry (Gill etal, 1980). Further research seems justified to study the effect of the geometry of disk plough blades on soil structures so as to quantify the optimum disk blade geometry for disk ploughing and the magnitude of its effect on the soil during tillage operations .

1.2 Objectives of Study

The objectives of this study are as follows.

a) To evaluate the effect of tillage tool geometry and speed of disk plough on soil structural behavior under different tillage parameters.

b) To evaluate the draught requirement for implement under study.

c) To conduct laboratory analysis of soil sample for the determination of parameters like mean weight diameter, water stable aggregates (indices of soil structure)

d) To establish an equation relating the draught requirement and the final soil characteristics of the soil type under study.

e) To formulate general guidelines for farmers on optimal use of disk implement.

CHAPTER TWO

LITERATURE REVIEW

2.1 Soil Tillage

According to FAO (1993), the term "tillage" is a generic term and is broadly used. It embraces all operations of seedbed preparation that optimise soil and environmental conditions for seed germination, seedling establishment and crop growth. It includes mechanical methods bounded on conventional techniques of ploughing and harrowing, weed control using chemical herbicides and growth regulation. It also involves fallowing with an aggressive cover crop that can be easily controlled for direct seeding through its residue mulch . Odigboh (1991) however 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 (thereby) altering the physical condition of the soil to create optimum environmental conditions for plant growth. (Lal, 1995).

Tillage has been an important aspect of technological development in the evolution of agriculture in particular food production. According to Kepner et al, (1987) the objectives of tillage include: Development of desirable soil structure for a seedbed or root bed, management of plant residues, incorporation and mixing of fertilizer and other soil amendiments or pesticides into the soil, control of weeds and removal of unwanted crops, increased infiltration rate and erosion control, establishment of a specific surface configurations for planting, irrigation, drainage, and harvesting and compaction reduction and drainage control.

Development of desirable soil structure for a seedbed or rootbed is usually done to allow rapid infiltration and good retention of rainfall, provision of adequate air capacity and exchange within the soil and minimizing resistance to root penetiation. The type of seedbed required is dependent on the types of crop and its method of establishment. During tillage operation, the soil is exposed to the atmosphere and hence to the changes of temperature and humidity brought about by wind, sun, rain etc, therefore further aeration and tillage productions is achieved. Tillage operation promotes effective management of plant residues, incorporation and mixing of fertiliser and other soil amendiments or pesticides into the soil. Thorough mixing of trash is desirable for good tillage and decomposition .Primary cultivation is an appropriate point in the crop cycle to start on the process of weed control. with effective weed control at this stage it will reduce the requirement for subsequent weed control measure. In dryland farming systems where catchment of seasonal rains is important; "opening up" the soil prior to the rains is sometimes done with the objective of increasing the infiltration rate. This can be done in the dry conditions before the rain, or at the end of the growing season when any moisture left in the soil will make operation easier and power requirement less. In order to combat erosion, a number of cultural practices e.g maintaining a cloddy trashy seed bed, cultivating along the contour and contour bunding are usually done in order to reduce rainwater runoff and subsequent erosion of the soil.

A certain amount of land forming is associated with cultivation as the land forming is done in between or in association with cultivation, operations. (Carruthers, 1992). Such operations include ridging, bed making. For irrigated rice, unlike other crops, a hard pan or bottom to the field is required in order to impede drainage, maintain the water level in the field and provide a hard base for subsequent cultural operation. This pan is built up by the smearing together of soil particles caused by implements rods, and slipping wheels operating repeatedly at the same depth.

Tined implements are used for combating compaction. By the opening and loosening of the top soil excess surface water is able to filter through to the subsoil and so, eventually, unto the field drainage system. The relative importance of these objectives of tillage may vary between one field and another, according to the type and condition of the soil, the time of year and the requirement of the intended crop.

2.1.1 **Tillage Techniques and Systems**

For the transformation of the soil from its initial state into that required, it may be necessary to perform one or combination of the following basic cultivation operation:

- Form or destroy soil aggregates
- Alter the clod size distribution
- Rearrange the soil particles and aggregates by either loosening compacting, puddling, inverting, mixing or smearing.

- Transform the soil surface by either smoothing moving or forming.

Tillage operations for seedbed preparation are often classified as primary or secondary although the distinction is not always clearcut (Kepner et al, 1987). Primary Tillage Operation constitutes the initial major soil - working operation. It's major objectives are to reduces soil strength cover plant materials and rearrange aggregates. It results in the inverting, lifting, pulverizing and inverting of the soil with relatively deep penetrating tools, leaving a rough surface texture. Secondary Tillage Operation usually follows primary tillage operation it is usually designed to create refined soil condition before seed planting. It results in the pulverisation, leveling and making firm the soil in order to prepare a good seed bed and to control weeds, mix and chop trash and conserve moisture. Secondary tillage normally works the soil to a shallower depth (about 51mm - 152mm).

Other tillage operations exists which are normally required after secondary tillage to create the best surface configuration or tilt for the crop to be planted. These include ridging. Ridging is required for row crops. It is also used for making field furrows or channels, inverting up and other similar operations. Ridge planting is practised in the cultivation of most crops in Nigeria. Ridging often helps to conserve soil and water.

Tillage systems generally include the following conventional tillage operations: minimum tillage, stubble mulch tillage, listing, deep tillage, zero tillage and strip tillage. Minimum Tillage involves the minimum soil manipulation necessary for crop production or for meeting tillage requirements under the existing soil conditions. The major objectives of minimum tillage according to Kepner et al (1987) are :-

- The reduction of mechanical energy and labour requirements;
- Conservation of moisture and reduce soil erosion;
- Performance of only those operations necessary to optimise the soil conditions for each type of area within a field; and,
- Minimizing the number of trips over the field.

Stubble Mulch Tillage is the system of soil preparation in which plant residues and other mulching materials are purposely and specifically left on or near the soil surface for reasons of moisture conservation or erosion control. The proper disposition of the residue depends upon the amount present and the subsequent operations involved. The large amounts of residue at or near the surface protect the soil but introduce problems in planting (since the planter must penetrate the mulch) and in cultivation if row crops are included in the crop rotation. 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. Deep tillage is the system of primary tillage which manipulated 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 subsoiler which shatter the soil. Zero tillage is a procedure whereby a planting is done directly into an essentially unprepared seedbed. It is also called no - tillage planting. The entire field is not ploughed or disked, leaving surface plant residues standing. Strip tillage 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 areas is covered. 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.

2.1.2 Effects and Problems of Tillage Practices

Tillage operations, inspite of its usefulness, is faced with numerous problems particularly in developing countries. Also, tillage has physical, chemical and biological effects which can either be favourable or otherwise. It has effect on soil structure, crop growth and soil water.

The cultivation of soils for crop production has a profound effect in the formation and stability of soil aggregates. Soil tilth, defined as the physical condition of soil in relation to plant growth is related to size distribution of aggregates in the soil. The tillage operation affects the size distribution of peds, density and packing of soil particles, amount of organic matter and moisture contents of soil. (Biswas and Murherjee,1987). Coarse textured soils usually have a good physical condition but too small capacity for supplying enough water and plant nutrients. Fine textured soils on the other hand, have a satisfactory nutrient and water reserve but often contained less air because of the close packing of its soil particles. Tillage have little impact on coarse soils but a profound impact on fine textured soils. The short term effect of tillage is generally favourable because the implements break up the clods, incorporate organic matter into the soil and make a more favourable seedbed. The nature of the clods produced depends on the type of the implements. Friable conditions of soils are the optimum soil condition for tillage operations to produce aggregates of suitable size. Tillage, however can be detrimental if performed at inappropriate times. In the case of fine - textured soils such as clay, if the soil is too dry, big hard clods will be turned over by plough action and these will not be pulverized to smaller ones. On the other hand, under wet condition the aggregates will be broken down to very small sizes, leading to puddled condition of soil, i.e with complete destruction of structure .

Over longer periods, the good effects of tillage usually deteriorates under the usually tillage operations. Tillage operations have detrimental effects on surface soil granules, reduced aggregation, increased compaction of layers below the tilled area, reduce aeration and water circulation. The effect of tillage on bulk density resulting in increased compaction of layers below the tilled area is shown in Figure 1.

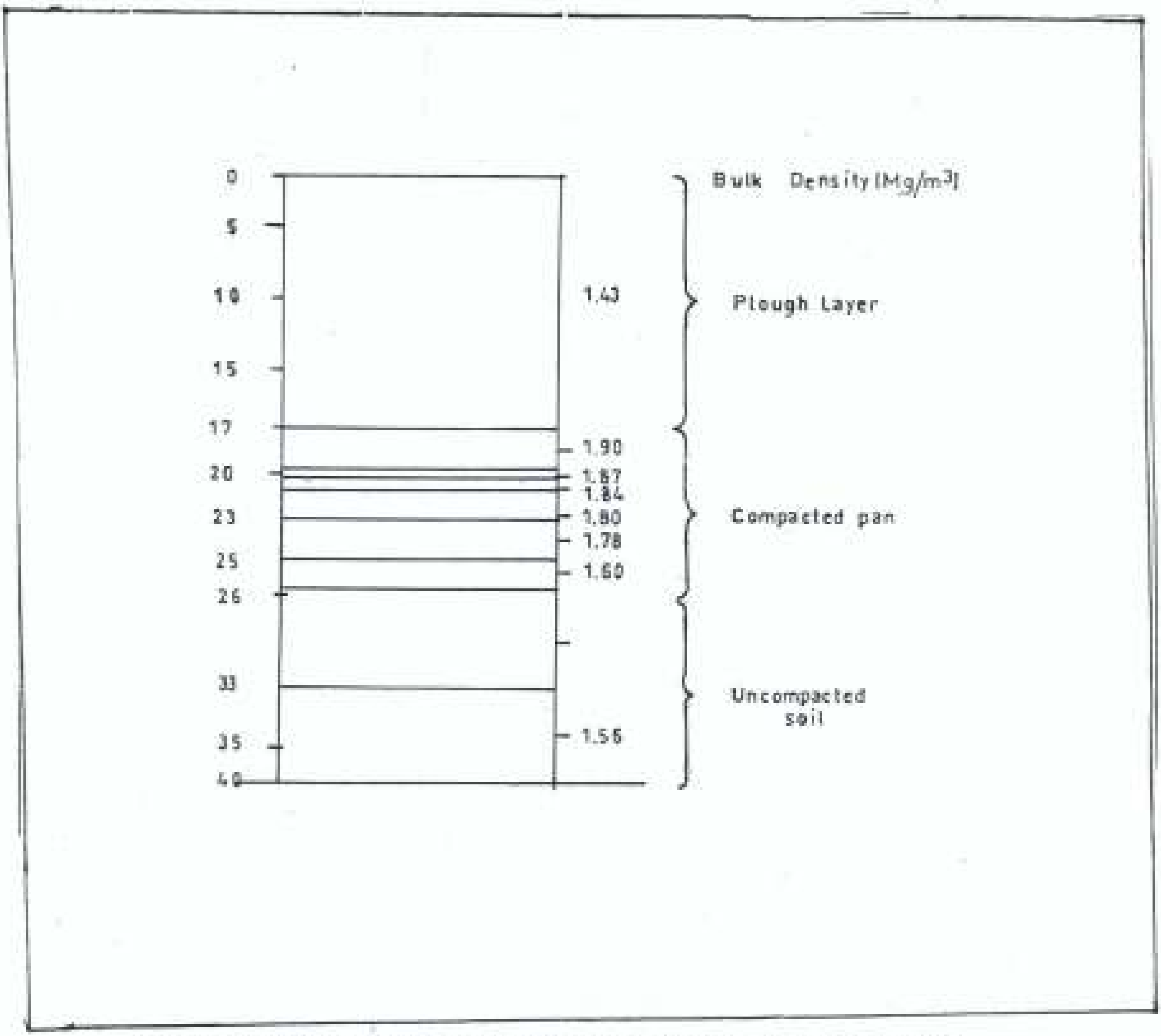


Figure 1 Effect of tillage on bulk density (Source: Brady, 1990).

Tillage destroy soil crust, loosen the soil and generally increases water intake when water is applied after tillage. Burwel etal, (1968) in Hillel, (1980), was said to have found that infiltration increases with increased degree of pulverization. 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 soil pulverization, oxygen supplies and water intake among other things. It has been shown that more than 50% of the roots of a developed plant remain within the tilled layer (Finney and Knight, 1973 in Braunack and Dexter, 1989).. Tillage for seedbed preparation is most needed when planting small and/or high cost seed like lettuce, tomatoes, and sugar beets. It is less critical for large seeded plants corns, small grains, soybeans, dry beans and sorghum. According to Donahue & Miller (1992) emergence of seedlings is easier when the planting and working of soil are done in a moist soil rather than in dryer soil followed by wetting.

Some of the problems facing tillage operations include: high energy requirement, high cost of machines and operations, low annual usage of tillage implements, lack of skilled labour for tillage operation, tropical conditions and field machinery and the peculiarity of tillage research. Tillage operations are especially consumptive of energy. The amount of earth work involved in repeatedly loosening, pulverizing, inverting etc is indeed very considerable. Approximately 20% of the energy for agricultural production is used for field operation with a majority of these applied in tillage operations (Wilkes et al., 1993). Also, it is estimated that tillage operations require over 60% of the power used on American farms (Jacob and Harrell, 1983). Attempts have been made to reduce the draught requirement of tillage operations by utilising parts of a tractor's output through non tractor means such as the tractor PTO and through vibratory tillage. However, total power requirement are high and often times, pulverization may be excessive. Also one of the major objectives of minimum tillage systems is to reduce mechanical energy and labour requirement in tillage operations.

Tillage machines are rather very costly, especially the tractor and it is almost unaffordable by individual farmers. Thus, farmers tend to continue with the use of crude methods of hiring of machines. The high cost of machines could be traced to poor value of the national currency. The tractor and many of its accessories are still imported, thereby resulting in high cost of machines.

Effective tillage operations are time and site specific which leads to low annual requirement of tillage implements. The cumulative effect of low annual requirement of tillage implement is high cost of production which makes the product of a farm to compete unfavourably with products from other farms. With good planning however, use of tillage machinery could be increased appreciably (Hunt, 1977).

Availability of skilled labour is the only guarantee for efficient output in agricultural machines. When machines are operated under the control of people with little or no mechanical skill or aptitude, the overall result is an unwanted increase in non productive operations time and cost and this has resulted in loss in soil productivity. (FMO, 1980).

When most tillage machinery that are imported are sent to the tropics they do not meet soils condition which may be drier and harder or wetter and sticker than in the temperate countries. Hence, it is difficult to adapt imported machines to local conditions. The general lesson learnt in such countries is often the machinery chosen has not been matched to the various agro-ecological zones and soil types. (Carruthers, 1992). Also as a result of the fact that machines are imported, it is difficult to get spare parts for their maintenance or repair as when due. The tendency is that expensive machines are left discarded when they have simple faults.

Lack of farm records normally hinders good management of agricultural machinery. When adequate records are not kept, decision taking and planning on the operations of the machines will be difficult. A good way of ensuring that all maintenance is performed on schedule is to keep records. Research work in the area of tillage often proofs difficult in developing countries like Nigeria due to lack of necessary data on tillage. (Odigboh, 1991).

The study of soil structure management has two aspects: defining the optimal soil physical state for any given purpose and determining the most feasible means to achieve such an optimum state. Any attempt to define soil crop tillage interactions in a fundamental way involves a complex array of factors relating to the mechanics of implement design and mode of operation, as well as to the dynamics of soil deformation and failure and of soil aggregation. The problems is most often approached empirically form two partial and alternative points of view, the engineering and the agronomic. The engineering approach aims at improving operational efficiency, while the agronomic approach aims directly at improving crop yield. Needed, and often lacking is a unified approach. Part of the difficulty encountered so far has been the lack of measurable criteria of universal significance. Because of the many factors (mechanical, soil physical, climatic and agronomic) and the complex interactions encompassed, tillage investigation must necessarily be long term undertaking. Short term experiments so often attempted under constraints of time, means and personnel seldom yield conclusive results even for the location on which they are carried out. Though the tillage methods compared may differ widely in cost, performance and measurable effect on the soil final crop yields many indicate no consistent or significant difference. This is probably due in large part to faulty selection of measurable criteria, inexact measurements, and soil variability as well as to the fact that crop response to tillage often tends to be marked by impredictable yet decision, variable acting on the field.

2.2 The Parameters Affecting Tillage Operations

2.2.1 General Review.

Soil tillage involves the interaction between tractor as the prime -mover, the implement and the soil. Also, the key to the development of a scientific approach to tillage is the establishment of a soil machine mechanics capable of desembling and predicting the action of a tillage tools on the soil. Once this is developed it can serve to predict soil behaviours and help in the selection or design of appropriate tillage tools and in the improvement of tillage efficiency. For a particular soil textural class, the extent of interaction between the prime-movers, the implement and the soil depends on the initial soil condition and the final soil condition desired. The ultimate goal of achieving the maximum crop yield depends on the final soil condition. By the time the final soil condition desired has been reached through the soil tillage operations, the soil structure has been changed. The control of the tillage operations determines whether the structural change is favourable or otherwise to the soil, especially over a long period of time. In order to be able to control the tillage operation the range of values of the tillage parameters required to achieve the desired result (power requirement or soil tilth) must be known. According to Godwin et al, (1987), the factor affecting the values of the design parameter for soil engaging implement include the physical properties of the soil, the type and shape of the implement and the operational parameters.

2.2.2 Tillage Operational Parameters

The operational parameters that affect the operation and design of tillage implement can also be described as the manner of tools movement (Kepner et al.,1987) . Experiment have been performed to confirm that tilling the soil is just as important as how it is exactly tilled (Kersten, 1991 as reported in FAO, 1993). A tool may be pulled along a straight line or it may be vibrated. The manner of tools movement depends on the tool orientation, its path through the soil and the speed along the path. The orientation of any tool having a particular shape may have a marked influence on both the manipulation and the soil forces (Kepner et al.,1987). The type of tool linkage to the prime mover also affects tool orientation and depth. According the Sharma et al. (1984), oscillated or vibrated soil working tool offers the following advantages - reduction in draught, better soil pulverization, better scouring of soil over the soil working components as a results of reduced adhesion, reduced tool wear and reduced tractor wheel ballasting and high energy utilisation efficiency. There is evidence indicating that vibration causes physical changes to take place in the soil that tend to reduce the shear strength.

Depending on the type of plough, the principle of attaching the implements varies with the source of power. In general, however, the aim is to make the best use of the source of power with minimum wastage atritable to side draught and improper traction, attendant poor work and excessive strain on the power source and the implements . Orientation of the tool is described by the approach angle and the slant angle. The approach angle comprises of the lift angle and the side angle in the vertical plane and horizontal plane. The lift angle also called the rake angle is the angle in a vertical plane parallel to the direction of travel. The side angle is the angle in the soil surface plane, between a centralised tool or reference axis and a line which is perpendicular to the direction of travel, while the tilt angle is that in a vertical plane perpendicular to the direction of travel between a centralised tool or reference axis and the soil surface.

Path of motion is the path the tool travels when passing through the soil. All tools that travel in straight lines can be describe by the depth and width of cut of the tools. Both depth and width are readily changed, and they are the means used most of ten to a"djust" design when the force required to move the tool is greater than can be easily supplied. Width and depth of disk cuts are variables which can be used to influence the nature of forces on disks (Gill et al, 1981). At the National Tillage Machinery Laboratory, Auburn (NTML), Mccreery (1959) in Kepner et al, (1987) studied the effect of width and depth of cut of 508mm diameter disk (540 mm radius of curvature on soil forces. In a lake land sand (typic quantizipsamments) with a width of cut of 152 mm, increasing the depth from 52 mm to 155 mm increased the draught and the side and vertical forces by as much as 300%. The side force changed less than either the draught on the vertical force. The same disk set at a depth of 104mm was operated at widths of cut from 51mm to 153mm, in 25.4mm increments although the side force remained nearly constant, the percentage of increase in draught and vertical forces was substantial. The absolute magnitude of the increase in draught and vertical force was 88N. Gordon (1941) reported in Gill et al, (1980) studied small changes of width and depth of cut at NTML. Although his data were limited, they indicated that changes in depth of cut had a greater influence on forces than changes in width of cut. He also reported that given a constant depth and width of cut, a large diameter disk had a lower draught than a small -diameter disk. Harrison and Reed (1968) reported in Reaves et al, (1981) conducted field studies to determine the influence of depth of operation on the draught of disks and sweeps. He found that a linear relation exist between draught and depth as expressed in Equation 1

$$\text{Draught (KN)} = 0.543 + 0.149\, d \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where,

d = the depth in mm. The disks and sweeps in these studies were operated at a velocity of 1.1mls. However the size and number of tools on the implement were not mentioned. Thefore the draught per disk could not be determined.

Gill and Hendrick (1976) in Reaves et al, (1981) discussed the irregular nature of soil disturbance by circular tillage tools. The basic geometry of soil-disk systems is such that a change in the depth at which disk cuts simultaneously changes the width of cut. When the paths swept out by adjacent disks intersect at the undisturbed soil surface, a unique relation exists that determine the projected width of the disk at the soil surface. This relationship is represented by:

$$P = D_h \sin \mu \quad \text{..}(2)$$

where,

P = the projected width of the disk.

D_h = the length of a horizontal line drawn through the plane of the disk at the soil surface

μ = the disc angle.

The projected soil - tool contact area in the transverse plane can be calculated and the forces can be expressed in terms of the force necessary per unit of projected cross - sectional area to provide the specific force . The specific force reflects both the width and depth contribution on the contact area and could be a better index of performance than force. Gunderson et al. (1981) reported in Nicholson et al (1984) was interested in depth control of implements and showed draught to be a quadratic function of depth for a field cultivator. Bloome et al, (1984) also developed a similar equation for chisel ploughs.

Operating speed is another tillage operational parameter.

All tillage implements experience an increase in draught as forward speed is increased mainly due to the more rapid soil acceleration (Kepner et al ,1987) Hence speed of operation has profound effect on tractor implement performance. The magnitude of the effect of speed upon draught is however a function of the relative magnitude of components that are independent of speed and the components that increase with speed.

Experimental tests with various soil engaging tools have confirmed that draught increases with speed (Yadav & Pandey, 1984, Sharma et al. , 1986) . Vibration of components also increases with speed. Various equations have been established that relate draught with speed. According to Gill and Vander Berg, (1967) these include

$$D = K(V-3) \quad \text{...................................}(3)$$

Where,

V = Speed in mph; K = coefficient varying from 5 to 15 depending upon the tool

$$\frac{D_v}{D_s} = 0.83 + 0.0189V^2 \quad \text{..............................}(4)$$

Where,

D_v = draught at speed v

D_3 = draught at 3mph

V = speed in mph

$w(v) = wo + \varepsilon v^2$ ....(5)

Where,

w = draft, v = speed, wo = basic draught independent of velocity (presumably the draught at a very slow speed of operation).

ε is a constant coefficient whose value is related to implement type and soil conditions.

$D = D_o V$ .... (6)

Where,

D = draught

Do = base draught for a specified speed and soil condition.

V = speed

All these equations show that a linear relationship exists between draught and speed. The effects of speed determined for a disk plough at disk angle setting of 45°, a tilt angle of 20° , a depth of 15cm indicated that when the speed was increased from 4.8km/h to 9.6km/h, the draught increased 40% in the clay loam and 90% on the sandy loam (Gordon, 1941 in Kepner et al. , 1987). This shows that the effect of speed on implement draught depends on the soil type. (Bloome et al 1983 in Nicholson et al, 1984) related draught of a mouldboard plough by a parabolic relationship to travel speed for a variety of soil types and speed ranges from 1.6 to 9.7km/h whereas for chisel plough he concluded that the response of implement draught to speed is linear for a range of 4 to 10km/h. Some researchers agreed that the normal operating speed of implements fall into a transition zone for linear and parabolic responses of implement draft to speed, due to the action of the shearing planes in the soil.

Reports have also shown that the interaction of speed and depth were related to draught. Sial and Harrison (1978) reported linear responses of draught to both speed and depth of field cultivators. The increase in draft for every increase in depth was greater with increasing speed. They concluded that the increase in draught with speed is associated with changes in the zone of disturbance coupled with changes in the amount of strain hardening of the soil. A study of sweep and chisel plough design indicated that depth is very significant with speed and soil interaction (Nicholson etal, 1984).

Soil breakup may increase as speed increases but this is not a general phenomenon (Soehne 1980 in Kepner et al, 1987) compared four general types of plough bottoms in two soils at 4.35km/hr and 12.2km/hr. In one soil there are some differences 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 draught. Also, in assessing the effects of speed upon draught any accompanying effects upon the degree of soil break up must be considered.

2.3 Tillage Tool Geometry

Koolen and Kuipers (1983) defined a tillage tool as an individual or single working element such as a plough bottom of a mould board plough, a disk blade of disc plough or a cultivator shovel. A tillage implement consists of a single tools or a group of tools together with the associated frame, wheels, controls, protection devices and any other structural and transmission components. Different types and geometry of tillage implements are in existence for tillage operations and different implements produce different tilth.. The purpose of a tillage tools is to manipulate (change, move or form) soil as required to achieve a desired condition. Of the three input factors of tillage-initial soil condition, tool shape and manner of tool movement that control or define the soil manipulation, the designer has complete control only of the tool shape. Tool shape cannot be considered independently of manner of movement or initial soil condition.

Gill and Vander Berg (1967) classified three shape characteristics of tillage implement as macroshape, edgeshape and microshape.

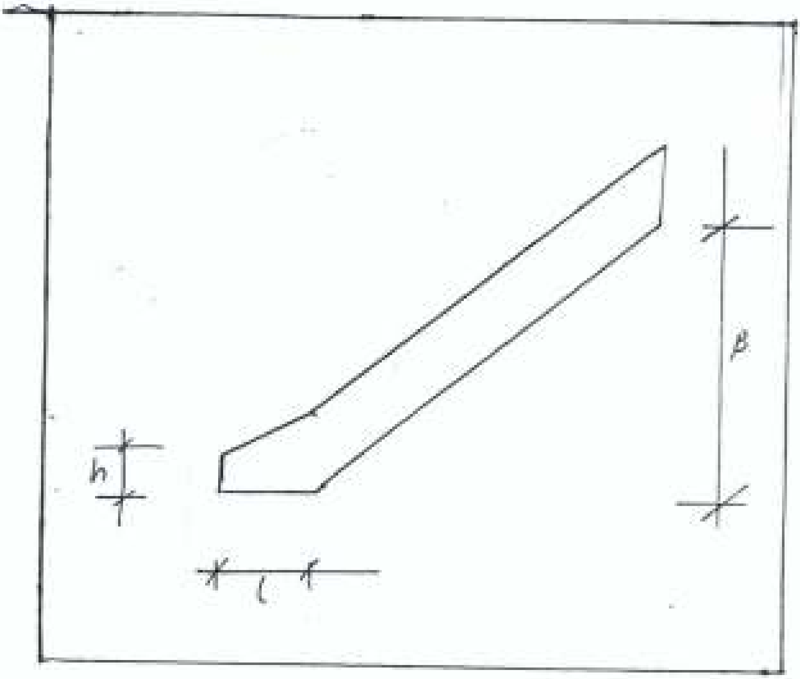
2.3.1 Macroshape, Microshape and Edgeshape

Macroshape is used to designate and emphasize the shape of the gross surface. Soil slides over the macroshapes of tillage tools. Because soil types and ploughing conditions vary widely many different types and shapes of tillage implements have been developed. Ancient Egypt, Greece and Rome tilled their field with Y shaped sticks pulled by draught animals and slaves. This plough design was practically unchanged until the 18th century (Richey et al., 1989) when formed metals were used for the mould board. Over many years, mould board plough shapes have evolved through the "trial and error" design efforts of many individuals.

Also, various shapes of soil engaging tools have been evaluated under soil in conditions. Such shapes include straight convex, concave and V shaped tine tools. Yadav and Pandey, (1984) found out that of all the four blades shapes mentioned above the straight blade required maximum draught while the V shaped and concave shaped blade performed better than the others (i.e straight and concave shapes) A concave or convex blade is also affected by its radius of curvature (Gupta et al, 1989). While a convex surfaced blade has a lower draught requirement it has a lower tendency of lifting tubers than concave shaped tools. Ademosun (1990) also performed experiments with different shapes of tine and mould board plough in a soil b in containing a tropical agricultural soil to determine the relationship between various tillage parameter and the draught requirement. The different shapes considered were wide and narrow tine, digger, semi -digger and general purpose plough. For all the tillage parameters investigated, the draught requirement of wide tine was higher than that of narrow tine and the draught requirement of digger plough was higher than that of general purpose plough . That of semi digger plough was half way in between.

Microshape referees to the roughness of a surface over which soil slides. Surface roughness many be caused by rust, abrasive wear, pohsh, scratches or small depression resulting in frictional resistance. Frictional resistance may be such a small proportional of the total draught that large changes in the microshapes and consequently the coefficient of friction may cause only a small change in total draught (Spoor, 1969). On the other hand, microshape could affect other aspects of soil movement such as scouring. As a general rule, frictional resistance should always be minimized and the control of microshape is the most practical way to do this. Improving microshape is synonymous to decreasing surface roughness. (Gill and Vander Berg, 1967) Gill and Vander Berg (1967)also reported that scouring non - stickiness may be poor in some soils if after ploughing the tools is exposed to air drying for a short time In these soils protecting film of oil or other preservatives are required when the tool is not in use. Also, Polytetra fluorothylene (Teflon) and polyethylene, which have non wetting characteristics are currently being used as coatings on tillage tools to reduce adhesion. The coefficient of friction of these materials can be as much as 50% less than that of smooth steel and draught can be reduced by as much as 25%. (Spoor, 1969).

Edgeshape refers to the peripheral and cross-sectional shapes of the boundaries of the soil-working surface. Common edge shapes for sweeps include the cutting edge height or taper thickness; length of underside rub; angle of underside clearance (Fielke, 1996). This is illustrated in Figure 2.



β is angle of underside clearance

h is cutting edge height

l is length of under side rub.

Figure 2: Side view of a sweep showing cutting edge parameters (Source: Fielke, 1996)

Fielke, (1996) reported that many manufacturers are producing tillage implements from thicker materials so as to give longer life, (This results in blunter cutting edges). There is however the need to consider the need not to cause a detrimental effect on the performance of tillage implement as this and many other advances are made. Researchers have shown that forces on tillage implements are altered by wear, which changes the geometry of the cutting edge, depending on the soil type and condition (Felke et al, 1993; Malov, 1979). The shape of the cutting edge can affect the draught as well as vertical and lateral components of soil forces.

A blunt cutting edge was consistently reported to increase draught force and the upward acting vertical force which tries to lift the implement out of the soil. (Gill and Vander Berg, 1967, Riley and Felke, 1993).

Also, there exist some interactions between cutting edges of varying geometry and the soil. Felke (1996) studied the effect of the cutting geometry of sweeps on tillage depth forces, soil failure and soil movement below the tillage depth. By changing from a tillage tool with a sharp cutting edge geometry to a blunt one, the results showed that the blunter cutting edges often formed cracks in the soil below the tillage depth. A small angle of interference (negative clearance between the underside of the tool and the soil) increased the cone penetration resistance of the soil below the depth of tillage while corresponding test in a glass-sided soil bin revealed that the tool smeared the soil as the cutting edge passed.

2.3.2 Review of the Geometry of Selected Tillage Implements

Agricultural engineers have been concerned with tillage implements for many years now in identifying and qualifying physical performance specifications for farm machines so that they can be selected and utilized properly for any given application. The shape of implements, size, design, materials or composition, angle of tilt and so on, have significant effect on their performance. A review of the geometry of selected tillage implements mould board plough, disk implements and tined implements were carried out with a view of assessing their performance.

2.3.2.1 The Geometry of the Mould-Board Plough

The mould-board plough is one of the widely used tillage implements. It does a good job of turning oversoil and is effective in retarding weed growth. This is accomplished by a specially shaped mould-board plough bottom. A mould-board plough bottom is a three sided wedge with the landside and the horizontal plane of the share's cutting edge acting as flat sides and the top of the share and the mould-board together acting as curve side. The size of a mouldboard bottom is the width of furrow, it is designed to cut. Different shapes of the bottom have been designed which produce the best results in certain soil or operating conditions. A general purpose bottom works well at speeds of 5 to 6 km/h and turns soil, stubble stalks, and cover trash (Jacob & Harnel 1983). The general purpose bottom penetrate the soil better than any other type of bottom.

Stubble bottoms produce the best trash coverage and pulverisation of the soil. They are scour the best in sticky stubble ground at 5 to 8 km/h. The high waist turns furrow uphill at slow speeds, making it ideal for ploughing on hillsides. A high speed bottom will operate at 10.5 to 11km/h because the mouldboard has a longer using and more curvature. Slattered mouldboards have approximated 50% open area, thereby offering less friction to turn sticky and waxy clay soils. Deep tillage bottoms have high mouldboards to permit turning a furrow slice when ploughing as deep as 406mm. They are used in soil irrigated section. Heavy duty bottoms are designed to crumble the soil and knave it smooth when operated at 8 to 10 km/h. They throw extra soil from the 500mm cut to leave more room for large tractor tyres. Figure 3 shows the types of mouldboard

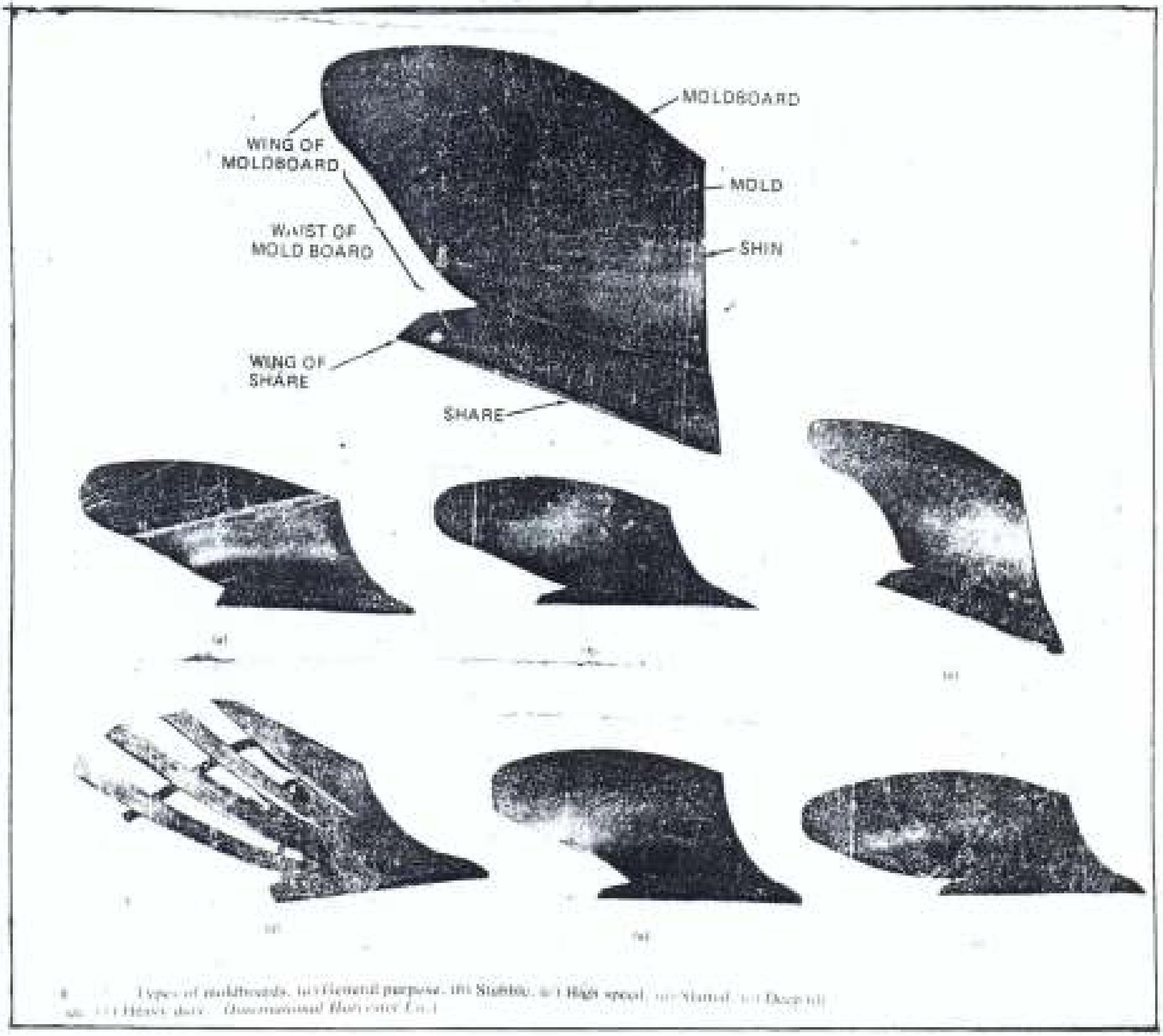


Figure 3 Types and parts of mouldboard (*Source: Jacob and Harrell, 1983*)

Wear resistance in abrasive soils and scouring in sticky soils such as clays and clay loams ate two importance factors that influence the choice of materials for plough bottoms. The share of the mouldboard plough are designed to pull the bottom into soil. The common types are the flat, curved and deep suction (Jacob and Harrel, 1983). Flat shares sever the entire furrow slice in order to cut all roots. They penetrate well and pull easier than flat sweeps. Deep suction shares have a point designed for quick penetration ands more stable ploughing depths in hard soils.

Other attachments for mouldboard plough include the rolling coulters which cut crop residue ahead of the mouldboard-plough bottom. Types of rolling coulters include the yoke type plain, the disk, the ripple edge and the serrated blade conlter (Jacob and Harrel, 1983; Kepner at al, 1987). Yoke type plain blade coulters are preferred for deep ploughing . Disk conlters is best for cutting and handling trash. Ripple edge blades are designed to mesh themselves to the soil as they penetrate with full speed while the separated edge coulters provide chipping action as they rotate and are preferred in heavy trash conditions provided they are kept sharp. Figure 15 shows types of coulters

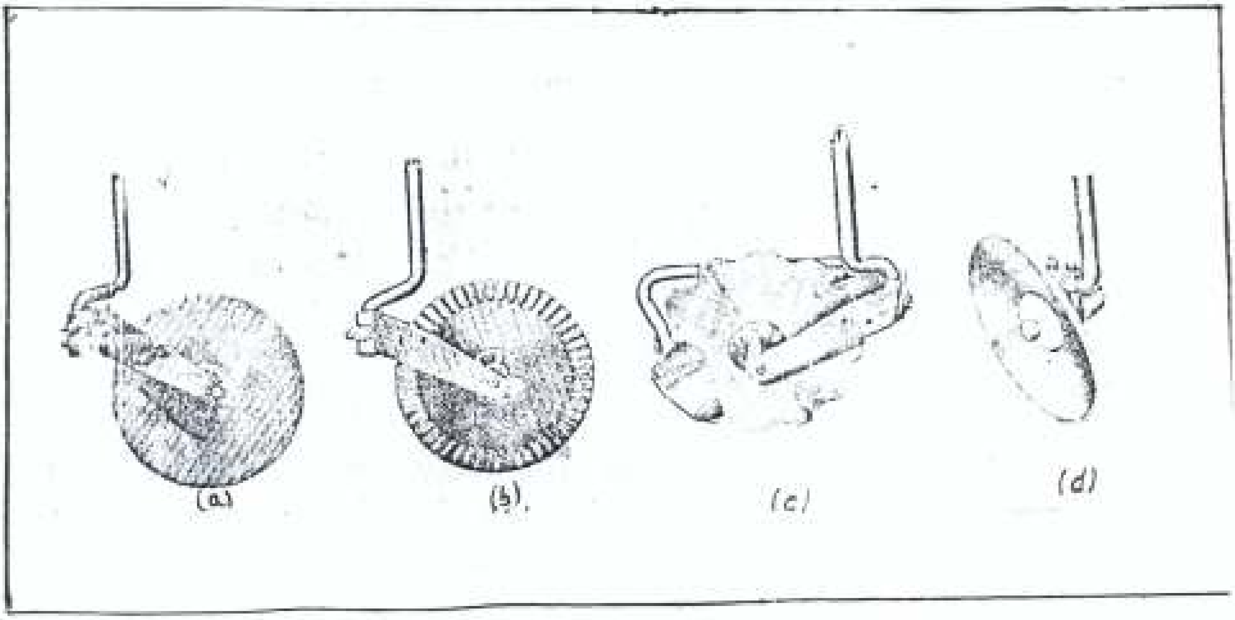


Figure 4 Types of Coulters (Source: Kepner et al, 1987)

(a) Plain coulter with spring cushion mounting to permit coulter to ride over obstructions

(b) ripple edge coulters

(c) Notched coulter with pointer attachment

(d) From view of concave coulter or disk jointer.

The shape of the mouldboard has a definite influence on draught although the relative effect are influenced by soil type and conditions. Speed and perhaps other factors (Kepner et al, 1987). In general, shapes that give the best trash coverage or the greatest degree of pulverization tend to have the highest draughts. Share edge-shapes can significantly affect draft. Three different shapes tested on a 36 - cm plough bottom in a day soil at the National tillage Machinery Laboratory Auburn had draught of 1.18, 1.29 and 1.4 km when new. Worn shapes may have substantially greater draught than new shares. Share wears occurs rapidly in many types of soils, particularly when the moisture content is low. Also, changes in design or materials to reduce soil-metal friction has significant effect on draught. Covering a plough bottom with Teflon reduced the draught by 23% in a soil where steel would not scour and by 12% in a soil where both scoured (Kepner et al, 1987).

2.3.2.2 The Geometry of Disk Implements

Disk Implement comprise of implement like disc plough, disc harrow, disc ridger, disc tiller etc. having concave blades usually representing sections of hollow sphere. The action of a concave disc is somewhat similar to that of a mould-board in that is lifted, pulverised, inverted and displaced to one side. Disc ploughs are primary tillage implement that works satisfactorily in abrasive sticky, harder and in non scouring soils better than the mould board plough. However the disc plough can not satisfactorily replace the mouldboard plough for ordinary purposes owing to their failure to bury rubbish completely. The disk blades on these ploughs can be tilted backward from 15^0 to 25^0 (tilt angle) in the vertical plane. It also makes an angle with the direction of travel (disk angle). These two angles can be adjusted. A rear furrow wheel provided with the plough takes care of the side thrust.

Disk harrows are secondary tillage implements which can be employed for great variety of purpose such as the preparation of seed beds, and destruction of weeds etc. The disks of a disc harrow are mounted on an axle to constitute a gang and several gangs may be mounted together to make a disk harrow. Unlike the disc plough, the angle of the individual disks in the disc harrow is fixed, but the angle of the gang may be set in relation to the direction of travel. Disc harrows may have single tandem disk arrangement or effect disk arrangement. The disc ridger is required for row planted crops. It is also used for making field furrows or channels earthing up. The ridger bodies, mounted on a frame can be staggered to give the required spacing. This spacing is usually adjustable. The disc tiller is also known as vertical disc plough. It's action is half-way between the standard disc plough and the disc harrow. It carries the disk at approximately a fixed angle, cutting and throwing soil in the same direction. The disks of a disc tiller one smaller than those of a plough but bigger than those of a disc harrow. Because the disc tiller is primarily a mixing tool, the draught is lower per meter than that of a disc plough with the same power requirement.

Disk tool geometry include the diameter, shape, radius of curtivature (or concavity), size, thickness, masses taper height, taper thickness and bevel angle. Each depending upon the manufacturer's design has influence on soil forces and reaction (Gill et al; 1980). Larger disc sizes permit greater operating depths than do smaller blades. Small diameter disks however, penetrate more readily than do large disks i.e. they require less vertical force to hold them to a given depth. Studies at the National Tillage Machinery Laboratory by Gill et al. (1980) and Reaves et al (1981) indicated that increasing the radius of curvature (increasing the disk flatness) of disk harrow blades reduced the force exerted on them by the soil. The draught and vertical forces were reduced and the side force was not only reduced but also sometimes reversed direction. Because of pressure on the blades of disks, an optimum angle in terms of draught occurs for operation of disk. For plough blades, it was also found in the USDA tests (1941) that increasing the disk concavity (smaller radius of currature) increased the vertical upward force, especially in the heavier soils and tended to increase the draught.

For disk harrows, reducing the concavity (larger radius of curvature) and sharpening disks from the concave side rather than the converse side improve penetration (less vertical force required or greater depth for a given vertical force) (Narka, 1990) These effects are related to the soil of the bearing area in contact with the soil on the convex side of the disk Some disk implements are equipped with cut-out or notched blades. These cut-out penetrates a little better than plain blades because of the reduced peripheral contact area (Kepner et al, 1987). They cut trash more readily because they tend to pull it under instead of pushing it ahead. They are also more expensive and wear more rapidly.

On soil reactions on disk harrow blades Nartov (1973), after a study of Soviet disk standards recommended that the radius of curvature 'R' be increased to as much as one and one half times the disk diameter 'D' to reduce soil throwing at high speeds of operation. The Soviet standard describes disk of large as 1250mm on diameter with 1800mm radius of curvature, an R to D ratio of 1.5. The R - to- D ratio of disks used in the United States rarely exceeds 1.0. However, the curvature of the disk determined the nature of back pressure in the disk and the amount of the soil transported at mounting angle disks with large radius of curative could reduce soil throwing distance, accomplished more soil fracture and soil inversion and piled more soil in front of the disk than the comparable flat disk. He also reported that the flat disks could be operated at higher speeds than special disks without bringing wet soil layers to the surface of the field.

Studies have also be conducted on the effects of changes on the disk angle on radius of curvature . Nartoz (1972) studied the radius of curvature of disks and reported that a decrease on the radius of curvature of disks had same effects as an increase in the disk angle. Thus, disk radius of curvature should not be varied without considering changes in disk angle. Gill et al (1981) tested a series of seven 610mm - diameter disks having radii of curvature varying from infinite (flat disk) to 494mm for draught, vertical and side forces. At disk angles between 0.2 and 0.3 rad, the smaller the curvature of the disk, the larger the soil force on the back surface of the disk. Because of the magnitude and direction of the side forces, they suggested that optimum shapes, both in terms of forces and soil handing, may lie in the intermediate range of radii of curvature to disk diameter (1.33 to 2.92) rather than at extremes studied.

2.3.2.3 The Geometry of Tined Implements

According to Koolen and Kuipers (1983), when a soil has to be loosened, a body (operating tool) can be moved through the soil. Such a body will be labeled a tine if the loosen effect reaches considerably further than the width of the body. Tines occur in chisel ploughs, spike tooth harrows, cultivator, p.t.o. driven implements for seedbed preparations, weeders and subsoilers. Chisel plough operates at a considerable depth to break open the subsoil and thus assist in drainage. Operating depth can be roughly equal to the depth of the arable layer. There are rigid tines, spring mounted rigid tines and spring tines. Tines having some flexibility are able to move around obstacles and have a better self-clearing action and sometimes a better crumbling action than non flexible tines. A share is mounted at the bottom end of a tine. Shares have many shapes and are usually wider then their shanks. The latter increases the loosening effect with a smaller soil displacement. Wear is concentrated mainly to the share area. Shares are exchanged when they are worn, or for purposes of tillage effects. Tines usually have a curved shape, the share cutting angle being between 30° - 60° . The larger this angle, the less upward is the soil movement, but the higher the draught, the more the crumbing and the more difficult it is for the tine to penetrate. Larger tines often have smaller cutting angle then smaller tines. The set working depth is generally stabilized by supporting wheels. Normal range of travelling speed is 6-8km/h. Crumbing increases with increasing travelling speed.

Subsoilers are used to break up the hard soil pan (or compacted soil) usually under the arable layer that can develop as a result of the continuous use of ploughs. Working depth of the continuous use of ploughs may even be well over one meter. The tine shank of the subsoiler is equipped with a share, which is wider than the shank and has a very small cutting angle. The shank is rigid and much steeper than the share. The subsoiler is usually rigidly connected with the tractor, so that tractor wheels also serve for depth control but sometimes depth is controlled by wheels rollers or sleds. Subsoilers requires a highly powered tractor, usually a crawler type to pull it through the soil.

The spike - Tooth Harrow consist 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 of spike - tooth harrow are the rigid and the flexible spike - tooth harrows. The rigid harrow section has one piece end rails holding the tooth bars which make all the teeth not at the same depth. The flexible harrow has jointed end rails which permit individual tooth bars to be raised vertically to go over obstructions. Flexible harrows can be rolled up like a rug for transport or storage. The gangs of the first section throw the soil out ward 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 back action that works the soil twice. The purpose of the spike - tooth is to thoroughly smooth and compact the topsoil, 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 vain formed crust and destroy small weeds (Micheal and Ojha, 1989).

Cultivators comprise basically of 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 spring tine cultivator has tines made of spring steel, thus enabling 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 hand materials. The spring action also help to break down any clods of soil left by the plough. However, this type of cultivator works at 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 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)

2.4 Quantification of performance of Tillage Implements

Tool forces and changes in soil condition are the two basic aspects of tillage tool performance (Kepner et al. , 1987). According to ASAE standard, (1989) performance rates for field machines depend upon achievable field speeds and upon the efficient use of time. Field speeds may be limited by rough ground and adequacy of operator control. To evaluate the performance characteristics of tillage machines the following parameter have been used or suggested: Force systems acting on tillage tools include draught force, vertical force and side forces (Gill et al 1980, 1989, Fielke 1996, ASAE, 1989; Shimmer et al., 1993, Ademosun, 1990); Soil disturbance (Bukhari et al. , 1988, Spoor, 1982); mean weight diameter (MWD) (

Yadav and Pandey, 1984; Gupta et al, 1989); field capacity (Bukhari et al. , 1992; Bukhari et al 1988; Bukhari et al 1986; Kepner et al, 1987; ASAE, 1989), travel reduction (ASAE, 1989; Bukhari et al., 1988) Fuel consumed (Bukhari et al., 1986) Uniform soil mixing (Kepner et al, 1987; Salokhe and Gee-clongh, 1987 Wang and Gee - clongh, 1993) Inverse performance index (Gupta et al., 1989).

2.4.1 Force Systems Acting on Tillage Tools

According to Kepner et al. (1987) a tillage implement (or tool) moving at a constant speeds is subjected to three main forces which must be in equilibrium. These are force of gravity acting upon the implement, the soil forces acting upon the implement, the forces acting between the implement and the prime mover. If torque from rotary power transmission is not included (as in mounted tillage implements), the resultant of these forces is the pull of the power unit upon the implement.

The horizontal component of the resultant force is parallel to the direction of the tractor travel. This is defined as the draught force of the implements. This is the force necessary to maintain movement at a constant velocity. The draught is the part of the force that determines the traction required from the tractor. Draught requirement determination is necessary to estimate or predict the power requirement of tillage implements and hence the power source selection (Shedd et al., 1940) Promer berger and Pratt (1958)in Nicholson et al (1984) identified draught as a function of soil condition, travel speed and tillage depth. The comparison of draught among different types of implements indicates that the variable associated with draught act differently depending on the configuration and function of the implements.

The vertical component of the pull is also very important. It has the effect of adding load to tractors rear wheels. It has therefore profound effect on the tractive ability of the tractor, its stability and on the facility with which it can be steered. It also has influence on the implement power to penetrate and maintain depth as well as on the draught of the implement because of the functional forces associated with the vertical force. The side draught is the horizontal component of pull, perpendicular to the line of motion (Kaul and Egbo, 1989).

2.3.2 Other Factors

Other factors used to evaluate the performance of tillage implement include the mean weight diameter (MWD), soil inversion and uniform mixing, field capacity etc. To quantify the final soil condition many researchers have measured the mean weight diameter of soil aggregates, as suggested by Yunker and Gunines (1957)in Singh, (1989). The mean weight diameter is an index of the degree of soil break up which is a function of the soil. Different types of crops require different types of seed bed for their establishment and different implements produce different tilths. Therefore the MWD is an index of tool performance.

According to Bukhari et al. (1988), soil inversion is expressed as the ratio of weeds and stubbles left on soil surface after implement operation to the total quantity of weeds and stubbles present before the operation. The soil inversion was computed by the formula.

$$F = \frac{wp - we}{wp} \times 100 \quad \text{.......................................} (7)$$

where

F = soil inversion,%

wp = weight of weeds and stubbles before implement operation (g)

we = weight of weeds and stubble on the tilled surface after implement operation (g).

Complete soil inversion is preferred where the clean and wet cultivation is needed while partial soil inversion is required in areas of soil erosion problems.

Field capacity and soil disturbance are two major factors in determining the performance of tillage implements. Field capacity of implements can be determined by using Hunt's formula assuming 70% efficiency of the implement (Bukhari, et al; 1988).

$$C = \frac{SWE}{10} \quad \text{...} (8)$$

$$= 0.075SW$$

Where

C = field capacity ha/hr

S = speed of operation km/hr

W = width of implement, m

E = field efficiency decimal.

The soil disturbance is the function of field capacity and depth of implement operation, (Bukhari et al, 1988). Soil volume disturbed in m^3h is measured by multiplying the field capacity with the depth of cut and 10,000

Travel reduction or wheel ship affects the traction efficiency of the pulling machine. Tractor drive wheels ship in all field operations. The distance a tractor moves forward in a given number of revolutions of the drive wheel decreases when wheel ships. A simple method in determining the amount of travel reduction was by making a mark with chalk on the drive wheel of the tractor and the distance the tractor travelled in 10 revolutions with no load (A) and with load (B) is measured The travel reduction is calculated by using the formula.

$$TR = \frac{A - B}{A} \times 100 \ldots\ldots\ldots\ldots\ldots(.9)$$

Where

TR = travel reduction

A = distance travelled with no load

B = distance travelled with load

Uniform soil mixing can be evaluated by applying tracer materials to the soil surface and determining their distribution after tillage. Easily identifiable granules or pellets, radioactive materials, dyes whose concentrations in soil sample can be determined by spectrophotometry and sodium or potassium chlorides have been employed (Kepner et al; 1987). According to Gupta et al. (1989) inverse performance index is the product of the specific draught and the mean mass diameter of soil aggregates. It was used as a measure of overall performance of different tools.

2.5 Soil Properties as it affects Tillage

Pearson et al, (1995) described soil as the major natural resource upon which sustainable cropping depends. Soils are needed for many purpose, the most important of which is to produce food and fibre for human kind. According to Biswas and Mukherjee (1987), soil is a dynamic natural body consisting of mineral and organic constituent possessing definite chemical, physical, mineralogical and biological properties having a variable depth over the surface of the earth and providing a medium for plant growth for land plants soils is a heterogeneous mixture of silicate particles, humus and a variety of insoluble salts and oxides of metal called the solid phase, a liquid phase and a gaseous phase and a variety of insoluble salts and oxides of metal called the solid phase. Soil exhibits exceedingly complex interactions among its constituent hence the need for its judicious and effective management. According to FAO, (1993),tillage is a major management practice that have a major effect on soil productivity. The choice of the most appropriate tillage methods depends on many factors among which is soil properties such as moisture content, texture, structure, compaction and soil strength. Ademosun 1990 described these soil properties as soil parameters of Tillage. The required strength of tillage machinery, the rate of wear and the power requirements are direct functions of soil physical condition during operation (Gill, 1979).

2.5.1 The effects of Soil physical properties on Tilth and Productivity

Brady 1990 described tilth as the physical conditions of the soil in relation to plant growth. It include all soil physical conditions that influence crop development. Tilth depends on granule formation and stability, bulk density, soil moisture content, degree of aeration, rate of water capacity and the history of cropping or otherwise of the soil (Ojeniyi and Dexter, 1979; Brady, 1990) According to Biswas and Mukherjee, (1987), two very important physical properties of the soil are soil texture and soil structure. Soil texture refers to the relative proportion of particles of various sizes in a given soil. Soil texture cannot be altered because it is a basic property of the soil. The three broad and fundamental groups of soil textural class are sand, silt and clays These soil fractions contributes to the consistence and strength of the soil and their packing determines bulk density.

Many of the important soil properties are related to texture. Texture affects water retention and release characteristics of soils its nutrient supply to plant. (Biswas and Mukherjee, 1987) and the workability of soils (Baver et al, 1972) In an experiment to describe water retention by soils , Biswasand Mukherjee (1987) showed that at the same suction, water is higher in clay soil, lower in loam soil and lowest in sandy soil. For the same quantity of water application, suction will be lowered quite significantly in coarse textured soils as compared with that in fine-textured soil. For this reason, even for a small amount of rainfall, water is available to the plants on coarse textured soils but this may not be so in fine textured soil. Hence, at the same moisture content, water is more available to plants in coarse textured soils than in the fine textured soil. Also, water infiltration is more rapid in coarse textured soil as compared with fine textured soil, Hence plants which require refine good drainage will thrive well in a coarse rather than in fine textured soil. Tillage has little impact on coarse textured soils but it has a profound positive impact on fine textured soils (Donahue and Miller, 1992)

Soil structure has to do with the physical constitution of a soil materials as expressed by the size, shape and arrangement of soil particles and associated voids. It include both the primary particles which form compound (secondary) particles and the secondary particles themselves (Brewer and Sleeman 1960 in Dexter, 1976).Soil structure modifies the influence of texture with regard to moisture and air relationship, ability of plant nutrients, action of micro-organisms and root growth (Foth, 1984). According to Bradfield and Janeson, (1951), soil conditions and characteristics such as water movement, heat transfer, aeration, bulk density and porosity are influenced by structure. In evaluation of soil structure the agriculturist's interest is associated with tilth. (Baver et al, 1972). The important physical changes imposed by the farmer in ploughing, cultivating, draining, liming and maturing his land are structural rather than textural. Soil structure has a direct bearing on ease of cultivation, the necessary implements, the applied methods and production costs. A good and efficient soil tillage tries to create strong and stable aggregates, resist the impact of raindrops, improves the infiltration and water holding capacity, thus improving soil structure.

Soil structure influences plant growth rather indirectly (Biswas and Mukherjee,1987). This is so because formation of structural clods leads to the formation of an array of pores of various shapes and sizes. These pores are the controlling factors governing water, air and temperature in soil which in turn, govern plant growth. One of the best examples of the effect of soil structure on plant growth is the emergence of seedlings on the seedbed (Biswas and Mukherjee, 1987). Successful seed germination depends upon careful preparation of the seedbed. The soil on the seedbed should have a crumb structure so that the beds are soft and porous and roots of the seedling can penetrate it easily. For seedbed, it is accepted that an aggregate size range of 1 to 5mm is required (Russel, 1973). In general, it is a fact the better the soil structure, the higher is the yield, other factors of crop production being optimum.

The moisture content of the soil affects the magnitude of power require to operate the mixture. It affects a number of soil characteristic such as cohesion, adhesion deformation and other soil strength properties (Godwin et al, 1984). The most convenient way of considering the effect of soil moisture is not in terms of soil moisture content but in terms of the soil consistency states. Soil could be in the cemented (hard), friable, plastic or liquid state. The idea time for carrying out tillage operation is when the soil is friable and is able to scour freely on the tool, the amount of deformation obtained from a given soil depends upon the type of soil and its condition (Spoor,1969).

Soil compaction also has a great influence on soil productivity and implement performance. According to Onwualu, et al 1987, soil compaction increases the bulk density of the soil and soil resistance which also increase the draught and energy requirement for soil breakup. The amount of compaction varies with the soil moisture content, soil type and the type and size of external loading. Increase in soil compaction changes the permeability of the soil, loss in porosity and may inhibit root penetration (Ohu and Folorunso, 1989). Soil compaction also reduces penetration by tillage implements, reduce the area covered/unit time and leads to increase in energy and power requirements.

2..5.2 Soil Structural Assessment

Soil structure is of prime importance in maintaining soil productivity and increasing crop yield. Measurement of soil structure is necessary for quantitative research into the performance of tillage implements and the physical factors which influence the development of plants (Dexter,1976). The methods of characterization and evaluation of soil structure may be broadly grouped as direct and indirect (Biswas and Mukherjee, 1987). The direct methods characterize the shape, size and arrangement of soil aggregates, while the indirect methods are based on the measurements of extent and stability of aggregates and also the properties related to soil structure.

2.5.2.1 Direct Methods of Soil Structural Assessment

Direct methods involves microscopic evaluation in the laboratory and macroscopic or field characterization of soil structure. The microscopic method involves the use of the thin section technique, in direct evaluation of soil structure in situ under the microscope. Such thin soil structure sections, when examined under a petrographic microscope, clearly show the nature, shape and size of the secondary particles and voids. (Biswas and Mukherjee, 1987). Permanent records may be made through photographs.

The macroscopic method is the field characterization and classification of soil structure. When a chunk of dry soil, excavated from soil in the field is allowed to fall gently on a smooth surface, it breaks into small pieces of peds of different sizes and shapes. The shapes and sizes are assessed in soil profiles from the cleavages. The shape and arrangements of peds determine the type of soil structure. Types of soil structure in the United State Department of Agriculture system of classification (Figure 5) are platy, columnar, angular blocky, subangular blocky, granular and crumb; From the agricultural point of view, crumb structure is most desirable. Crumb structure, indicates that the peds are small (maximum 5mm in diameter) soft and porous. This type of structure is helpful in root penetration, aeration and water retention which are essential for satisfactory growth.

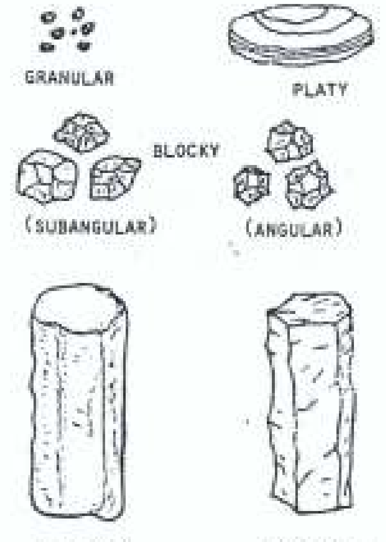


Figure 5 **Types of soil structure**. *(Source: Hillel, 1980)*

A direct method of quantifying the internal geometry of soil was developed by Dexter, (1976). Rectangular steel moulds of 45 x 25 x 18cm were pressed into freshly tilled soil across the direction of tillage. Paraffin wax (60° m.p) was melted and poured into each mould to impregnate the enclosed tilth. A wax layer of about 10mm thickness was left on top of the impregnated tilth to help to hold it together. When the wax had set, the impregnated tilth block samples were removed from the mould by heating their sides to melt the adjacent paraffin wax. Sections through the impregnated soil samples were cut using hacksaw blades. Tilth structure was quantified in the following way. A line, horizontal in the original soil was struched across each section at half the depth of tillage. A 1mm intervals along each line, raw data on the distributions of aggregates and voids were collected. A 1 was written if there was a void. A void was indicated by the presence of paraffin. Thus a string of 320 o's and 1's was written which represented the structure of the tilth at that depth on that section. The statistical analysis involves the computation of probabilities P (o) of a O in given position following the sixteen possible presursors or combinations of o and 1 in the four positions immediately to the left of the position in question. These probabilities may be thought of as being conditional porosities. Although this method has many desirable features, it suffers from the disadvantage that conventional statistical analysis of the results is not possible.

2.5.2.2 Indirect Methods of Soil Structured Assessment

(Biswas and Mukherjee, 1987) reported that indirect methods of evaluation of soil structure involve measurement of size distribution of aggregate stability of aggregates, and soil property which is function of soil structure. Size distribution of soil aggregates is important because the size of the aggregates determines their susceptibility to movement (erosion) by wind and water, and because their size is important in determining the dimensions of the pore space in cultivated soils (Singh, 1989). The choice of conditions under which the aggregate size distributions are to be measured is largely determined by the purpose of the analysis. Since no stand universal methods has yet been devised, the method used should be reliable, convenient and give valid results which indicate actual field conditions (Spoor, 1967)..

Aggregate screening methods were reviewed by Chepil (1962) in Singh (1989). He presented a detailed plan for a rotary sieve machine equipped with a nest of sieves of various aperture sizes. The operation of this machine can be standardized, thus minimizing the arbitrary personal factor and dogging is virtually eliminated. Samples for dry seizing analysis should be taken when the soil is reasonably dry to avoid breakdown or change in structure. The electrically rotated seizes are slanted downward so that the classified aggregates gradually tumble into separate bins for weighing . Various indexes have been proposed for expressing the distribution of aggregate sizes. A widely used index is the mean weight diameter, MWD based on weighing the masses of aggregates of the various size classes according to the respective sizes. The mean weight diameter X is thus defined by the following equation.

$$X = \sum_{i=1}^{n} Xi\,Wi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 10$$

Where

Xi is the mean diameter of any particular size range of aggregates separated by seizing and Wi is the weight of the aggregates in that size range as a fraction of the total dry weight of the sample analysed. The summation account for all size ranges including the group of aggregates smaller than the openings of the finest seize. MWD is also defined by the following equation according to Singh and Panesar, 1991.

$$MWD = \frac{\sum_{i=1}^{n}\left[Mi \; X \; \frac{(Di\text{-}1 + Di)}{2}\right]}{\sum_{i=1}^{n} Mi} \quad \ldots\ldots\ldots\ldots\ldots\ldots 11$$

Where ,

Mi = Mass of the soil retained in the i th sieve from top (kg)

Di = size of the i th sieve, mm

Do = Sizes (second major dimension) of the largest clod on top sieve, (mm).

The size range of the nest of sieves to be used for analysis depends on the purpose of the analysis. Singh and Panesar (1991) used a set of sieve consisting of sieves with square openings of 38.1, 25.4, 19.0, 12.7, 9.5 and 4.8mm and Pan for clod size distribution of tilled soil. Yadav and Pandey (1984) used a set of sieves consisting of 3.87, 3.81, 1.67, 0.81, 0.043mm agitated for 10mins for each sample while Thakur et al, (1988) used a set of sieves consisting of 40, 20, 10, 5.6, 2.4 and 1mm. Agitation was for 5 mins for each sample. An alternative index of aggregates size distribution is the geometric mean diameter Y calculated according the equation by (Mazurak, 1980 in Singh 1989)

$$Y = \exp [(\sum_{i=1}^{n} W_i \log X_i / (\sum_{i=1}^{n} W_i)] \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 12$$

where Wi is the weight of aggregates in a size class of average diameter Xi and $\sum_{i=1}^{n}$ Wi is the total weight of the sample.

Biswas and Mukherjee, (1987) defined aggregate stability is a measure of the degree of vulnerability of soil to externally imposed the destructive forces. For instance, a newly cultivated field may for a time exhibit a nearly optimal array of aggregate sizes with large interaggregate pores favoring high infiltration rates and unrestricted aeration. This blissful state often proves to be ephemeral as soil structure may change as the soil is subjected to destructive forces resulting from rainfall etc. An aggregate that is too stable and unable to breakdown in order to produce a good tilth is not good for agriculture. Most frequently, the concept of aggregate stability is applied in relation to the destructure action of water and the it varies from one soil to another. The relevance of the water stable aggregate is to be able to determine or predict the tilth that would result if a field is disrupted by the action of rain. If the percentage of water stable aggregate is high, then the tilth will remain stable. If it is low, then the tilth will eventually change. The wetting process also causes considerable distruption of previously dry aggregates.

According to Singh, (1989), the classical procedure for testing the water stability of soil aggregates is the wet seizing method. A representative sample of air dry aggregates is placed on the uppermost of a set of graduated sieves and immersed in water to simulate flooding. The sieves are then oscillated vertically and rhythmically, so that water is made to flow up and down through the screens and the assemblage of aggregates. In this manner, the action of flowing water is simulated. At the end of a specific period of sieving, the nest of sieves is removed from the water and the over-dry weight of material left on each sieve is determined. These are percentage aggregates of various sizes. All combined together will be percent aggregation or percentage of total aggregates. As pointed out by Kemper (1965) and presently adopted for use at Silsoe National College of Engineering, the results should be corrected for the coarse primary particles retained on each sieve to avoid designating them falsely as aggregates. This is done by dispersing the previously oven dried and weighed material by puddling in a beaker. After puddling the soil is washed through the same seize, oven dried and weighed. This new weight is then subtracted from the first weight to get the corrected weight. this corrected weight is then expressed as a % of the total weight of soil used. A range of seize set suggested by Spoor (1967) are of 2mm, 1mm, 0.5mm.

A number of measurements of soil properties which are a function of soil pores and thus soil structure have been used to evaluate soil structure. Such properties are bulk density, rate of water infiltration into soil hydraulic conductivity, rate of aeration, aeration pore space, available soil water degree of compaction, and capillary intake of water (Biswas and Mukherjee, 1987) Bulk density is a measure of the packing or compression of the three constituents of soil. It is defined as the mass per unit volume of soil consisting of solid and gas phases. Bulk density is generally measured by means of a core sampler designed to extract undisturbed sample of known volume from various depth in the profile, from the know volume of the core and weight of over-dry soil, bulk density is calculated. The lower the bulk density, the better is the structure. Water infiltration is the process of water entry with into soil through the surface and the direction of entering may be either downward or lateral or both. A major determining factor of water infiltration into soil is the porosity of the soil. Texture, structure and initial moisture content of soil control infiltration rate. Water infiltration rate of pounded water is measured in the field with the help of ring until meter or from the surface run off water applied artificially or from rainwater. Interlisation rate is the distance traveled by water through a soil column and is usually expressed as cm hr^{-1}

Hydraulic conductivity is the rate of flow of liquid through a porous medium under unit hydraulic gradient. Its measured in the laboratory using a constant head per ammeter with a packed column prepared soil sample or undisturbed soil care. Field measurements utilize a piezometer or auger hole method. The soil property directly influencing hydraulic conductivity is pore size and pore space .Hydraulic conductivity can be increased by improving the structure of a soil. In any process that bring about compaction of soil i.e increase in bulk density the hydraulic conductivity is reduced very significantly. Soil air is closely related to water contacts of soil Increase in water constant is followed by decreased in air filled pores.

Low porosity and hydraulic conductivity of soil cause inadequate aeration. Proper drainage lower ensures adequate aeration.

These structural indices are relative values. There is no absolute value to categorise a good structure and it is often useful to determine the structural index by more than one method.

2.5.3 The Effects of Soil Strength on Tillage

Soil is extremely weak in tension, very strong in compression and in practice, fails mainly in shear (Spoor, 1969). Soil strength is the ability or capacity of a soil in a particular condition to resist or endure an applied force (Gill and Vander Berg, 1967) Soil strength reflects the friction which is built up between the soil and an implement and depends on the density, roughness and shape of the soil particles. (Spoor 1969) reported two types of soil movement when forces are applied. These are:

(i) Soil-Soil shearing resistance

(ii) Soil-interface sliding resistance

Soil strength is measured by these two types of reactions

2.5.3.1 Soil -Soil Shearing Resistance

Crossley and Kilgour (1983) reported that the shearing of soils is considerably different from the shearing of most solids, in that the reaction may extend to a considerable distance on either side of the shear plane because of internal friction and the cohesive action of moisture films. The maximum shearing strength of the soil usually varies depending on the normal stress which is applied across the shearing area. The manner of this variation may be represented by the equation derived by Coulomb in 1773.

$$\tau_{\max} = c + \sigma \tan \phi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13$$

Where,

τ_{max} = shearing stress at soil failure

c = cohesion

σ = stress normal to plane of shear

ϕ = angle of internal friction

This equation shows that there are two components making up the soil shearing strength.

Cohesion and σ tan ϕ which depends on the angle of shearing resistance " ϕ. Cohesion is defined as the force that holds two particles of the same kind together. It is dependent upon soil moisture suction and hence moisture content and also on organic bonds. Internal friction results from interlocking of particles with in the soil mass. It is function of the soil unit weight the roughness and degree of interlocking of the particles and aggregate. The values of cohesion (c) and angle of internal friction (ϕ) vary with the type of soil and it's condition. Typical physical strength of some soil types at different conditions are shown in Table 1

Table 1 Soil types and physical strength

Soil Type	Typical particle (size mm)	State	O	CKN/m^2
Medium grained sand	1.1	Compacted	38 – 40	-
		Loose	32 – 35	-
Humus sands	0.5 – 08	Compacted	25 – 30	-
		Loose	18 –22	-
Loam sands	0.02 - 0.2	Friable	24 –28	20 –25
		Plastic	24 –28	10 –15
Loams	0.011	Friable	22 –26	25 – 30
		Plastic	15 – 19	15 –70
Clay	0.002	Friable	17 – 19	40 –60
		Plastic	10 -14	25 -30

Source: Crossley and Kilgour, (1983)

There is variation in shear strength with moisture content. A stress/strain and stress/ stress relationship exist for a soil sheared in bulk, the strength being termed the bulk shear strength. They also exist for the shear of individual clods or aggregates, clod shear strength.

For the disintegration of clods in the soil mass by shear the bulk shear strength must exceed the clod shear strength. Common values for the cohesion and angle of shearing resistance of many loam soils, when being cultivated on the friable state, are cohesion 1.0 -1.4 KN/m² and angle of shearing resistance of 30° (Spoor, 1969) The value of cohesion and angle of shearing resistance as determined by Osman (1964) are 0.1 Ib/in² and 31°, 0.Ib/in² and 32° and 1.5Ib/in² and 8° for wet sand, dry sand and clay respectively. Felke (1996) determined the angle of internal friction and cohesion of four experimental sites. The result is as shown in Table 2

Table 2: Soil properties at four Experimental sites

Soil Textural Class	Tillage Test Track Sandy Loam	Tillage Test Track Sandy Loam	Avon Sandy Loam	Hoyleton Clay Loam
Moisture Contennt d.b%	5	10	8	28
Cohesion, kPa	6	6	9	23
Friction angle Degrees (soil / soil)	35	32	35	22

Source: (Fielke 1996)

The angle of internal friction is a times referred to as the angle of repose but, there exist a difference between the two parameters. The angle of repose is the maximum slope at which a heap of any loose fragmented bulk material will stand without sliding (Sybil, 1979) It is a frictional property. Harvey (1988) reported that the angle of internal frictional is equal to the static angle of repose in granular non cohesive materials. This gives the relationship between the angle of internal friction and the angle of repose. Result have proved that the angle of repose of agricultural materials increase with increase in moisture content. (Adewumi, 1997)

2.5.3.2 Soil Interface Sliding Resistance:

This property of the soil is described by the adhesion (ca) and angle of soil metal friction 0. Adhesion refers to the sticking of soil to foreign materials such as tillage tools or wheels. (Kepner et al,,1987) All tillage operation involves a sliding action of soil over some surface of tool. Spoor, (1969) reported that friction of soil against a tool having large contact areas represents a significant component of the draught requirement. The resistance to sliding at a soil metal interface (Tangential Resistance) is frequently a function of the normal stress between the surface as shown in Figure 6.

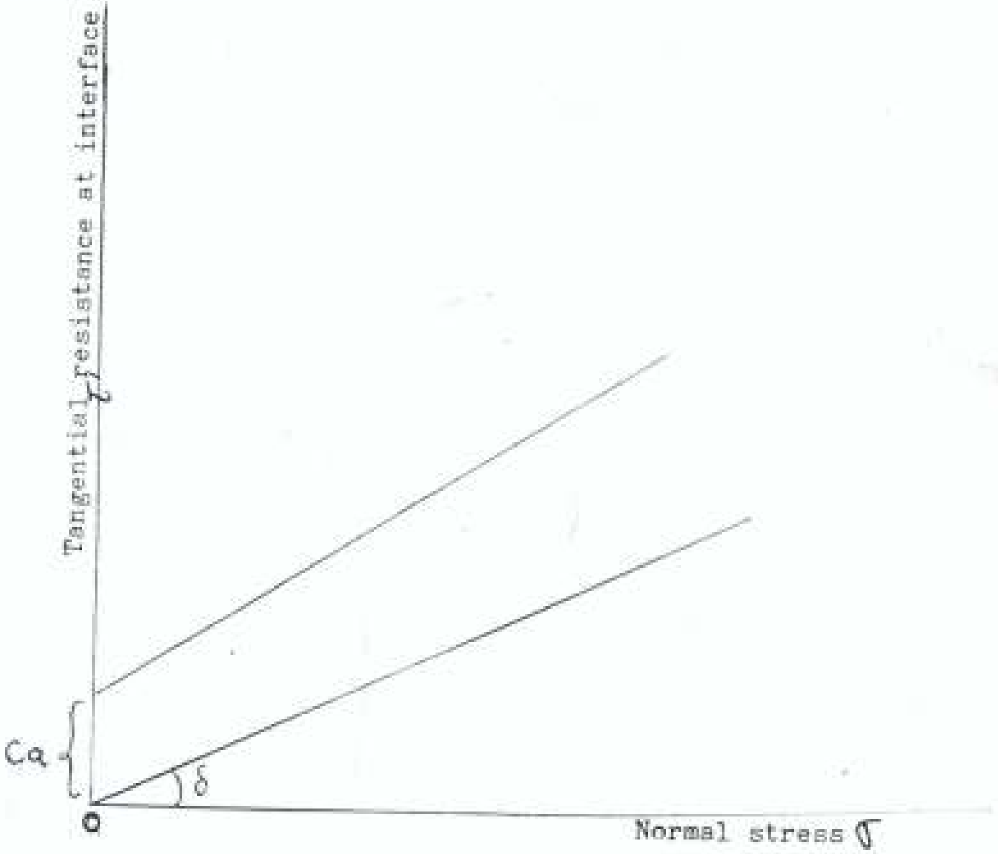


Figure. 6 Relationship between Tangential resistance and normal stress (source: Spoor, 1969)

Where, $\tau' = C_a + \sigma \tan\delta$ ------------ (15)

τ'	is the tangential resistance at interface
ca	is the adhesion
σ	is the normal stress
δ	is the angle of soil metal friction

The adhesion component is usually very small except under certain plastic soil condition when a non-scouring condition frequently develops. (Gill and Vander berg 1967) Soil metal friction has an important effect on draught particularly at low rake angles in frictional soils (Osman, 1964). In the experiment described by Osman (1964), he discovered that reducing δ from ϕ (as in a really rough blade) to 10^0 (the practicable minimum) reduces the draught of a 4in deep blade at $\alpha = 30^o$ by about 40%.

The polish on an implement surface is usually more important in influencing the value of the angle of soil metal friction. (Kepner et al; 1987) . A large reduction in δ can be achieved by removing the rust from a tool. Minimizing the normal loads on the interface and the interface area will minimize the frictional and adhesive components respectively when they are present. The normal load can be reduced by eliminating all unnecessary surcharge and attempting to lift the soil away from the interface, for example, by providing an air cushion using compressed air or by vibrating. Under friable soil conditions (or friction phase), adhesion is normally zero or very small (spoor, 1969) and coefficient of friction is independent of moisture content . Adhesion is a function of the wet ability of the implement surface and is related to the soil moisture suction. The angle of soil metal friction is a function of the roughness of the surfaces and any lubrication (e.g. moisture) between them.

One of the most important aspects of the sliding action of soil is scouring of a tool. Scouring or shedding is a soil - tool reaction in which soil slides over the surface of the tillage tool without significant adhesion (ASAE, 1989). The ability to scour is affected by the coefficient of soil metal friction and soil adhesion among other things (Kepner et al, 1987). In practice, the angle of soil metal friction is usually less than the angle of shearing resistance. An increase in the normal load will increase the soil shearing resistance more than the interface resistance, so improving scouring. When scouring is adequate soil flows over the tool along a path that is determined by the shape of the tool. In non-scouring situation, soil flows over a layer of soil attached to the tool surface, usually resulting in increased draught and poor soil inversion (Kepner et al, 1987). Non scouring is likely to occur in areas of low spots or other surface irregularities in areas of abrupt change in surface direction and in other low-pressure areas. Adhesion may be reduced by employing a materials that resists wetting. Bacon,(1918) as reported in Kepner et al,(1987)explained that mould boards coated with plaster of paris or covered with hoghides scoured better in sticky texas soils than did steel, iron, glass, brass or aluminum. He also cited instances in which heat apparently improved scouring by reducing adhesion, Adhesion can be reduced by using non wettable materials such as (phlytetra fluroethyleme) (PTFE) but due to the susceptibility of these materials to abrasion their useful life on most agricultural soils is extremely short. A slatted implement (mold board) reduces the interface area without reducing the soil - soil shear interface and it also increased the normal load.

2.5.4 **Determination of Soil Strength Parameter**

An important proportion of the total force required to power implements through soil is effected by the magnitude of soil metal function, adhesion, cohesion and angle of shearing resistance hence the need for their measurement. Bowles, (1984) reported that the measurement of soil strength is based on some procedure for determining the stresses acting at incipient failure. Two principal methods are being used to measure failure in soils These are the direct tests and the triaxial test.

The direct test involves the failure surface being controlled over a small area of soil and the shearing stress samples with differently applied values of normal stress. Normal stress is applied to the shear plane by loading the surface of the soil. Shearing is induced by gradually increasing the lateral, or tangential stress until failure. These values are plotted directly on a shear stress. Normal stress coordinate system. The line connecting the points is an envelope from which cohesion C and angle of shearing resistance ϕ can be read directly. The test can be carried out either at a constant rate of stress increase, or at a constant rate of deformation.

The direct shear test has several draw backs. The shearing plane does not remain constant during the test, so the stresses can vary even if the normal and tangential forces remain constant. Moreover, the size and shape of the container influence the test results. The torsional shear box is exceptionally good in that it is possible to have an "in situ" test which will give accurate results. Godwin 1977 however reported that the torsional direct shear apparatus consists of a cylindrical box fitted with a removal lid. On the inside walls of the box there are equally spaced small fins which prevent the soil from slipping relative to the box. The box is turned using a torque meter and weights can be loaded on the top of the box. The test is repeated at different normal loads. A normal stress range of 0-62 KN/m² is suggested (Godwin , 1977). The torque reading is then converted into shear stress using the following equation.

$$T = \frac{3m}{2\pi r^3} \qquad \text{...(16)}$$

Where T = shear strength

m = applied twisting moment

r = radius of shear box.

Thereafter a graph of shear stress is plotted against normal stress, to determine apparent cohesion and angle of shearing resistance. Other direct methods of shear stress measurement as reported by Osman (1964) include the use of an annulus, Bevameter, e.t.c. These two methods help in overcoming the error due to the use of shear box in soil strength determination.

Godwin (1980), reported the alternative and more fundamental based method for determination of shear strength known as the triaxial shearing test. In this test, the failure surface is not predetermined but allowed to form within a specimen as successive combinations of lateral and axial stresses are applied to a series of samples of the same soil. The lateral pressure is applied by means of pressurised water and the axial pressure by a loading ram which applies the load by moving the sample upward at a constant rate at the point of soil failure, the lateral stress denoted by σ_3 and axial stress is noted The axial load is measured by a proving ring. The axial stress,

$$\sigma_1 = \sigma_3 + \Delta\delta \quad \text{................(17)}$$

Where,

$\Delta\delta$ is the deviator stress (proving ring reading $\Delta\delta = \sigma_1 - \sigma_3$).

A series of Mohr circles representing shear failure states are determined and the envelop of these circles yields the deserved soil strength parameters values (Hillel, 1980).

Another common method of measuring soil cohesiveness, suitable for undisturbed in situ determination is the vane shear test. It is used for mean shear strength particularly for clay . To use this equipment for soil strength determination, the vane is driven into the soil to the desired depth, and then rotated. The shear stress required to shear the soil along the surface, a cylinder generated by the blade edges, is read directly from a gauge provided. The advantage of this method is that measurement can be made at successive depths without extracting the apparatus to obtain a complete strength profile of the natural soil (Hillel,1980). However, this method cannot measure the two components of soil shearing strength C and ϕ separately.

A different techniques for characterizing soil strength in the field is the use of a Penetrometer. This instrument is designed to evaluate soil resistance to the penetration of a narrow probe. What is measured is not soil strength per-se, but a composite parameter considered to be related to soil strength, though the quantitative nature of its relation to soil strength is not generally known in any exact sense. Nevertheless, the technique is particularly advantageous in the ease and simplicity of in situ measurement. Penetrometer tips most often used are conical but tips of other shapes e.g disks have also been used (Hillel, 1980). Penetrometers have been used very extensively to estimate the draught required to plough soils under various conditions as well as to indicate soil trafficability.

The methods for measuring soil shearing failure are also used for soil interface friction measurement. Both torsional apparatus and sliding friction apparatus as described by Godwin (1992) are used and generally the tangential stress is measured at various loads. The diagram of sliding shear apparatus as described by Godwin (1992) is shown below in Figure 7. The measurement of soil shear strength is independent of the method used as long as drainage conditions are comparable (Osman 1964). Table 3 shows good agreement between ten different methods of strength measurement as described by Osman 1964.

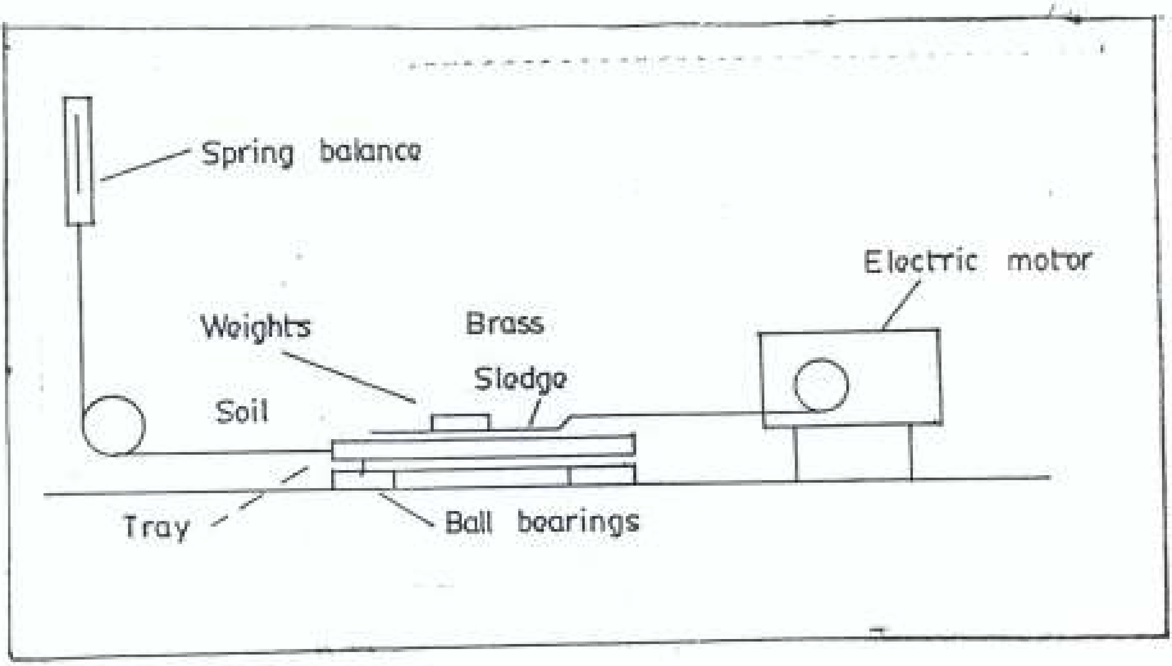


Figure 7 : Sliding shear apparatus (Source: Godwin 1992).

Table 3 Results of soil shearing resistance by different methods.

	WET SAND		DRY SAND		CLAY	
	C	0	C	0		
Translational Shear Box	0.1	33	0	35-42	1.5	7
Triaxial Test	0.1	32.5	0	33	1.5	7
NIAE shear bos	0.1	31.5	-	0	1.5	8
Bevameter test	0.1	29	0	-	1.49	7
Shear annuls and hand torquemeter	0.11	32	-	-	1.47	8
Vane test	-	-	-	-	1.5	-
Angle of repose	-	-	0	32	-	-
Clayed – annulus	-	-	-	-	1.5	8.5
Sand - coated annulus	-	-	0	32	-	-
Sand Coated slider	-	-	0	31	-	-
Average value used for theoretical Computation	0.1	31	0	32	1.5	8

(*Source : Osman 1964*)

2.4.5. Soil Failure Analysis

According to Stafford, (1984). Soil failure may be defined as the alteration of a soil structural condition by mechanical forces such as shearing, compression or tearing. As a tine moves, it causes permanent deformation of the soil which is referred to as soil failure. The amount of deformation resulting from a given applied force depends upon the soil type and its condition. The concept of soil failure under stress underlies the very important concept of soil strength which has to be overcome when a tillage tool is applied to break the soil.

A lot of effort has been expended in developing theories of soil failure with tillage tools in develop countries of the world. The following types of soil failure have been identified namely: Shear, Plane, Flow, Bending. Tensile (Elijah and Webber, 1971). Compression

(Payne, 1956) and Brittle failure (Stafford, 1984). Each type of failure would depend on tillage parameters that are called into play. According to Spoor, (1969), most soil failure patterns in practice are extremely complex, but for simplicity, it is possible to consider them as being built up of two basic types:

Wide tine or blade failure and

Narrow tine failure.

The wide tine failure is common in situations where the width out is very large compared with the working depth. With background raked blades (large rake angles) the failure pattern is a little more complex but the general analysis is the same. With curved blades, the failure pattern is similar, but the surcharging pattern can vary depending upon whether soil moves along the blade or not i.e. whether scouring occurs. With scouring, a triangular shaped surcharging wedge is formed (Spoor, 1969). When the blade does not scour, the curved portion of the blade fills with soil and a more rectangular surcharging pattern is produced; here implement behaves like a straight blade. The mode of soil failure at the surface depends on the blade curvature at a given rake angle. With slightly curved blades (large radius of curvature) the soil rises up the blade and emerge straight upward front. As the blade curvature increases, the soil tends to roll until it almost roll over completely with forward curvature, the curved blade behaves exactly like a straight blade (Spoor, 1969). The narrow tine failure is common in situations where depth of working is large compared with the width and where the end effects cannot be neglected. The pattern of soil failure with narrow tines is such that a soil wedge is formed immediately in front of the tine and behaves as though it were part of it. As the tine/wedge combination moves forward, a crescent shaped prism of soil is formed sliding forwards and upwards and it eventually split in half by the leading edge of the wedge. The lower failure surface of the prism is similar to that formed in wide tine failure and the rupture distance can be predicted in the same way.

2.5 Review of Instrumentation for Soil Tillage Studies

Instrumentation involves designing, manufacturing, utilising physical instrument or instrument systems for detecting, observation, measurement, automatic control, computation ,communication or data processing (Wildhack, 1987).

The term instrumentation is also used for the ensemble of instruments and auxiliary equipment used for an experiment or test. This use of instruments in outdoor, indoor soil bin and field experiments have been in existence for quite a long time. The equipment and instrumentation by different researchers are reviewed as follows:

2.5.1 Instrumentation by Osman (1964)

Osman (1964) carried out experiment to study the mechanics of symmetrical soil cutting blades of various rake angles and surface finishes on dry sand, wet sand, and clay. This work was as initial investigation into the mechanical properties of soil and the performance of implements. The ultimate aim of the studies was to enable the performance of any implement to be predicted by evaluating the parameters that describe it and the soil. A simple hypothesis was developed concerning the effect of curvature of the cutting blades on the draught forces.

The results obtained can be used to developed practical conclusions concerning the design of cutting blades. The instrument system used for the experiments includes one vertical and two horizontal strain gauge ring dynamometers to measure the force system , a winch driven by a variable speed D.C. motor was provided on the soil tank carriage system to drive the blades through the soil at constant controlled velocity. A suspension capable for supporting the cutting blades in a fixed position while allowing them to move parallel with the soil surface was also provided. The blades were suspended from a rigid framework by the vertical and two horizontal strain gauge ring dynamometers. The tine was restrained against movement in its own plane by the three dynamometers and against movement in other directions by a system of ball bearings supported in suspended strip cages between parallel flat plates fixed to the time holder and main frame. This arrangement allowed random unsymmetrical forces to be supported with very little friction and ensured that the dynamometers were only loaded axially. The signals from the three dynamometers were recorded by a six channel N.E.P. mirror galvanometer recorder. To photograph soil rupture a camera was clamped on a frame fixed over the soil tank. Each dynamometer was calibrated individually by applying dead weights. The accuracy of the apparatus in measuring the magnitude direction and the point of application of the soil forces for varying magnitudes of the forces was tested by applying known loads with the apparatus at different angles and then measuring the forces. The angles were measured accurately by a clinometer.

2.5.2 Instrumentation by Gill et al. (1980)

Gill et al , (1980) studied the effect of geometric parameters on disk forces at the soil bin of the National Tillage Machinery Laboratory Auburn, America (NTML). These and other soil bins have been developed which permit conducting tests under carefully controlled uniform soil and operating conditions. Although the final proof of a design must come from field tests and field experience, a great deal of time can be saved and costs reduced when tests are conducted in soil bins to duplicate field loading and environmental conditions. The dimension of the soil bin must be such that allow easy interactions between the parameters on which studies are to be conducted.

The soil bins of the NTML as described by Gill et al, (1980) in their experiment has dynamometer car for controlling the position of disks while continuously changing one variables and holding other parameters constant Data acquisition system was used to continuously measure and record the disk angle, depth of cut, width of cut, the forward and rotational velocities on the disks, and the draught, side and vertical forces. This data acquisition system employ strain gauge force transducers for measuring the force system. Forward speed was measured with a tachometer generator which gives an electric signal that can be put into one channel of the same instrument used for the force transducers. Soil force direction were determined using the conventional right hand rule draught is positive in direction opposite direction of travel, side force is positive toward the face of the disk vertical force is positive in the downward direction . After a soil condition was prepared for a test, soil moisture, bulk density and cone penetrometer resistance (cone index) were measured. Results from this study showed that disk harrow design conditions are influenced by disk blade geometry. Increase in draught caused by increase in velocity were essentially linear and because of pressure in the blades of disk an optimum angle in terms of draught occurs for operation of disks.

2.5.3 Instrumentation by Ademosun (1995)

Ademosun 1990 developed a small scale soil tillage dynamic equipment with a spring balance installed vertically to indicate the values of draught. The equipment was used to determine the effect of soil and operational parameters on specific draught of tillage tools. The equipment consisted of three major components. These were a power transmission system for determining the speed of operation, a mini-track laying tractor with the spring balance installed vertically in it so that the values of draught can be read as the tractor moves and a soil bin inside which the tractor operates. The track laying tractor was designed for stability and good traction. A spring loaded attachment link designed with curved upper and lower links allowed the rake angle and depth of operation of tools to be easily varied. However, it required great effort and good human judgment to observe the reading on the spring balance dial as the tractor moves from on end to the other inside the soil bin. Nevertheless, results obtained with the use of the equipment to determine the effect of some soil and operational parameters on the draught requirement of a tine implement in an agricultural soil of Nigeria was us good agreement with past research finding. It was found that draught increase with increasing depth and speed of work but decreases linearly with increasing soil moisture content. Soil moisture was determined during the experiment with a speed moisture meter.

2.5.4 Instrumentation by Ademosun and Agbetoye (1995)

Ademosun and Agbetoye (1995) incorporated a hydraulic dynamometer on an equipment developed for studying root crop harvesting parameters in a soil bin. The equipment was designed to be hitched to a mini track laying tractor drawn by a 1.5kW electric motor. It consisted of a blade whose digging and lifting unit operations are controlled by landwheels driven can and two extension springs.. The results showed that, for harvesting of cocoyam at depths of 50 N to 200 N and at speeds of 0.87 to 1.10m/s the draught requirement ranges from 50 N to 480 N 20 N to 425 N and 190 N to 500 N for blades with straight convex and concave surface respectively. During the experiment, the speed of operation was varied by changing the forward speed of the mini track laying tractor. The depth of operation was varied by changing the position of attachment of the blade support an the top frame of the tractor used. The depth of operation was measured with a steel rule soil moisture content was determined by use of a speedy moisture meter A wooden plank was used to compact the soil gently and uniformly. A hand held soil penetrometer was used to determine the degree of soil compaction at five different points and the mean value calculated. The draught requirement of the harvesting operation was determined from the difference between the readings on the pressure gauge of the hydraulic dynamometer during the harvesting operation and when the blade was removed and at the lifting position of the implement.

2.5.5 Instrumentation by Bukhari et al. (1988)

The objective of this present study was to evaluate the performance of selected tillage implements. The performance parameters were draught requirement, travel reduction, speed of operations, depth of cut, width of cut field capacity, soil disturbance and soil inversion.

To measure the draught requirement of the implements, a hydraulic dynamometer (pull type) was attached to the front of the tractor on which the implement was mounted. Another auxiliary tractor was used to pull the implement mounted tractor through the dynamometer. The auxiliary tractor pulled the implement mounted tractor being in neutral gear but the implement in the operating position. This is illustrated in figure. 8 The soil type on the experimental site was determined mechanical analysis. Soil moisture content was determined by the gravimetric method. Bulk density was measured by taking cylindrical core of soil at specified depths. The diameter and length of the cylindrical soil sample were measured with vernier callipers. The working width of the implement was measured using a steel tape determined by making a mark with chalk on the drive wheel of the tractor and the distance the tractor traveled in 10 revolution with no load and with load was measured. The travel reduction was calculated using the formula

$$TR\% = \frac{A - B}{A} \times 100 \qquad \text{.......................................} (18)$$

Where TR = travel reduction

A = distance travel with no load

B = distance travel with load

The draught was recorded in a measured distance of 50m as well as the time taken to transverse it. On the same field the implement was lifted out of the ground and the rear tractor was pulled to record the idle draught force. The difference gave the draught of the implement. The speed of operations was determined from the time required for the tractor to cover 50m distance. A stop watch was used to record the time of travel. The findings of the study showed that the cultivator requires the lowest draught/meter of width whereas the highest draught/meter of width was recorded for disc plough at all levels of operation.

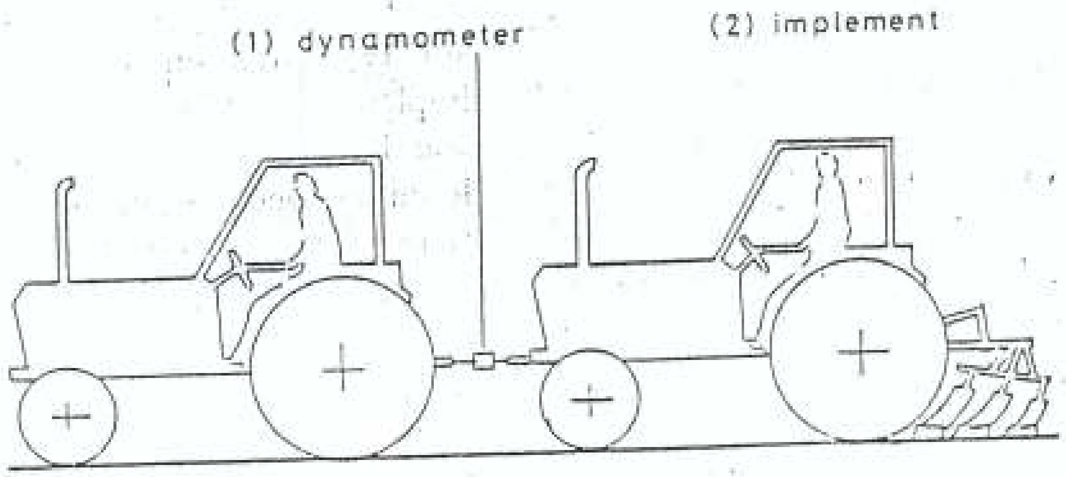


Figure 8 : Measuring Draught For a Tractor Mounted Implement
(Source : Bukhari et al, 1988)

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The Experimental Design and Study area

3.1.1 Description of Study Site

The field experiment was conducted at the Edu field rotational farm of the Federal College of Agriculture Akure which lies on 7° 5'N latitude and 5°10'E longitude in the rain forest zone of Nigerian. The soil is classified as Alfisol (Ojeniyi, 1989). Edu field rotational farm is normally planted to arable crop for teaching purposes. The site used for this study has been under fallow since 1994. The site was last planted to maize, however in 1994, it was prepared by ploughing, harrowing and ridging using disc plough, harrow and disc ridgers, but, it was not cropped. This farm was selected based on its proximity and availability of necessary facilities for the research work. Edu field rotational farm Experiences two rainy seasons per annum. Generally, rainfall ranges from 1250mm to 2000mm starting in April, and continues until July. Usually, there is a break observed in August after which rain continues until November. There use to be some variations in the rainfall pattern from year to year. The present study was conducted in August 1997 when there were scanty rainfall. However, there was a heavy downpour on the previous day to the time when the experiment was performed.

The site of the experiment as shown in Appendix I - was selected because of its relative level gradient compared to its surroundings. The vegetation on the test plots is made up of few shrubs and grasses of about 2 - 25 meters high .The test plot was cleared of all vegetation before the commencement of the experiment so that there could be free access to take all necessary measurements during tillage operation and also to give room for uniform distribution of stubble on the test plot. The experimental plot was marked and planned as described in Figure 9 before the start of the experiment.

3.1.2. **Experimental plan:-** The experiment was conducted using a Factorial design comprising of three levels of tool surface roughness, four levels of speed in km/hr (3.2; 40, 4.8 and 5.4) and two levels of tilt angle (18°: 22°). These levels of speed and tilt angle setting were used so as to have a relatively wide range of experimental conditions. The field layout of the experimental site is as shown in Figure 9.

A Factorial design was used because it was easier to completely randomise the order of the runs within the blocks. That is, it is easier to choose to change from one speed to another with the same tool surface treatment and cutting angle setting before changing the entire setting of treatment combination. This therefore controls experimental error to a great extent since it was easier to select a treatment combination that is most convenient in a randomise order. All experiments were replicated three times.

	T_1			T_2			T_3			
θ_1										
θ_2										S_1
θ_1										
θ_2										S_2
θ_1										
θ_2										S_3
θ_1										
θ_2										S_4
	R_1	R_2	R_3	R_1	R_2	R_3	R_1	R_2	R_3	

Figure 9 - Layout of the Experimental Plot

3.2 Experimental tillage tools and Procedures

3.2.1. The Experimental Tillage Tools

A two - bottom disc plough of 8.5cm with for this experiment 3 sets of disk blade of uniform size (58cm diameter, 7.6cm concavity 56.9cm radius of curvature and edge thickness of 2.80mm (sharpness) were carefully selected and by inspection. The surface roughness of the blades was however varied. One set of blade was left with the normal smooth surface. Another set was painted with Aluminium gloss paint to make a slippery surface. While the third set of blades have a 1mm deep corroded surface to make a rough surface. The photographs of the three sets of blades are as shown in figure 10, 11 and 12 respectively.

Figure 10 - The normal (smooth) surfaced blade.

Figure 11- The painted slippery blade surface.

Figure 12 - The deeply corroded, (rough) blade surface.

The soil - metal friction properties of the 3 blades surface (namely the angle of soil - metal friction and adhesion) were determined to further define the surfaces. The values are given in Table 7 in Appendix 2.

3.2.2. Experimental Procedures

The implements were mounted :- on a steyr 768 tractor with 75kw. The machines were serviced to ensure high efficiency during operation. All the bolts and nuts of the disc plough were run prior to the start of the operation so as to enhance quick and easy changing of the blade during operation and was ensured that only one operator operated the tractor during the experimental so as to minimize variations. The cutting angle of the disk was adjusted in both the vertical and horizontal planes during the experiment.

According to the design of the disk plough used, there are two grooves on the disk bearing bracket as shown in Figure 13. The setting in the first groove gives a tilt angle of 18^0 while that in the second groove gives 22^0 . The disk angle was kept at an angle of 46^0

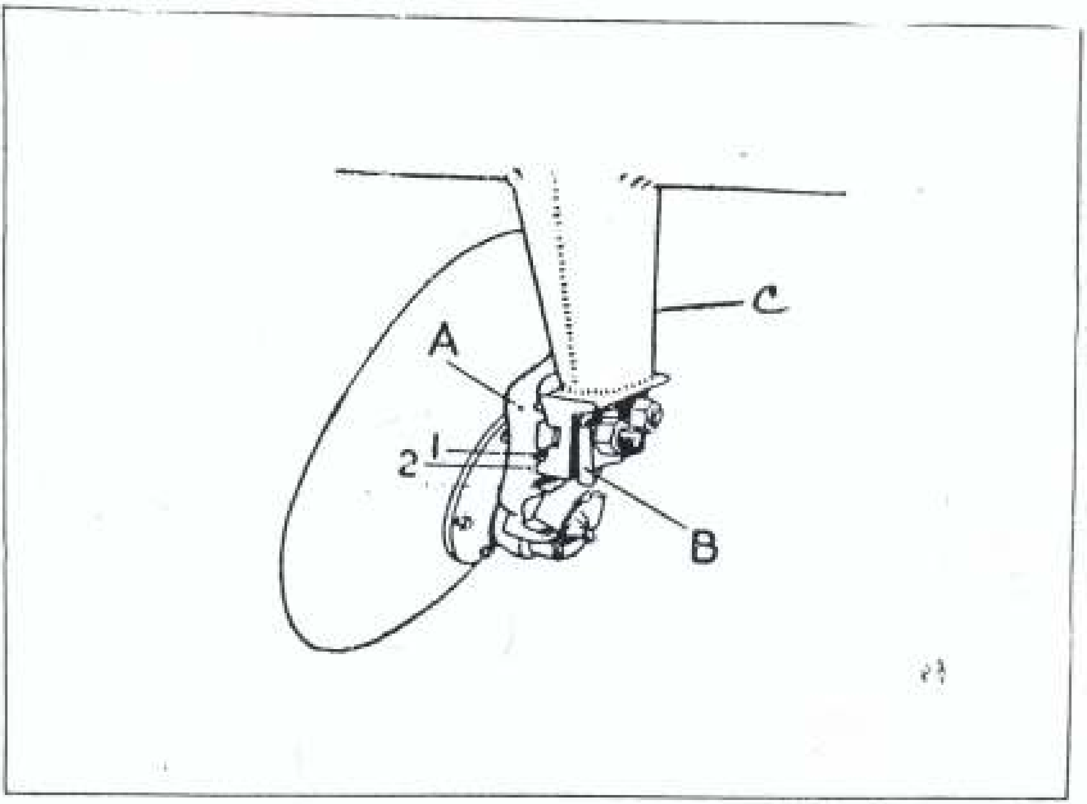


Figure 13 - Changing the tilt angle of the disk plough under study.

Prior to tillage, soil sample were taken to determine the initial soil condition of the experimental site. The soil properties determined include the soil - strength, bulk density, and moisture content. After the layout of the field, a set of dics with a specific surface treatment were fixed to the plough assembly and coupled to the tractor. Whenever one parameter was varied, all other parameters were kept constant. Those parameters that were varied one at a time include, the tool surface roughness and the tilt angle. The tractor was operated at the different speed levels on the corresponding plots in the layout. All necessary data are then taken on the field. Photographs of the differences in soil disturbance at different stages were taken to compare the effects of the three surface of disk blades on soil pulverization. Also soil samples were collected in polythene bags from the tilled plots and taken to the laboratory for further analysis. Each ploughing operation on any particular treatment combination was replicated three times.

3.3 Data Collection and Analysis

To evaluate the performance of the implement under study, data were collected on the following parameters. These are the draught requirement, initial soil conditions, final soil condition attained, forward speed, Implement shape, tilt angle: Efforts were made to conduct each test carefully and measurements made accurately. The data collected were analysed by use of charts, graphs and by computer statistical tools. The computer package used for the statistical analysis was the Shazam econometric package, Version 7.0 (1993). Multiple regression analysis was used to establish an equation relating the final soil condition obtained with other determining features under study. Also, analysis of variance was computed. One way analysis of variance and Least significance Difference follow up tests were performed on (Special package for social science, (SPSS) computer programmes.

One particular limitation this study is the lack of readily available data on soil, implements and other facilities used of the experiments. Appropriate methods were therefore developed to estimate the required data.

3.3.1 Determination of Soil Properties from the Experimental Site.

3.3.1.1. Soil Texture:-

The soil textural class was determined by the hydrometer method. This method was measured as a function of time. A 50 gms of 2mm of sieved air - dried soil sample was weighed into a 250ml beaker. 100ml of 5% calgon was added and allowed to soak for 15 minutes. The suspension was stirred for 3 mins, then transferred to a sedimentation cylinder and filled to the required mark with distilled water with the hydrometer placed in the suspension. After another 2 hours all the silt would have settled, remaining clay in suspension. The hydrometer reading was noted after 40 seconds and 2 hours and recorded. The stem of the hydrometer reads directly in grams or soil/litre of solution. To correct the hydrometer reading for temperature, 0.36g/litre was added for every 1°c temperature above 20°c. the percentage of sand silt and clay were then calculated by the following formulae

$$\%\ \text{silt and clay} = \frac{\text{corrected 40 secs. Hyrometers reading} \times 100}{\text{Dry weight of soil.}}$$

$$\%\ \text{clay} = \frac{\text{Corrected 2 hrs. Hydrometer reading} \times 100}{\text{Dry weight of soil}}$$

% silt = % silt + day - % clay

% sand 100 - % silt + % clay

Each hydrometer reading was replicated three times to reduce experimental errors. The result for four soil samples are shown in table 4. These percentages were need to determine the textural class on the textural triangle.

3.3.1.2 Soil Moisture Content and Bulk Density:-

The gravimetry method of measuring soil moisture content was used for determining the soil moisture content of the test plot during the experiment. This method is the classical procedure used as the check for all other methods of soil moisture content estimation and it is possible to use the method since soil samples were collected in polythene bag and taken immediately to the laboratory for analysis. For measurement of soil moisture content percent, the core samples of soil taken from depth of 5, 10, 15, 20 and 25cm at 4 different locations of test plots were used. The soil moisture contact was calculated by using formula.

$$\text{Moisture } \% \text{ (Wet basis)} = \frac{(W - D) \times 100}{(W)}$$

Where

W = weight of wet soil sample

D = weight of oven dry sample.

Measurement of bulk density (g/cm³) of the soil.

The diameter and length of the cylindrical soil samples were measured with vernier callipers. Soil samples were taken in soil corer of 8cm diameter and 5cm length. The bulk density were determined using the following formula.

$$\text{Bulk density of soil } (g/cm^3) = \frac{m}{v}$$

Where m = mass contained in core sampler of oven dry soil (g)

v = Volume of cylindrical core sample (cm³).

Results obtained for moisture content and Bulk density are shown in Table 5. Also the Average moisture content and bulk density value were plotted and presented in Figures 16 and 17 respectively.

3.2.1.3 Soil Strength:-

The soil strength was obtained by using triaxial compression test. There undisturbed soil sample taken in 30 x 30 x 20 cm mould from different spots were used for the experiment. Three core samples 76 mm x 38 mm were trimmed for the experiment from each 30 x 30 x 20 cm soil samples in the mould. The proving ring factor was 0.02 kN/div. The cell water pressure used were 120, 240 and 360 kn/m². The results obtained from the triaxicil test are shown in Table 6. Mohr Circles were plotted for each three tests. An envelope line produced is then drawn by joining the series of Mohr circles by a common tangent. The angle of internal friction 0 is the slope of the line while the intercept give the cohesion (Figure 18 - 20).

3.3.1.4. Soil Metal Friction Properties

The method of sliding friction apparative which is normally used for measuring soil shear failure was used for soil friction measurement as described by Godwin et al; 1992. The first measurement of soil metal friction properties was done when the soil was air dried. Water was then added to the soil gradually to attain other levels of soil moisture content. The surface treatments T_1, T_2 and T_3 used for the field experiments were simulated on the steel sledge the laboratory test. Three sledges were made the smooth sledge. these are (the normal smooth steel surface), the painted sledge (smooth steel painted with gloss paint) and the rough sledge (A 1 mm deep corrodded steel). The normal loads used for the test were 500g; 750; 1000g; 1550g, 2000g and 2700g. Data obtained from the tests are shown in Table 7 A graph of shear resistance against normal stress for each of the three surfaces used were plotted, as shown in Figure 21. Also a graph of apparent coefficient of friction against moisture content were plotted for each of the three surfaces are shown in Figures 33 -35 in Appendix 2.

3.3.2. Implement Parameters

The implement parameters considered of the disc plough under study include the shape, radius of curvature, diameter of disc, edge shape and the surface roughness of the blade surface. All these other parameters except the surface roughness were kept constant throughout the field experiment. Since the angle of soil-metal friction is a function of the roughness of the tool surfaces, (Spoor, 1969) it was used as the index of surface roughness for the three surfaces considered. Data were collected as described below:

The radius of curvature of the disc plough blades under study was determined taking the following steps:

A number of old disc blades were selected from different Agricultural establishments to the site of these experiment. Each of these disc blades was placed one by one on a flat - horizontal surface with the concave side facing the table. Eleven small holes were drilled at 5 cm intervals each on a flat wooden bar. This bar was placed horizontally on the blade with the centre hole lying on the centre hole of the blade. A calibrated rod was then dipped vertically through each hole to touch the disc and this vertical distance (l) was noted for each hole.

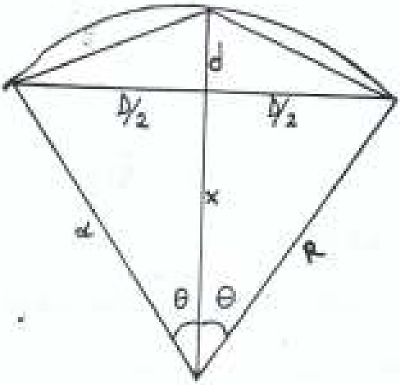
A graph of l against corresponding distances from centre was plotted to determine the concavity and diameter of the disc. This is shown in Figure 36 in Appendix 2.

To estimate the radius of curvature, the following mathematical procedures were taken:

From the arc got (Figure 36) two chords were drawn slanting from the centre of the arc to the extreme edge of the arc. Perpendicular bisector of the chords were constructed. When extended, the bisectors will intersect at the radius of curvature. The line joining the centre of curvature with any point on the arc is the radius of curvature. Any blade with radius of curvature different from the most common ones was set aside. Also those having uniform diameters were selected. Out of these ones, tests were carried out to determine the ones having uniform edge shape.

To determine the edge shape, two types of mould vis:- wire mould and rubber mould and direct measurement were used. The wire mould and rubber mould, 10 cm long were folded into two and inserted on the edges of the blades. The resulting shapes of the mould from each blade were then compared and those with uniform edge shapes are selected. The value of the selected edge shapes were measured with a micrometer screw gauge. The result obtained from the experiments on Disc blade geometry are shown in Table 9. The weights of the Disc blades were determined using a 100kg capacity weighing scale.

To check the validity (accuracy) of the method used to estimate the concavity radius of curvature of the blade, a mathematical relationship described below was used.



From Figure 14, - $R = x + d$.

$$R^2 = x^2 + \frac{D^2}{4}$$

$$x^2 = R^2 - \frac{D^2}{4}$$

Figure 14 - Relation between Radius of curvature, Diameter and Concavity of Disc blades.

Where R = Radius of curvature

D = Diameter of Disc

d = Concavity of Disc

$x = R - d$.

Also $d = R - x$.

$$d = R - \sqrt{R^2 - \frac{D^2}{4}}$$

$$R^2 - 2Rd + d^2 = R^2 - \frac{D^2}{4}$$

$$d^2 - 2Rd = -\frac{D^2}{4}$$

$$d^2 - 2Rd + \frac{D^2}{4} = 0$$

$$4d^2 - 8Rd + D^2 = 0$$

$$d = \frac{-(-8R) \pm \sqrt{8(R)^2 - 4(4)\,Q}}{2 \times 4}$$

$$= \frac{8R \pm \sqrt{64R^2 - 16D^2}}{8}$$

$$= \frac{8R \pm 4\sqrt{4R^2 - D^2}}{8}$$

$$d = R \pm \tfrac{1}{2}\sqrt{4R^2 - D^2} \quad \text{.................................} (19)$$

The theoretical value was obtained for d using the equation. The correlation ratio of the method used to estimate the specification of the disk blade was determined by comparing the actual value obtained using the procedure discussed with the theoretical value.

$$\text{Correlation ratio} = \frac{\text{Actual value}}{\text{Theoretical value}} \times 100\%$$

3.3.3. Speed of Operation

To evaluate the speed of operation, a field length of 30 meters was used for each of the tillage operations performed. The time required for the tractor with implement to cover this distance was measured with a stop watch. Speed was calculated from the following formula.

$$\text{Speed m/s} = \frac{\text{30m test run}}{\text{Time taken (s)}}$$

$$\text{Speed km/hr} = \text{Speed (m/s)} \times \frac{1000}{3600}$$

Four levels of speed were used because of the limitation in the test facilities and methods of measurement. It was impossible to go beyond a speed of 5.4 km/hr because of the roughness of the field surface.

3.3.4. Determination of Draught Requirement for the Tillage Operation

A simple spring type dynamometer was fabricated and used for measurement of draught (see Figure 15). The spring used for the dynamometer was calibrated using the following procedure.

The spring rate (k) was first determined from the relation $F = Kx$

where F = Force

k = Constant

x = extension.

To ensure that the spring still obeys Hookes law, an experiment to measure the extension of the spring per unit force was performed by suspending vertically standard known weight were then suspended on it The corresponding extension were measured. The result is shown in Table 10. To measure the draught required for each tillage operation, the spring dynamometer was used with the tractor arrangement described by Bukhari et al. (1988). The auxilliary tractor used was a Ford 6600 tractor with 70 Horse power . The results of the experiment are shown in Table 19. A graph of draught versus speed for each treatment combination was plotted as shown in Figure 22 -24.

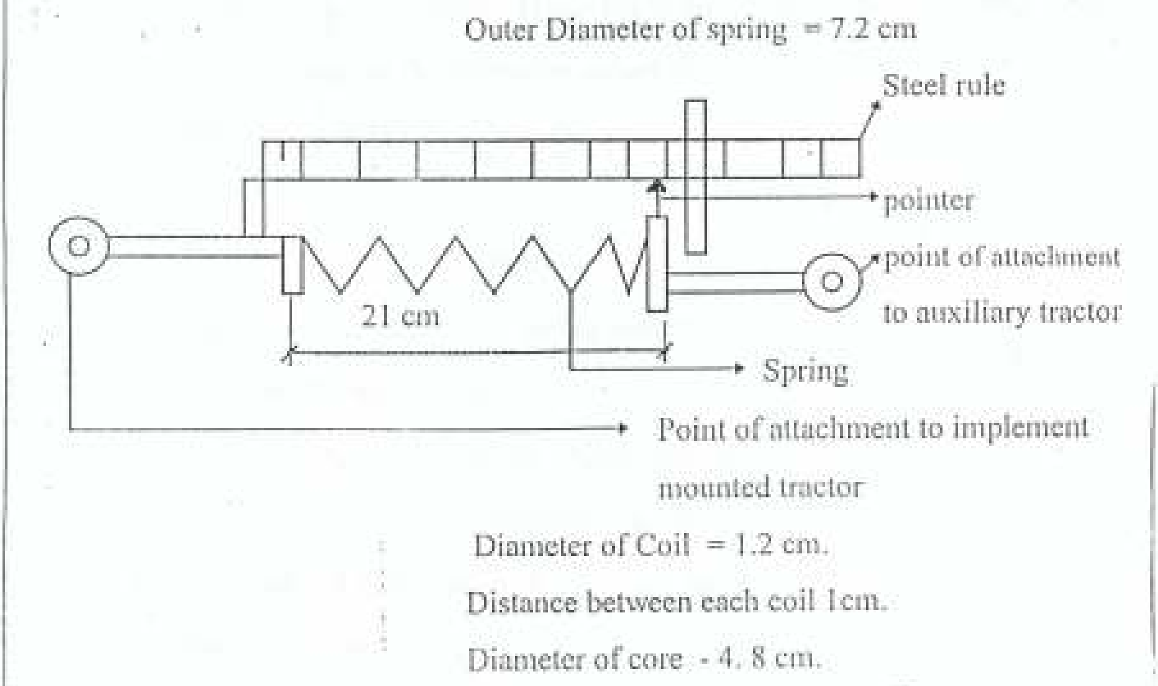


Figure 15- Description of the spring dynamometer used for the experiment

3.3.5. Determination of Soil Structural Behaviour of the Tilled Area.

Two indices of soil structure namely distribution of aggregate sizes and Aggregate stability were used to describe the structure of the tilled area.

3.3.5.1. Aggregate Size Distribution

To express the distribution of aggregate sizes of the tilled area, the concept of Mean Weight Diameter (MWD) was used. Eight size range of sieves were used for the experiment. These are, 19mm 6.70mm, 4.75mm, 2.36mm, 1.18mm, 425um. 212um, and 75um. The diameter of each seize was 20cm. These sieve sizes were chosen based on the sizes of aggregates of the tilled area. 1kg of each soil sample collected from each plot of the ploughed area was air dried and placed in the next set of sieves arranged in descending order. The top sieve was also covered with a pan of same diameter and the whole next set of sieves was filled on a rotary sieve shaker and bolted. The machine was operated for a uniform period of 10 minutes for each soil samples analysed. The different soil residue remaining on different sieves were carefully collected and weighted. From the data obtained from the experiments, the MWD was then calculated from the following equation.

$$\text{MWD} = \frac{\sum \left[\text{Mi} \times \frac{(\text{Do} + \text{Di})}{2} \right]}{\sum \text{Mi}}$$

where Mi = mass of the soil retained on the ith sieve from top (kg)

Di = size of the ith sieve (mm)

Do = size (second major dimension) of the largest clod on top sieve (mm).

The result obtained from these experiments are shown in Table 12 and Figures 28-30. Anova and Least Significant Difference (LSD) Anova follow up tests were performed to show if there were differences in the means.

3.3.5.2. Aggregate Stability

The procedure used for testing the water stability of soil aggregate (WSA) in this study was the wet sieving method as described by Godwin (1967) . However, the sieves used are of 6.7 mm, 4.75 mm, 2.36 mm, 2.0 mm, 0.425 mm, 0.212 mm and 0.075 mm. The result obtained during the experiment are shown in Table 13. Test for WSA was performed for all soil samples collected from the tilled area. The experiment for each soil sample was replicated three times to minimize the experimental error. The percentage of soils passing through each sieve size was calculated. A graph of each percentage of soil passing through each sieve was plotted against the corresponding sieve size for twelve different soil samples as shown in Figure37.

CHAPTER FOUR

RESULTS AND DISCUSSION

The results of the experiments carried out during the study are grouped into two. The first is the result of tillage parameters while the second is the result of performances during tillage operation and data analysis.

2.1 Result and discussion on tillage parameter

The results of the tillage parameters measured are presented in Tables 4 - 8 (Appendix 2) and Figures16 – 21, and 33 -36. They include soil properties at the experimental site, Implement parameters and Operational parameters.

Evaluation of some relevant Soil Properties

Particle size analysis (Table 4) has shown that the soil in the experimental site is mainly Sandy loam. There are however a few traces of clay loam. Sandy loam soils are better worked upon during tillage operations and shows better field efficiencies than clay loam (Razzaq and Sabir, 1992). The mean value of moisture content (Table 5) of the soil from the experimental plot during the field work, taken from a depth of 25 cm was 16.8 %. However, as shown in Figure16, this value increased with depth up to a depth range of 11 - 15cm and then started to decrease. This moisture content value is within the range required for an efficient tillage operation Razzaq and Sabir, (1992) discovered that field efficiency reduced below this range of moisture content while above the range the resistance of tillage implements is high due to cementation effect among the soil particles and there is increased sinkage in sandy loam.

The mean value of soil bulk density (dry weight basis) of the soil samples obtained from the experimental site, taken from a depth of 25 cm was 1.3 g/cm^3 as shown in (Table 6). Figure 17 shows that the bulk density increased with depth up to 15 cm and then decreased. This bulk density varies in the same manner as the moisture content. The low value of bulk density is an indication that the structure is good for agricultural purposes. (Biswas & Murkherjee,1987). The result of the triaxial tests to determine the soil shear strength of the experimental site is presented in Table 6. The values of soil strength parameters,:

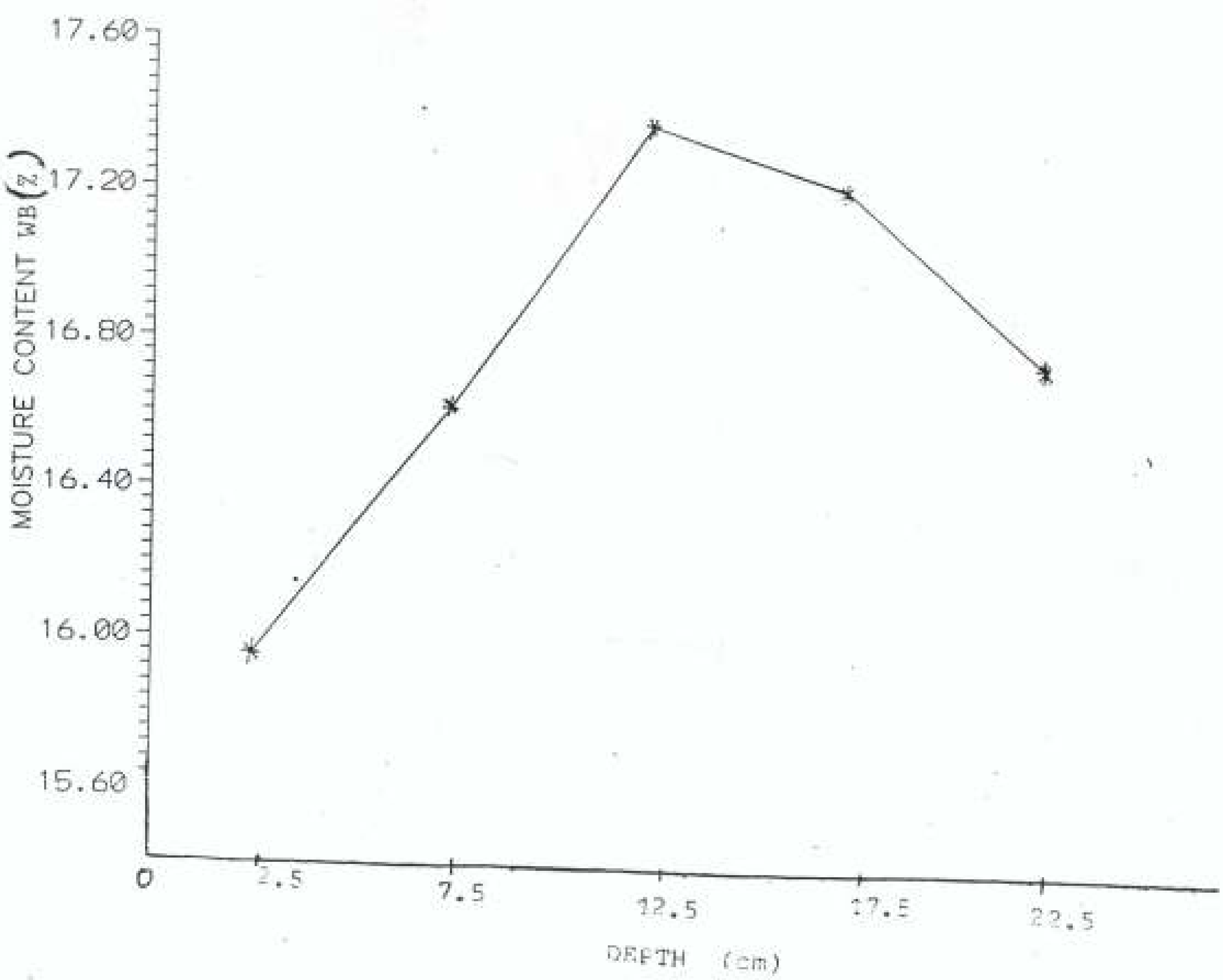


Figure 16 - Graph of moisture content versus Depth

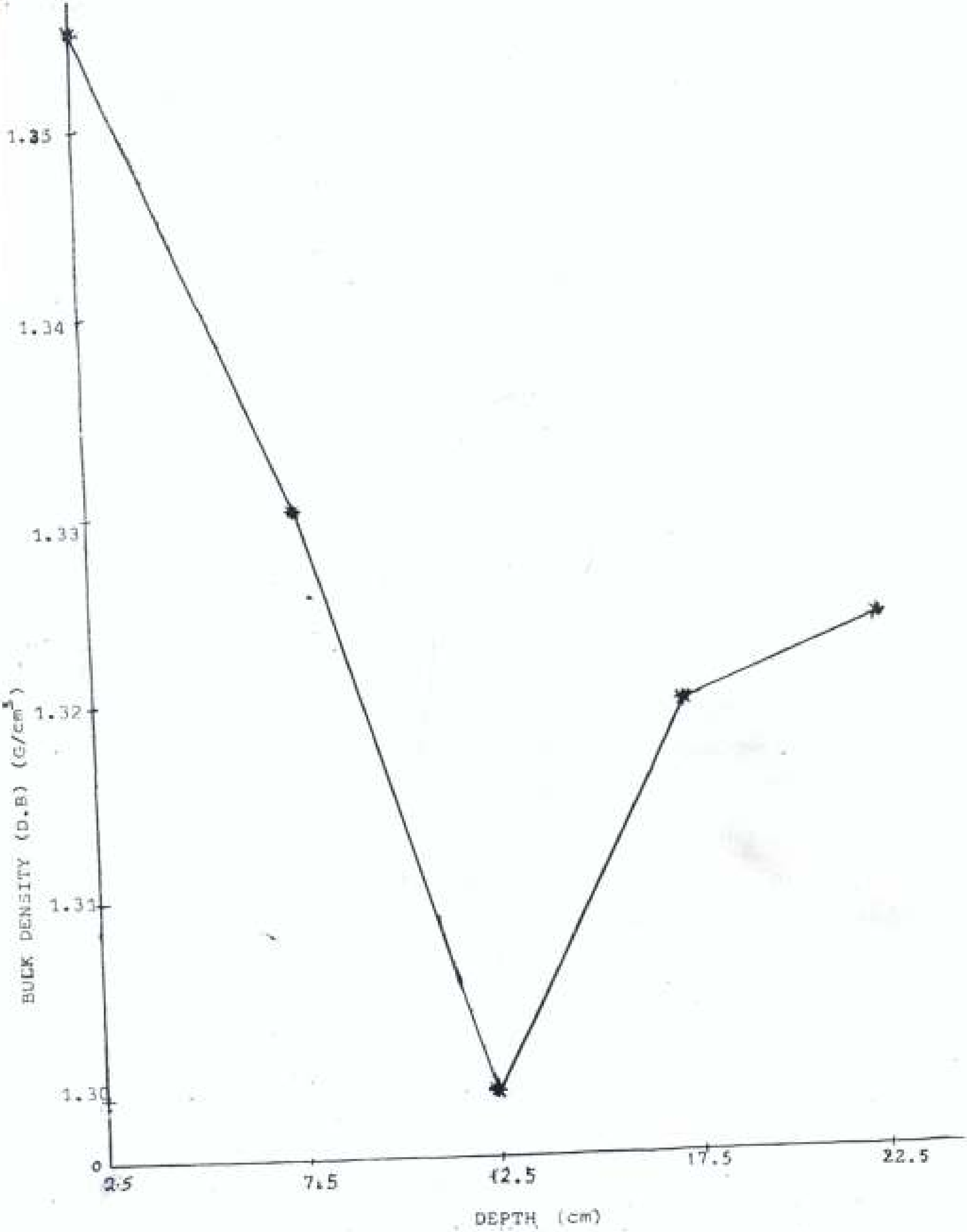


FIGURE 17 - Graph of Bulk Density Versus Depth

Cohesion and angles of internal friction are shown in Figures 18 to 20. These show that the cohesion varies between 15 kN/m² and 40 kN/m² on the test plots. The 40kN/m² value indicates that there are traces of clay loam. This is substantiated by the results of the experiment performed during soil textural class determination (Table 4). It was necessary to determine the soil strength in this research in order to evaluate the effect of soil strength on the performances of implements during tillage operation. Furthermore, the magnitude of the angle of internal friction varies from 20° to 22°. The sandy loam soil having a cohesion varying between 15kN/m² and 40kN/m² and angle of shearing resistance of 20° and 22° is typical of agricultural soils. (Crossley et al., 1983)

The magnitude of the soil - metal sliding resistance are shown in Table 7. Figure 21 shows that the adhesion properties of the discs with surface treatment T_1 and T_2 are negligible at a moisture content of 16.8%, while the adhesion of discs with surface treatment T_3 was 0.18 kN/m². This is because under friable soil conditions, adhesion is normally zero. (Spoor, 1979) Because of the roughness of the surface of the disc with treatment T_3, the area of surface exposed to moisture (wetting) is increased, hence, the adhesion which is a function of the wet ability of the implement surface also increased.

The value of the angle of soil - metal friction for the three sets of discs T_1, T_2, and T_3 as shown in Figure 21 are 19.0°, 14.0° and 21. 6°" respectively. This shows that the angle of soil - metal sliding resistance value (6) for surface T' is within the range of the angle of soil - soil shearing resistance (ø) determined (Figure 17). This is in agreement with the findings of Osman, (1964) that a really rough surfaced blade has $\delta = 0$. Furthermore, the fact that for surfaces T_1 and T_2 (ie 19.00 and 14.00) are lower than that of surface T_3 is in agreement with the fact that the angle of soil- metal friction is a function of the roughness of the blade surface (Gill & Van de Berg, 1968).

Result of the test conducted to determine the macroshape, Microshape and edgeshape of the disc plough under study are presented in Table 9 (Appendix 2). The radius of curvature determined for the three sets of blade was 56.2 cm. The magnitude d concavity was 7.4 cm while the mean diameter was 58.8 cm. The value of concavity was measured theoretically and gave 8.3 cm Therefore correlation ratio of the measured theoretical value was 89.2%

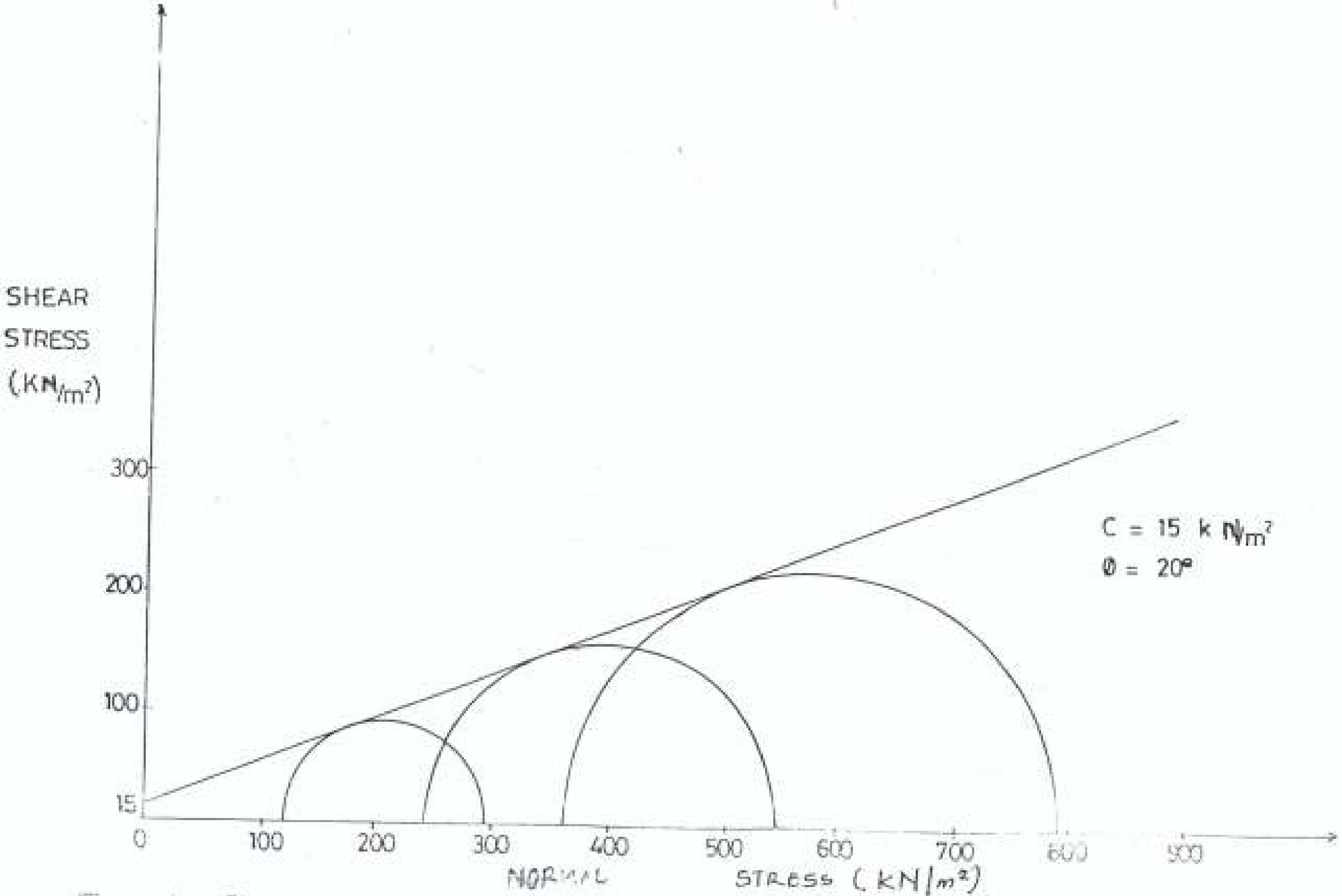


Figure 18 · Shear Strength of Soil (Soil Sample No 1)

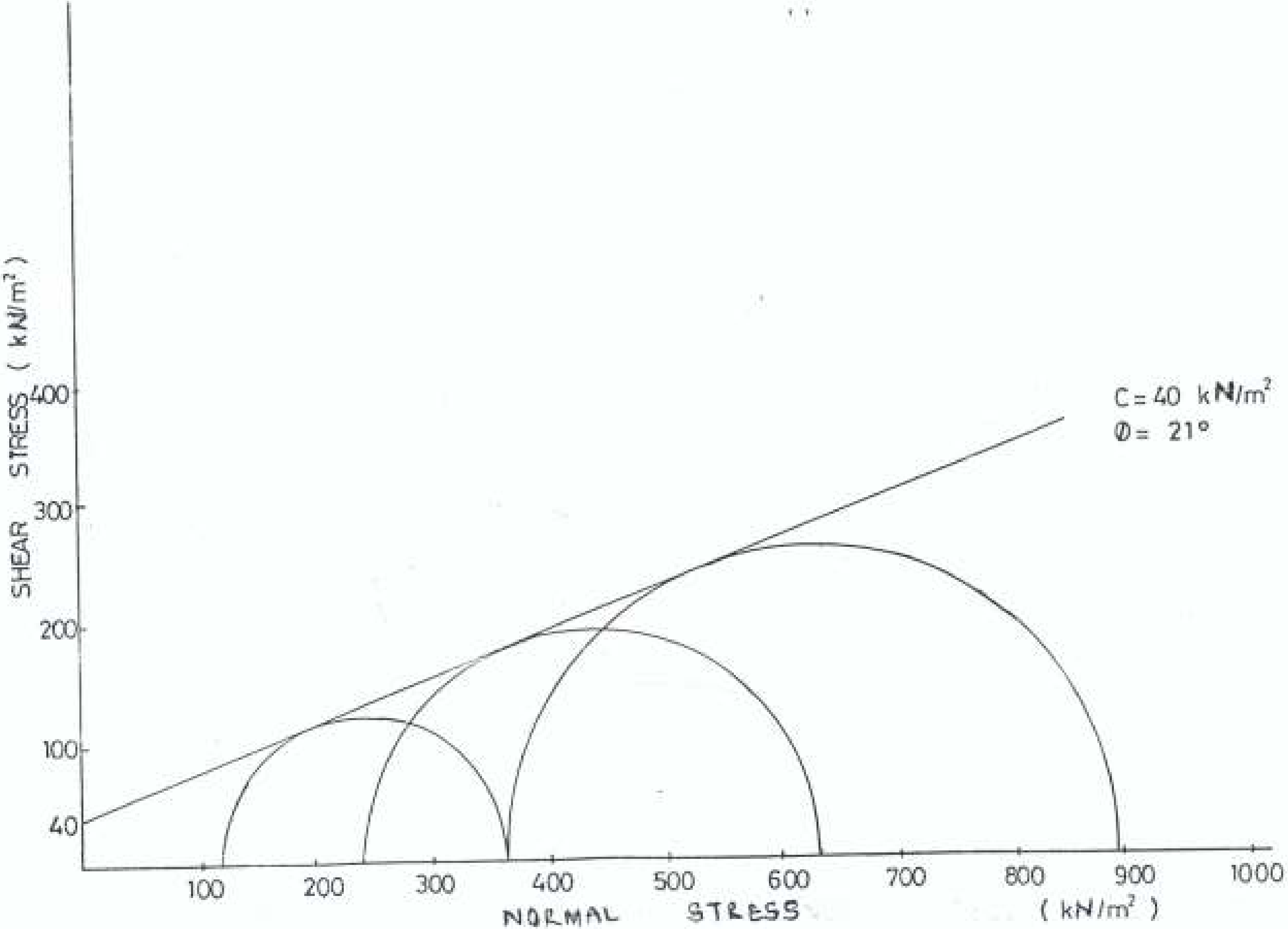


Figure 19: Shear Strength of Soil (Soil Sample No 2)

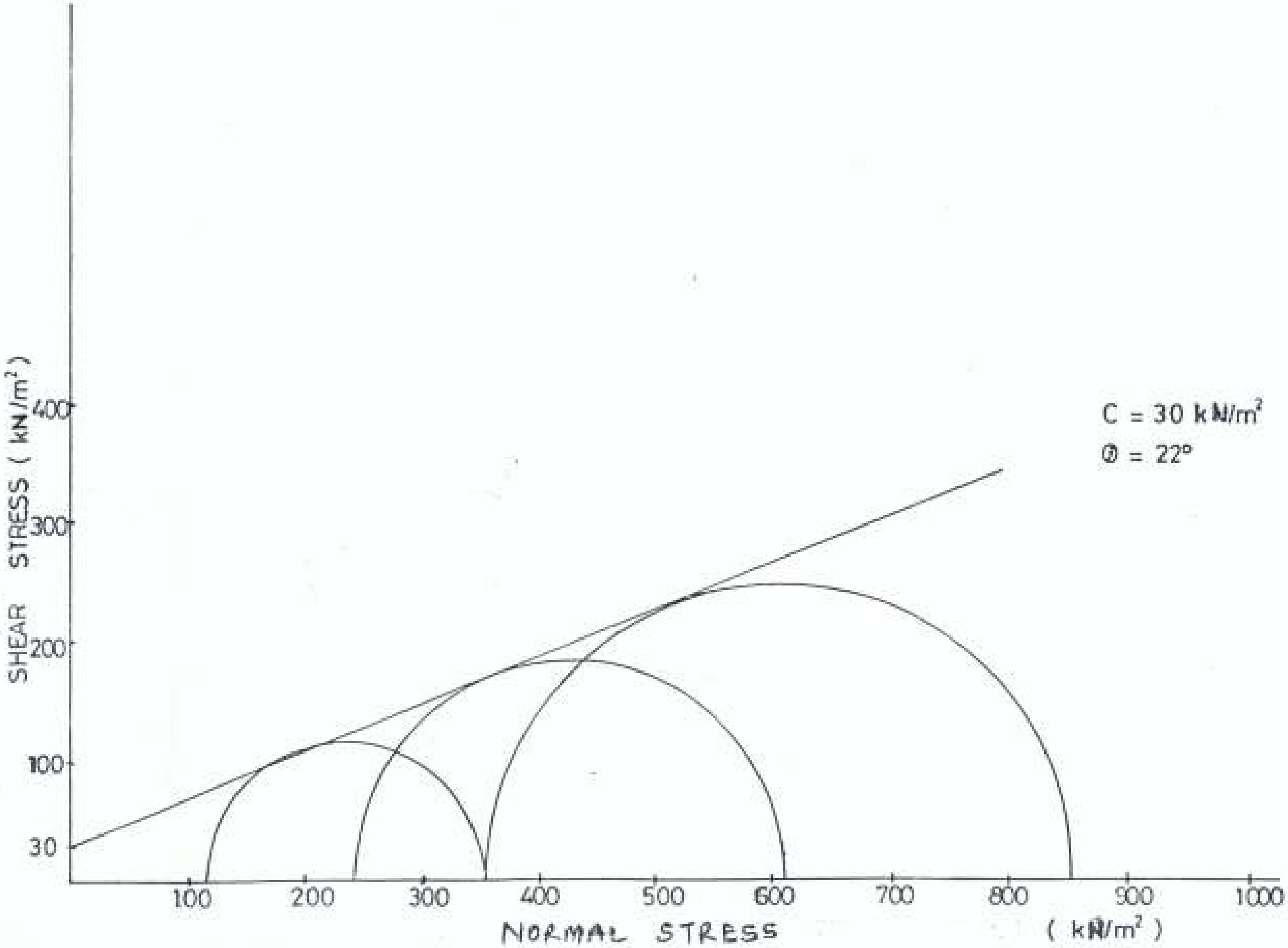


Figure 20 : Shear Strength of Soil (Soil Sample No 3)

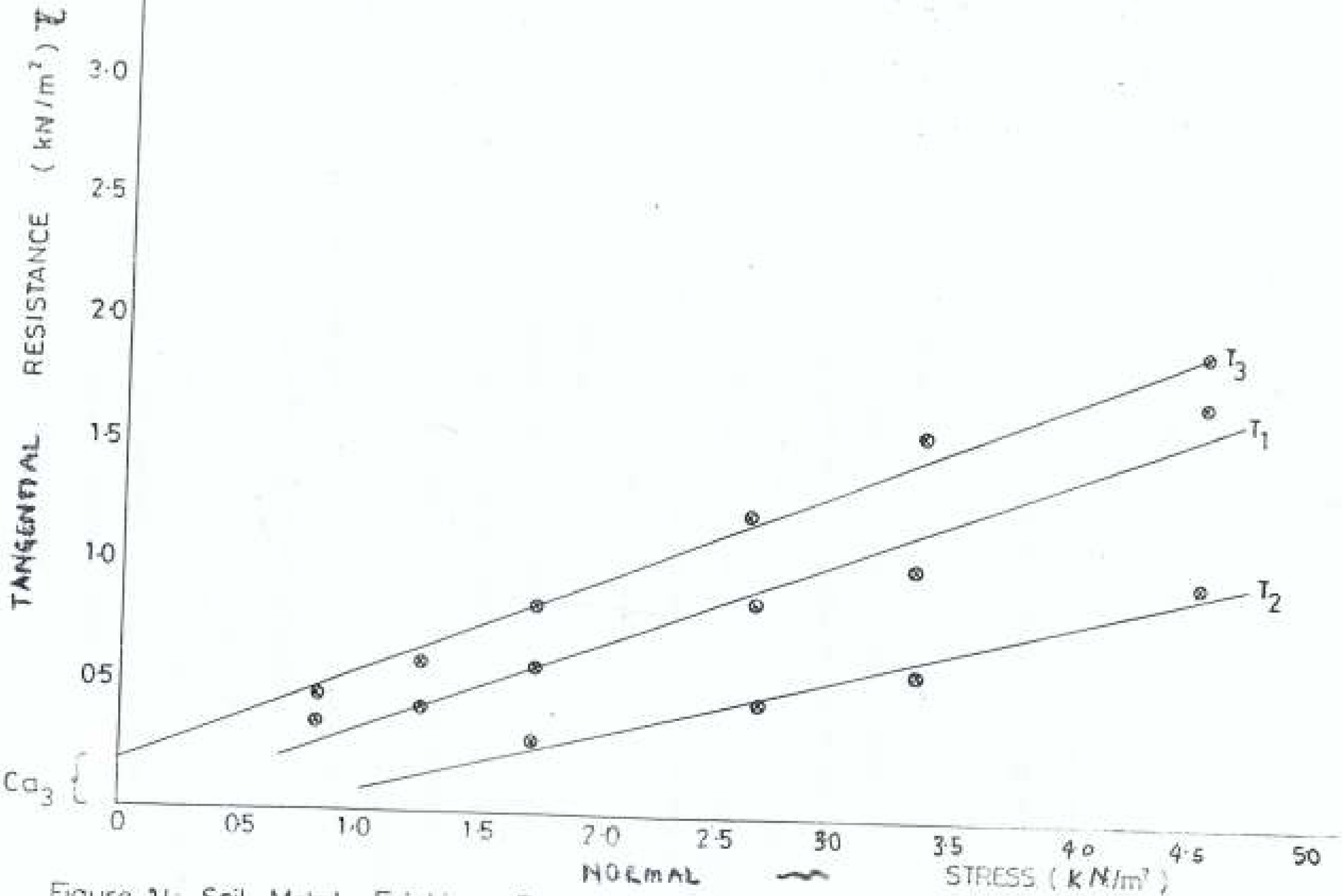


Figure 21: Soil Metal Friction Properties at 16·75% Moisture Content (W·B)

Results of Parameter evaluation in Tillage Operations.

Test performed on the spring dynamometer showed that the spring is yet within the elastic limit. The spring rate determined was 90.21kg/ cm (Table 10 in Appendix 3). The performance of the tillage implements were presented by use of graphs and evaluated by statistical analysis. The rate of change of draught with speed increased positively as the speed was increased for all the tillage operations. (Table 11 in Appendix 3) Also there was an increase in draught as the tilt angle increased from 18° to 22° Figure22-24 give the speed versus draught curves for the three surface treatments T_1, T_2 and T_3 at cutting angle settings Θ_1 and Θ_2. All tillage implements experience an increase in draught as forward speed is increased due to more rapid soil acceleration (Kepner et al; 1987). The increase in draught as the cutting angle is increase because soil confinement increased on the front surface of the discs as the angle increased.

According to Narka, (1990), draught also increase with increased cutting angle because of increased back pressure on the disk. Increased forward speed of operation was accompanied by soil throwing during the tillage experiment. This is illustrated in figure 25. Here it could be seen that the furrow formed by the tillage implements at higher speeds was wider than that formed at a lower speed (figure 26) because the soil was thrown farther away from the furrows. Although soil throwing can be caused by other factors apart from speed such as smaller radius of curvature however, since the radius of curvation was kept constant with all other factors apart from speed in each of the experiments, then the soil throwing must have come from the change (increase) in the speed of operation only. Plate 5 shows that at cutting angle setting 1 and low speed 3.21km/hr, there was good inversion for implements with surface treatments T_1 and T_2. Whereas for the same surface treatments and same low speed, there was poor inversion and poor penetration at cutting angle setting 2 (figure 27). It could be seen that even though the initial field condition were the same e.g. vegetation cover, because all the grasses and weeds on the experimental site had been cut with a cutlass prior to the start of the experiment. The only factor that could bring about this variation in thrush coverage on this experiment is variation in tilt angle.

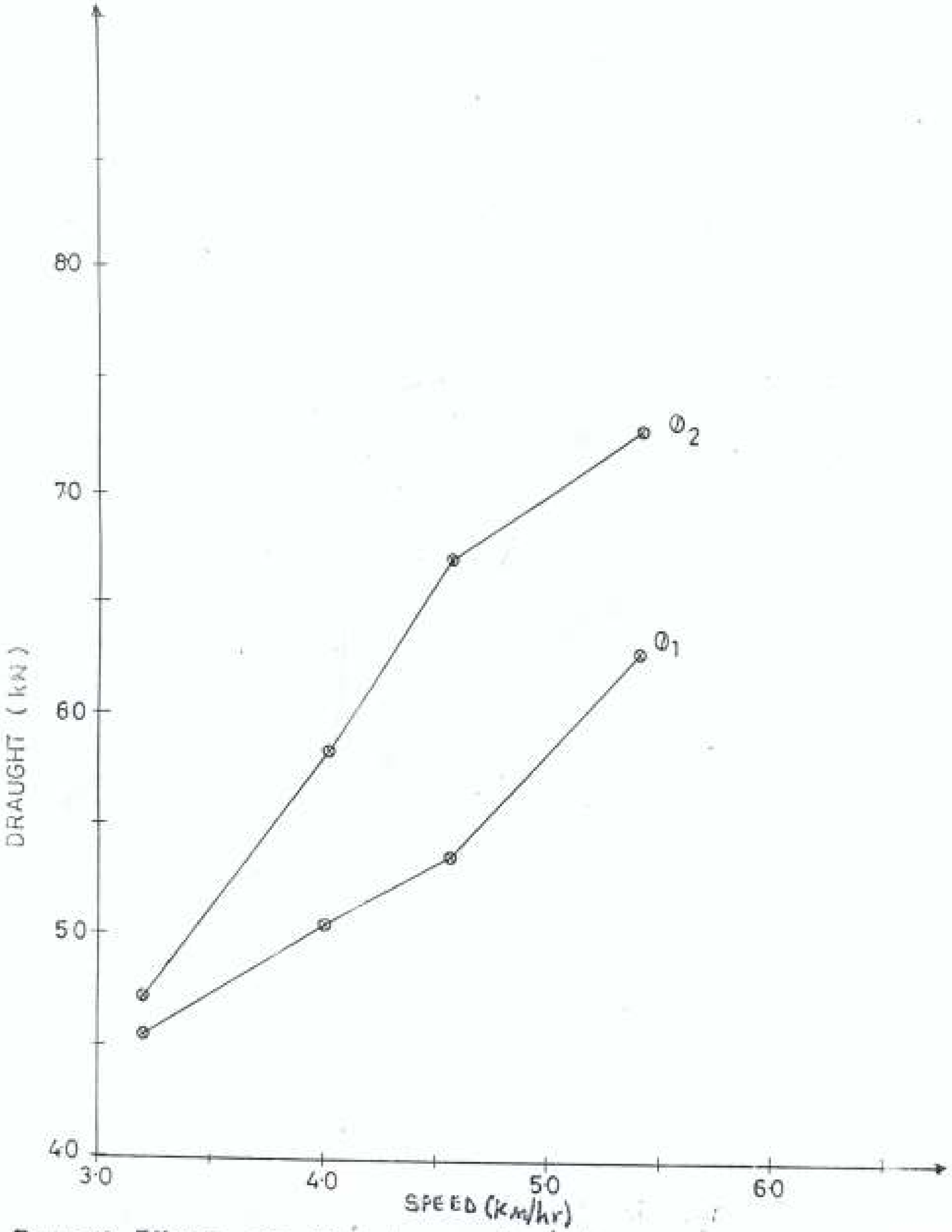


Figure 22: Effect of Speed on Draught at cutting angle setting Ø1 and Ø2 for Tool Surface T1

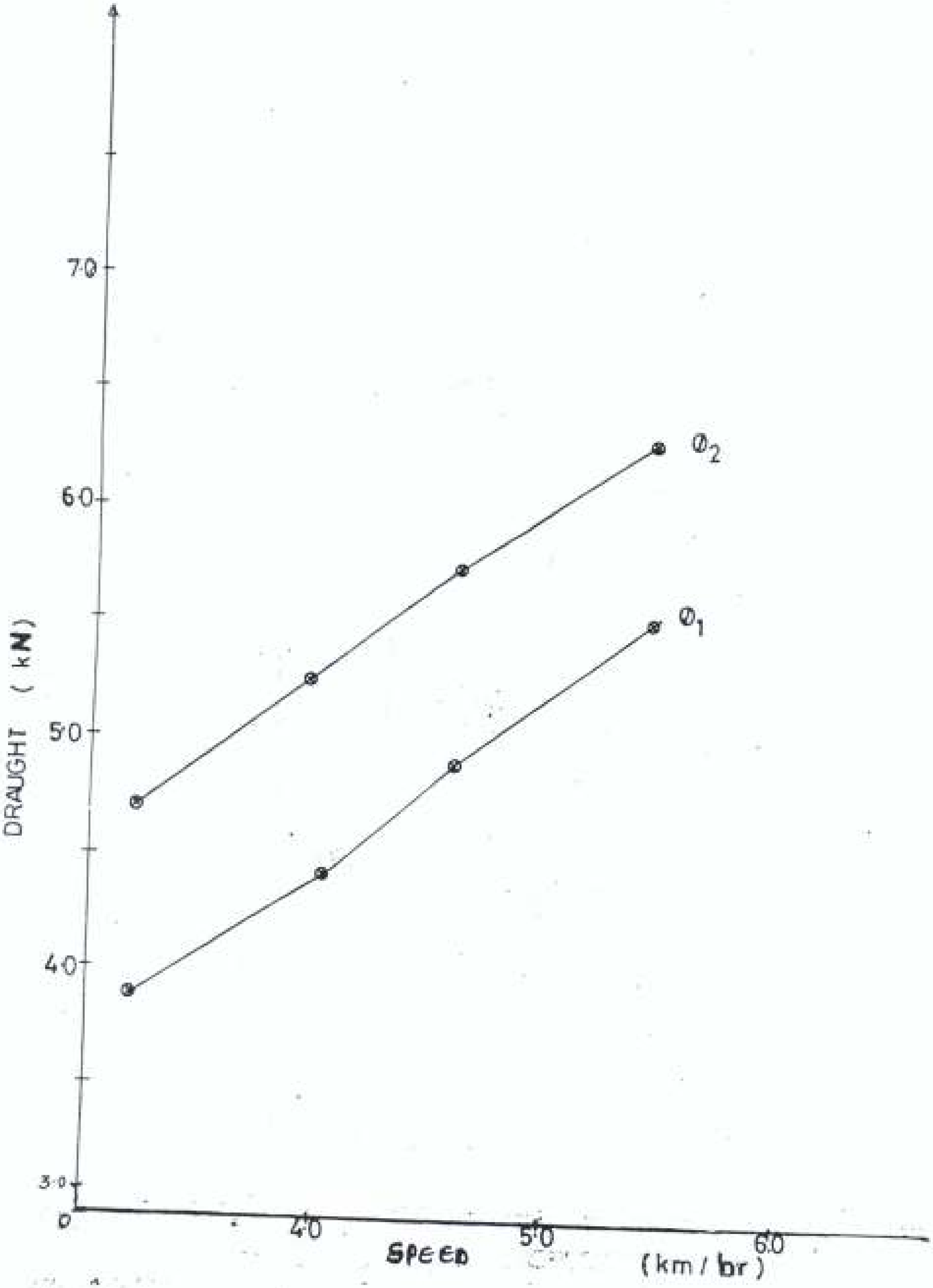


Figure 23: Effect of Speed on Draught at angle $\emptyset_1$ and $\emptyset_2$ for Tool Surface T_2

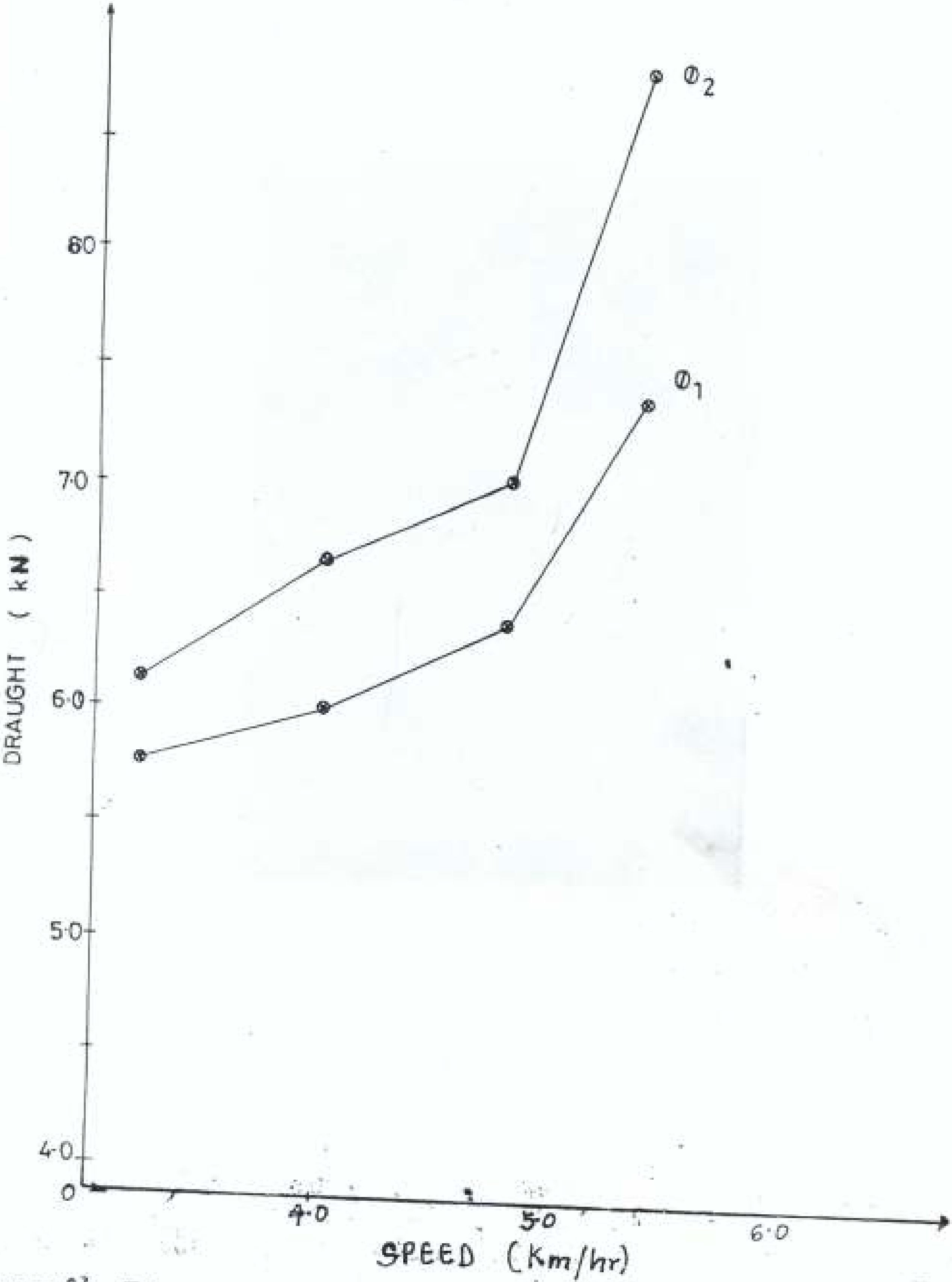


Figure 24: Effect of Speed on Draught at cutting angle setting $\emptyset_1$ and $\emptyset_2$ Tool Surface T_3

Figure 25:- Soil throwing at higher speed of tillage operation. The arrow shows the wide furrow formed and the spread of the soil. The degree of soil pulverisation is higher compared with Figure 26.

Figure 26: Effect of tillage operation at a speed of 3.21 km/hr and a tilt angle 180 showing good inversion and pulverisation

Tables 11 and 12 in Appendix 4 show the result of the final soil measurement. Figures 28-30 show the effect of the MWD produced by the three disk surface treatments on the speed of operation measured at the two tilt angles 18⁰ and 22⁰. Here, it could be seen give the values. The rate of change of MWD with increasing speed increased negatively while it increase with increase in disk angle. The reasons for this are obvious. In - the first instance, the lower the value of MWD, the better the soil structure produced, because with soil throwing at increased speed, the soil acquired more kinetic energy of than at low speed to shatter it. The volume of soil disturbed increased with increase in tilt angle until the critical angle is reached after which the volume of the soil disturbed on the surface remains constant (Abo El Gee and Wills, 1986). Therefore the rate of soil throwing at high speed with increase in tilt angle is reduced and consequently the kinetic energy required for soil break up in reduced and the MWD is increased.

Figure 27: Effect of tillage operation at a speed of 3.21km/hr and a tilt angle of 22° showing poor inverstion and consequent poor pulverisation.

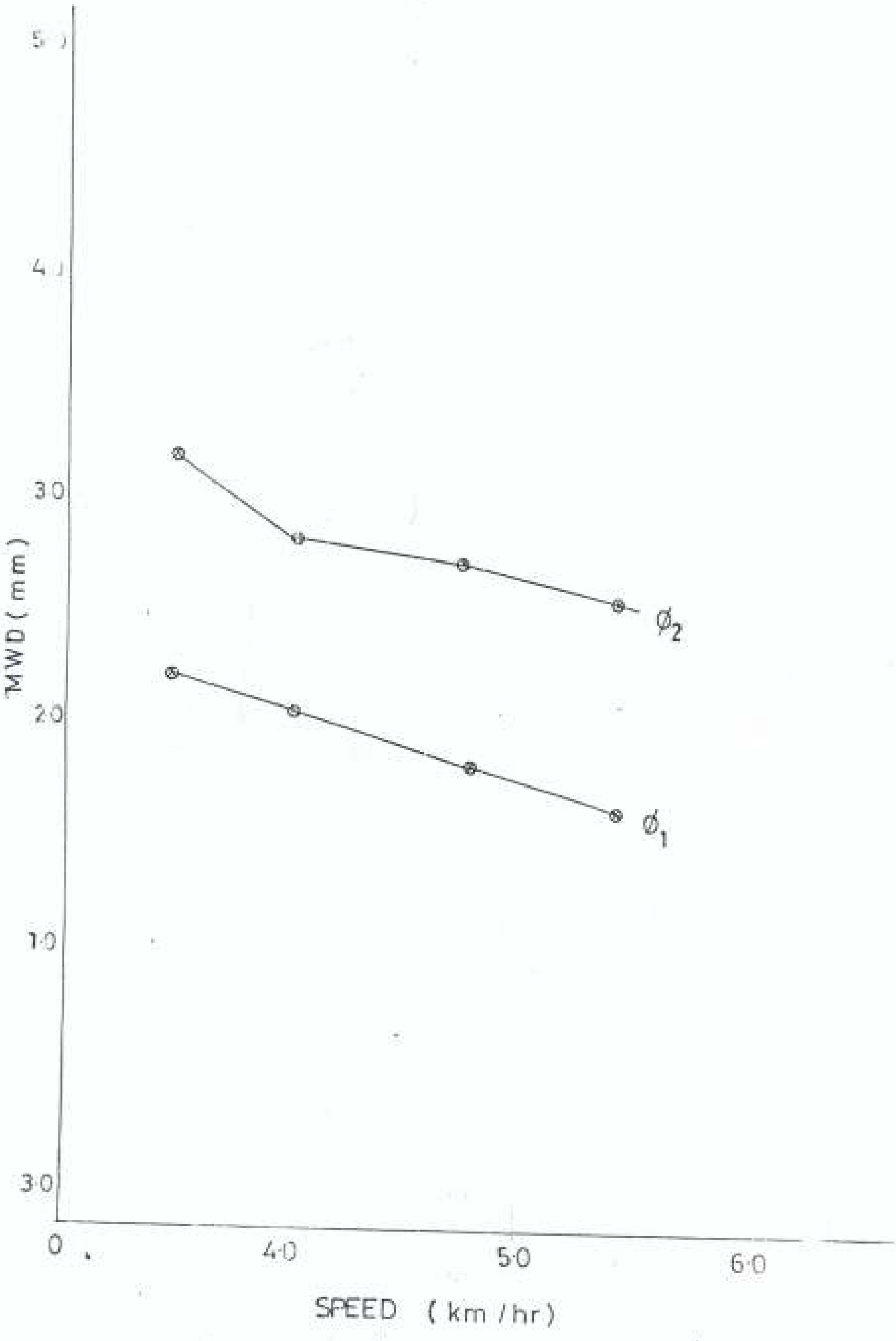


Figure28: Effect of Speed on MWD at angle ϕ_1 and ϕ_2 for Tool Surface T_1

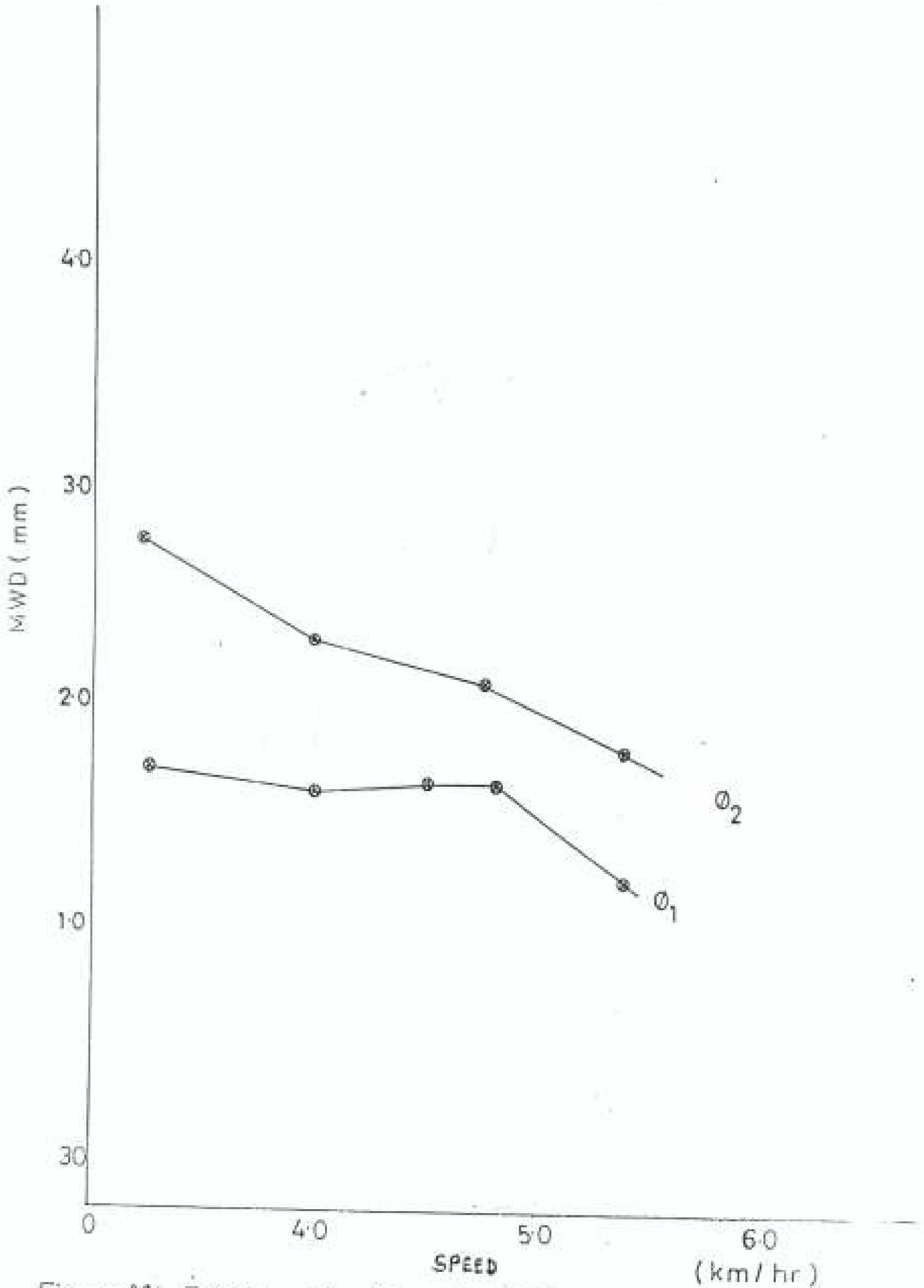


Figure 29: Effect of Speed MWD at Cutting angle Sett ϕ_1 and ϕ_2 for tool Surface T_2

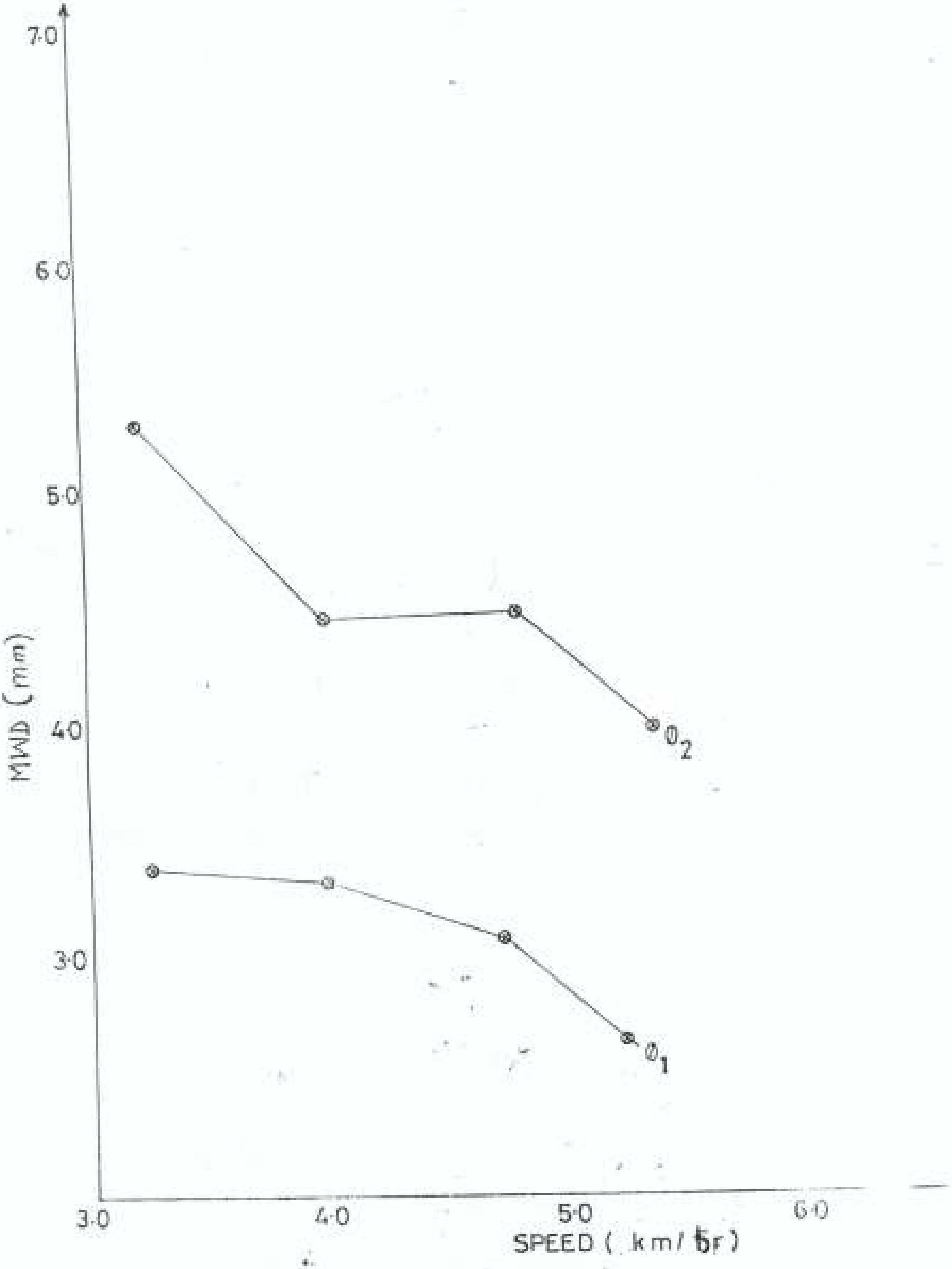


Figure 30: of Speed on MWD at angle Settings ϕ_1 and ϕ_2 for tool Surface T_3

Effect of Surface Roughness on Implement Performance.

Figure 31 shows the influence of tool surface roughness, operating speed and tilt angle on the draught of different surface treatments of the disc blades. An increase in the surface roughness from 14.0° to 21.6° was associated with an increase in draught at all four levels of operating speeds and tilt angles. The draught of surface T_3 with the greatest surface roughness was the highest. This may be due to soil adhering to the surface of the blade. When the surface of the tool was smooth, there was no friction between the surface of the tool and the soil, therefore soil scoured freely. There was also good soil inversion. However, ever when the surface of the tool was rough, friction developed between the tools surface and the soil. As a result, soil tends to cleave to the surface of the blade which resulted in increased draught than the corresponding smooth surfaced disc. This finding is contrary to that of Osman (1964) about curved blades. Osman discovered that if the soil does not scour on a curved blade and soil adhered to its surface, the blade will revert to a soil-covered straight blade which may happen at large curvatures and rake angles. Since curved blades always have a greater draught than the corresponding straight blades, the draught of a curved blade which has reverted to a straight blade because of soil adhering to its surface was lower than the corresponding smooth surfaced curved blade.

The reason for the different results could be attributed to the fact that disc ploughs have revolving disc compared with other ploughs like mould-board plough and the chisel plough. The revolving action of the disks does not allow the complete build up of soil over the disk surface. Hence the discs did not revert to a straight blade even though there was adhesion. This shows the advantage of disk plough over the mould board plough in that the revolving discs of a disc plough can work satisfactorily in rough and adverse conditons without clogging better than the mould-board plough. Figure 32 shows the effect of tool surface roughness on Mean Weight Diameter (MWD) at two tilt angles for the three surface treatments T_1, T_2 and T_3. An increase in surface roughness of the disc blades from 14.0° to 21.6° was associated with an increase in MWD. A similar trend was noticed with an increase in tilt angle from 18° to 22° for all four levels of speed. The minimum MWD was indicated by the tool surface T_2, followed by surface T_1 and lastly surface T_3. This was because there was soil scouring in the case of surfaces T_2 and T_1 due to negligible adhesion. The fact that the soil did not scour on the case of surface T_3 in evidenced by the higher MWD.

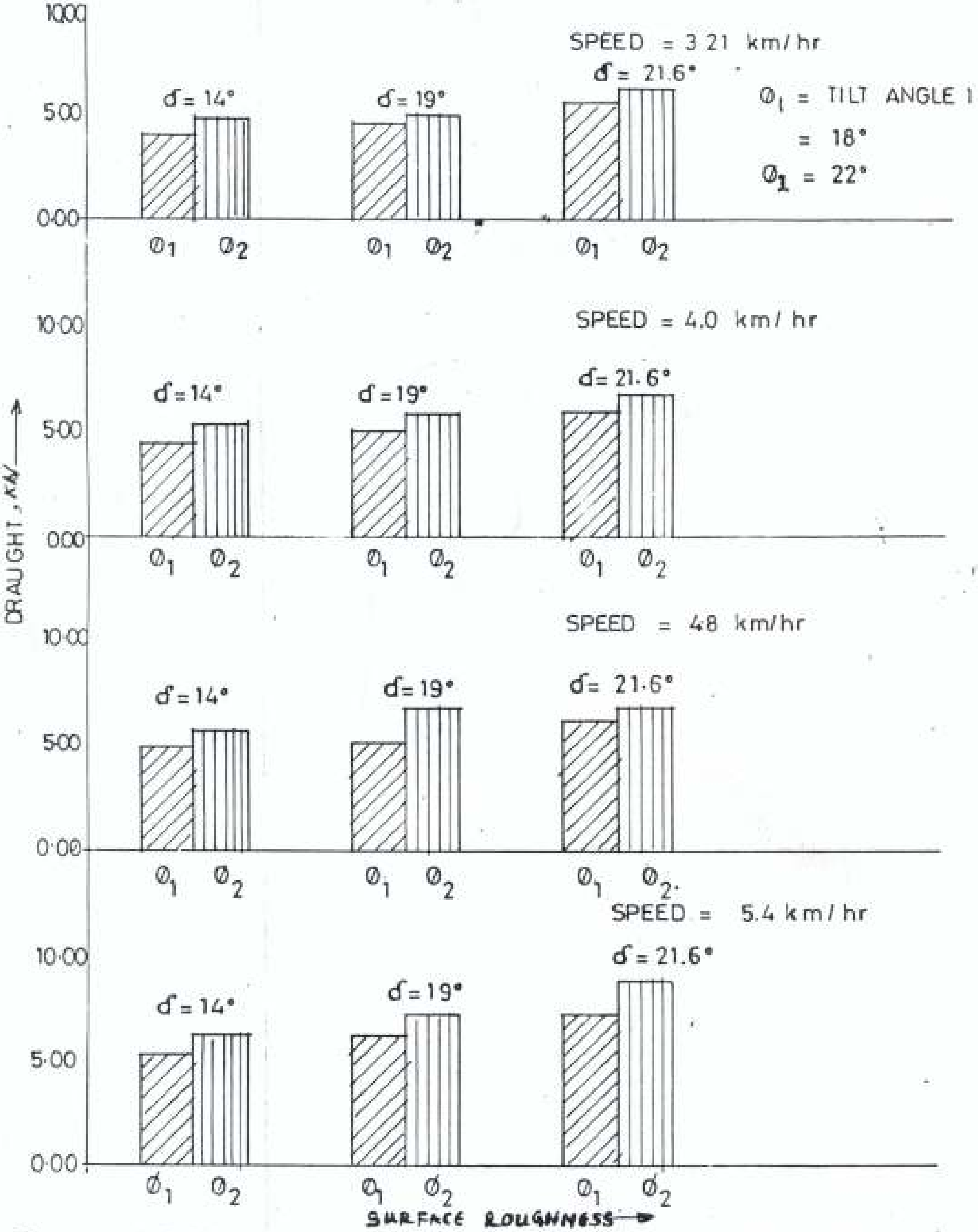


Figure 31: Effect of Tool Surface Roughness on Draught

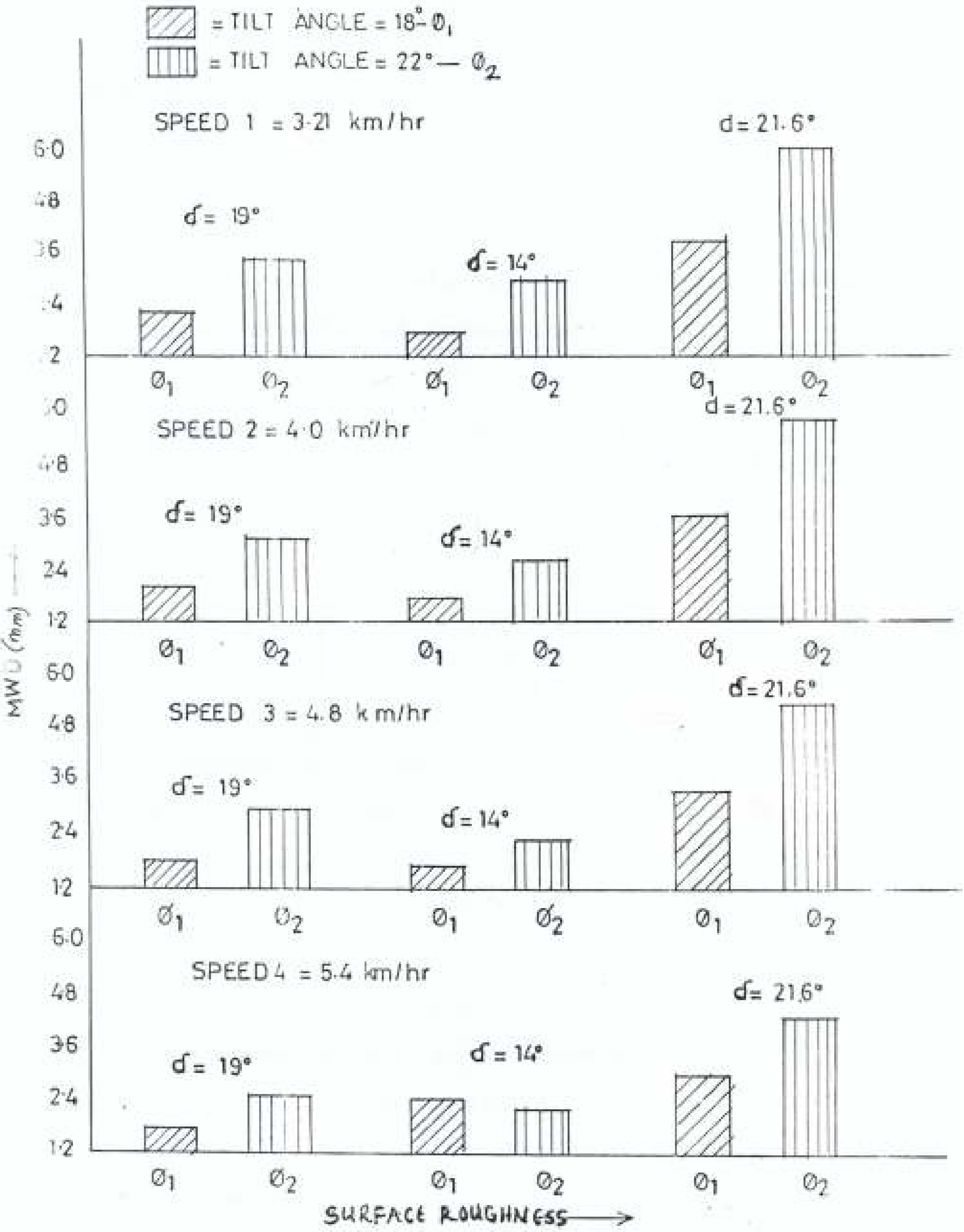


Figure 32: Effect of Surface Roughness on MWD

The effect of tillage operations on soil structure.

Table 12 shows the result of the percentage water stable Aggregates of the different plots at the experimental site from the analysis, it would be deduced that % WSA of the experimental site comes between 39.34 and 58.00. There was however no observed differences of the effects of surface roughness of the tools on the % W S A.

Model Development and Testing

The result of the multiple regression analysis of the data is shown in Appendix 5. The regression equation relating MWD and other parameters under study is

$$\boxed{\text{MWD} = 0.11R - 1.33S + 0.16\theta + 1.02D - 1.88}$$

where MWD = Mean Weight Diameter (mm)

R = Angle of soil-metal friction (degrees)

S = speed in km/hr

0 = tilt angle (degrees)

D = Draught (kN).

The standard error of estimate $S_E = 0.687$. In relation to the values of the dependent variable, this standard error of estimates has a small value which indicates a good fit. This judgements is supported by the coefficient of determination $R^2 = 83.3\%$. The R^2 value tells us that 83.3% of the variation on MWD is explained by the variation in the dependent variables; only 16.7% is unexplained. Also, residual sum which is 0.4×10^{-13} is very small indeed. This shows that there is good comparison between observed values of MWD and the predicted value. To interprete the coefficients of the regression model. b1 = 0.1103 means each unit increase in MWD should increase by 0.1103.

b2 = 1.332 means that each 0.1 unit increase in speed would result in 0.1332 decrease in MWD. b3 = 0.15903 means that for each unit increase in tilt angle, the MWD would increase by 0.15903 while b4 = 1.0180 means that for every unit increase in draught we would expect an increase of 0.1 on MWD.

All this signs of the coefficients are reasonable and expected from the observations already discussed in the results. To test the utility of the model by the analysis of variance, the rejection region at a 0.5% confidence interval F0.5, 4, 19 = 2.90. Since the computed value of F is 23.73, it means there are significant differences in the means of the different MWD obtained from the six different treatment combinations. This shows that different treatment combinations affect MWD. To determine which treatment combinations are statistically different, the results of the one way analysis of variance between Draught and surface roughness and between MWD and surface roughness are as shown in Appendices 6 and 7 respectively. From these results, it could be inferred that there are significant differences between the Draught of blade with surface roughness T_2 and T_1. Also there are significant differences between the MWD produced by blade with surface roughness T_1 with T_2 and between T_3 and T_1.

The result of the analysis of variance for the three factor factorial experiment in Appendix 8 shows that each of the null hypothesis is accepted. With respect to the three tool surface roughness of the discs, there are no significant differences in the resulting MWD means. This implies that if selection of the best surface roughness is to be made, any of the three tool surface roughness is suitable. Since none of the first order interactions, that is, (AB, AC, BC) and the second order interaction (ABC) are significant, it meaning that the factors (tool's surface roughness, tilt angle and speed) are independent.

The variable which appears to be the most important in predicting the MWD from this study are those with the largest absolute t-statistic. Hence speed which has absolute t-statistic value = 3.281 is the most strongly linearly related variables to MWD. This is also indicated by the corresponding small P-values = 0.02.(Appendix 5).

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

Research has been conducted in the field of soil-implement interaction to study the macroshape of a disc plough. A disc plough with three sets of blade of different surface roughness were slotted for draught requirements and final soil tilt on a sandy loam soil of South Western Nigeria. Soil data were acquired to help support the findings of the study. The soil strength parameters namely cohesion and angle of shearing resistance were found to vary between 15kN and 40kN and between 20° and 22° respectively. Soil-tool friction properties were found to be different for the three different tool surface roughness considered. Soil metal friction property is proved to be a good index of tool surface roughness. This fact has not been adequately researched until now. The tool surface with the greatest surface roughness gave the highest draught and highest MWD. Generally, the draught requirement of the disc ploughs with the different disk surface roughness increases with increasing speed and tilt angle and surface roughness. The MWD decreases with increasing speed, while it increases with increasing tilt angle and surface roughness. An advantage of the disk plough over the mould board plough is revealed here in that the disk plough required less effort and is highly efficient while working in rough and sticky soils where there is adhesion than mould board plough.

Mathematical relationship was established between MWD which is an index of final soil tilt and other determining features of tillage under study namely draught, Speed, tilt angle, tool surface roughness of disc plough on a tropical Agricultural soil of soil to Western Nigeria .It was found that it is possible to produce the required soil tilt for particular crop by means of the established relationship. This will make future planning of tillage machinery a possibility. Also from the analysis, Speed is the most strongly linearly related variable to MWD. The three input factors (tools surface roughness, tilt angle and speed) are independent. Also the %WSA of the tilled layer was quantified. The result showed that tillage operation has no significant effect on % WSA. Hence, % WSA is not an index of tool performance.

The following recommendation are note worthy

(1) To attain high productivity of disc ploughs, the surface roughness of the disks should be kept to the bearest minimum as it has no significant effect on the soil pulverised (MWD), although it increases the draught requirement.

(2) For further research in tillage, the angle of soil metal friction is a good index of tool surface roughness.

(3) The soil properties such as soil type and the state of moisture content should be determined before ploughing operations are performed. This will aid the use of suitable values of tillage parameters for optimum tillage.

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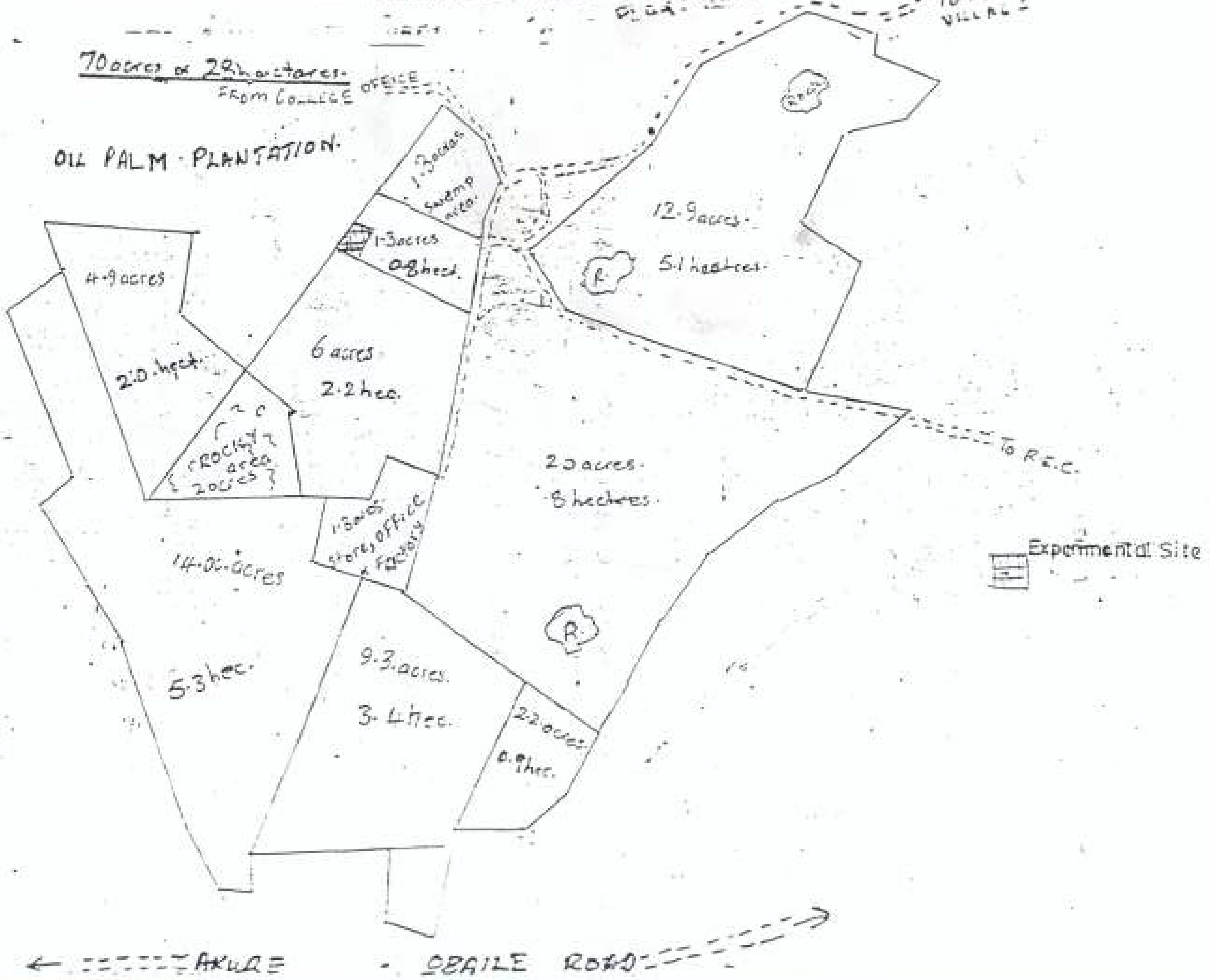
APPENDIX 1 EDU FIELD ROTATIONAL FARM



APPENDIX II

Results of measured Tillage parameters
(Tables 5 - 8 and Figure 33 - 35 and 36)

Table 4: **Determination of Soil Textural Class**

Sample No	Corrected Hydrometer Reading Replicates (g/l)					
		1	2	3	Average	%
1	Silt + Clay	20.2	19.40	19.38	19.66	-
	Clay	12	12.60	12.50	12.37	24.74
	Silt	-	-	-	7.29	14.58
	Sand	-	-	-	30.34	60.68
2	Silt + Clay	8.5	8.4	8.3	8.41	-
	Clay	4.5	4.7	4.5	4.57	9.14
	Silt	-	-	-	3.84	7.68
	Sand	-	-	-	41.59	83.18
3	Silt + Clay	9.6	9.8	9.4	9.59	-
	Clay	5.9	5.8	5.9	5.86	11.72
	Silt	-	-	-	3.70	7.40
	Sand	-	-	-	40.44	80.88
4.	Silt + Clay	11.50	12.00	12.20	11.90	-
	Clay	4.85	5.40	5.08	5.11	10.22
	Silt	-	-	-	6.79	13.85
	Sand	-	-	-	37.95	75.92

Summary of Table 4

Soil Sample	% of Sand	Silt	Clay	Remark
1	60.68	14.58	24.74	Sandy clay loam
2	83.18	7.68	9.14	Sandy loam
3	80.88	7.40	11.72	Sandy loam
4	75.92	10.88	13.96	Sandy loam

Table 5: Bulk Density (g/cm^3) and Moisture Content (% Wet basis)

Weight of Wet Soil Sample = 407.3g

Depth (cm)	Replicates	Weight of Core sample + Wet sample (g)	Weight of Oven dried sample + Core sample	Weight of sample (g)	Core Weight of oven dried sample (g)	Weight of Water (g)	Volume of Core sample	% Moisture Content (wb)	Bulk density (dry basis) (gcm^{-3})
0 - 5	1	667.43	603.73	260.13	343.60	63.70	251.33	15.64	1.367
	2	661.83	595.83	260.13	335.70	66.00	251.33	16.43	1.336
	3	658.10	590.63	260.13	330.50	67.47	251.33	16.95	1.315
	4	673.41	612.33	260.13	352.20	61.08	251.33	14.78	1.401
Average								15.95	1.355
6 - 10	1	662.54	596.83	260.13	336.70	65.71	251.33	16.33	1.340
	2	659.53	592.63	260.13	332.50	66.90	251.33	16.75	1.323
	3	654.66	585.93	260.13	325.80	69.73	251.33	17.42	1.296
	4	665.32	600.73	260.13	340.60	64.59	251.33	15.94	1.355
Average								16.61	1.329
11 - 15	1	656.85	589.93	260.13	328.80	66.94	251.33	17.12	1.308
	2	654.44	585.63	260.13	325.50	68.81	251.33	17.45	1.295
	3	642.26	574.63	260.13	314.50	67.63	251.33	18.55	1.251
	4	662.40	596.63	260.13	336.50	65.77	251.33	16.36	1.339
Average								17.37	1.298
16 - 20	1	658.37	591.03	260.13	330.90	67.34	251.33	16.91	1.317
	2	660.54	594.03	260.13	333.90	66.51	251.33	16.61	1.329
	3	648.66	577.83	260.13	317.70	70.83	251.33	18.23	1.264
	4	657.43	589.73	260.13	329.60	67.70	251.33	17.04	1.311
Average								17.20	1.315
21 - 25	1	660.54	594.03	260.13	333.90	66.51	251.33	16.61	1.329
	2	665.81	601.43	260.13	341.30	64.38	251.33	15.87	1.358
	3	650.75	580.63	260.13	320.50	70.12	251.33	17.95	1.273
	4	661.84	594.93	260.13	334.80	66.91	251.33	16.52	1.334
Average									

c. 6: Data for Soil - Soil Shearing Resistance Parameters

ple No	Strain dial	Change in Length ΔL (cm)	Strain ε $\frac{\Delta L}{L}$ x10^{-3}	Corrected AC (m²) $\frac{Ao}{1-\varepsilon}$ x 10^{-4}	Area	Υ_3 = 120 KN/m²			Υ_3 = 240 KN/m²			Υ_3 = 360 KN/m²		
						P.R.R div	Load KN	Yd KN/m²	P.R.R div	Load KN	Yd KN/m²	P.R.R. div	Load KN	Yd KN/m²
	50	0.05	6.57	11.416		15	0.03	26.29	45	0.09	78.84	50	0.00	87.60
	100	0.10	13.15	11.492		27	0.054	46.99	62	0.124	107.90	69	0.138	120.08
	150	0.15	19.74	11.569		35	0.07	60.51	76	0.152	151.10	83	0.166	143.49
	200	0.20	26.32	11.648		45	0.09	77.21	88	0.176	170.55	90	0.180	154.53
	250	0.25	32.90	11.727		52	0.104	88.68	100	0.200	189.72	110	0.220	187.60
	300	0.30	39.47	11.807		60	0.12	101.64	112	0.224	205.23	123	0.246	208.35
	350	0.35	46.05	11.889		67	0.134	112.71	122	0.244	220.53	141	0.282	237.19
	400	0.40	52.20	11.971		73	0.146	121.96	132	0.264	235.59	159	0.318	265.64
	450	0.45	65.79	12.055		76	0.152	126.09	141	0.284	245.47	169	0.338	280.38
	500	0.50	72.37	12.140		82	0.146	135.00	149	0.298	255.19	182	0.364	299.84
	550	0.55	78.95	12.226		87	0.174	143.33	156	0.312	266.39	198	0.396	326.19
	600	0.60	85.53	12.313		92	0.184	149.44	164	0.328	277.38	209	0.418	341.89
	650	0.65	92.11	12.402		97	0.194	154.48	172	0.344	283.49	226	0.452	367.09
	700	0.70	98.68	12.558		100	0.200	159.06	178	0.356	288.76	235	0.470	378.97

	750	0.75	105.26	12.675	102	0.204	160.95	183	0.366	294.46	242	0.484	385.41
	800	0.80	111.84	12.769	105	0.21	164.46	188	0.376	296.93	250	0.500	394.48
	850	0.85	118.42	12.865	109	0.218	169.40	191	0.382	299.36	257	0.514	405.52
	900	0.90	125.00	12.961	113	0.226	174.37	194	0.388	304.75	264	0.528	410.42
	950	0.95	131.58	13.06	117	0.234	179.17	199	0.390	308.53	271	0.542	418.18
	1000	1.00	138.16	13.159	118	0.236	179.34	203	0.406	309.81	276	0.552	422.16
	1050	1.05		13.261	118	0.236	177.96	206	0.412	307.40	283	0.566	403.12
	1100	1.10	144.74	13.363				207	0.414		289	0.578	435.80
	1150	1.15	151.32	13.468				207	0.414		293	0.586	438.52
	1200	1.20	157.90	13.574							293	0.586	435.11
	1250	1.25	164.47										
	1300	1.30											
T2	50	0.05	6.57	11.416	20	0.04	35.00	50	0.10	87.60	65	0.130	113.40
	100	0.10	13.15	11.492	33	0.066	57.43	67	0.134	116.60	91	0.182	158.37
	150	0.15	19.74	11.569	43	0.086	74.43	80	0.160	138.30	120	0.240	207.45
	200	0.20	26.32	11.648	55	0.11	94.44	91	0.182	156.25	133	0.266	228.37
	250	0.25	32.90	11.727	64	0.128	109.15	104	0.208	177.37	158	0.316	269.46
	300	0.30	39.47	11.807	76	0.152	128.74	115	0.230	194.80	179	0.358	303.21
	350	0.35	46.05	11.889	84	0.168	141.31	129	0.258	217.01	194	0.388	326.35

400	0.40	52.63	11.971
450	0.45	59.20	12.055
500	0.50	65.79	12.140
550	0.55	77.37	12.226
600	0.60	78.95	12.313
650	0.65	85.53	12.402
700	0.70	92.11	12.558
750	0.75	98.68	12.675
800	0.80	165.26	12.769
850	0.85	111.84	12.865
900	0.90	118.42	12.961
950	0.95	125.00	13.060
1000	1.00	131.58	13.159
1050	1.05	138.16	13.261
1100	1.10	144.74	13.363
1150	1.15	151.32	13.468
1200	1.20	157.90	13.514
1250	1.25	164.47	

93	0.186	155.39	140	0.306	233.90	209	0.418	351.59
100	0.200	165.91	153	0.320	253.84	227	0.454	379.25
107	0.214	176.28	165	0.320	263.60	236	0.472	391.54
114	0.228	186.49	178	0.356	291.18	248	0.496	408.57
120	0.240	194.92	189	0.378	306.99	267	0.534	436.77
125	0.250	201.58	198	0.396	319.30	279	0.558	449.92
130	0.260	207.04	209	0.418	332.86	290	0.580	461.86
136	0.272	214. 60	220	0.440	347.14	298	0.596	472.22
141	0.282	220.85	231	0.462	361.81	316	0.632	494.95
146	0.292	226.97	239	0.478	371.55	325	0.650	505.25
151	0.302	233.01	246	0.492	379.60	332	0.664	512.31
155	0.310	237.37	251	0.502	384.38	341	0.682	522.21
158	0.317	241.05	254	0.508	386.05	339	0.678	515.24
158	0.317	239.05	256	0.512	389.09			
			256	0.512	386.01			

50	0.05	6.57	11.416
100	0.10	13.15	11.492
150	0.15	19.74	11.569
200	0.20	26.32	11.648
250	0.25	32.90	11.727
300	0.30	39.47	11.807
350	0.35	46.05	11.889
400	0.40	52.63	11.971
450	0.45	59.20	12.055
500	0.50	65.79	12.140
550	0.55	72.37	12.226
600	0.60	78.95	12.313
650	0.65	85.53	12.402
700	0.70	92.11	12.558
750	0.75	98.68	12.675
800	0.80	105.26	12.769
850	0.85	111.84	12.865
900	0.90	118.42	12.961
950	0.95	125.00	13.060
1000	1.00	131.58	13.159

20	0.040	35.00	45	0.09	78.84	50	0.100	87.60
33	0.066	57.43	64	0.128	111.38	70	0.140	121.82
43	0.086	74.43	79	0.158	136.57	82	0.164	141.76
55	0.110	94.44	92	0.184	157.97	91	0.182	156.25
64	0.128	109.15	108	0.216	184.19	111	0.222	189.31
76	0.152	128.74	120	0.240	203.27	125	0.250	211.74
84	0.168	141.31	131	0.262	220.37	145	0.290	243.92
93	0.186	155.39	140	0.280	233.90	161	0.322	268.98
100	0.200	165.91	149	0.298	247.20	182	0.364	301.95
107	0.214	176.28	158	0.316	260.30	200	0.400	329.49
114	0.228	186.49	165	0.330	269.92	226	0.452	369.70
120	0.240	194.92	174	0.348	282.63	239	0.478	388.21
125	0.250	201.58	181	0.362	291.89	255	0.510	411.22
130	0.260	207.04	190	0.380	302.60	269	0.538	428.41
136	0.272	214.00	196	0.392	309.27	280	0.560	441.81
141	0.282	220.85	203	0.406	317.96	286	0.572	447.96
146	0.292	226.97	209	0.418	324.91	290	0.580	450.84
151	0.302	233..01	215	0.430	331.76	295	0.592	456.75
155	0.310	237.37	221	0.442	338.44	299	0.598	457.89
158	0.317	241.05	226	0.452	343.49	302	0.604	459.00

1050	1.05	138.16	13.261	158	0.317	239.05	230	0.460	347.42	305	0.610	460.12
1100	1.10	144.74	13.363				232	0.464	350.00	305	0.610	456.50
1150	1.15	151.32	13.468				232	0.464	343.35			
1200	1.20	157.90	13.574									
1250	1.25	164.47										
1300	1.30											
1350	1.35											
1400	1.40											

Table 7: Data for Soil Metal Friction Properties

Surface areas of sledge = 0.006m^2

Tool Surface Treatment	Normal Load (N)	Normal Stress (kN/m^2)	Moisture Content (wb)%	Spring Balance reading (N)	Tangential Resistance/ Unit Area (KN/m^2)	Apparent Coefficient of Friction U
T_1	5.0	0.83	0.4	-	-	-
	7.5	1.25	0.4	-	-	-
	10.0	1.67	0.4	-	-	-
	15.5	2.58	0.4	2.2	0.37	0.14
	20.0	3.33	0.4	3.2	0.53	0.16
	27.0	4.50	0.4	3.8	0.63	0.14 (Average = 0.146)
	5.0	0.83	5.8	-	-	-
	7.5	1.25	5.8	-	-	-
	10.0	1.67	5.8	-	-	-
	15.5	2.58	5.8	2.5	0.42	1.06
	20.0	3.33	5.8	3.5	0.58	0.175
	27.0	4.50	5.8	5.0	0.83	0.18 (Average = 0.17
	5.0	0.83	15.46	-	-	-
	7.5	1.25	15.46	-	-	-
	10.0	1.67	15.46	2.5	0.42	0.25
	15.5	2.58	15.46	3.2	0.53	0.21
	20.0	3.33	15.46	4.2	0.70	0.21
	27.0	4.50	15.46	5.5	0.92	0.20 (Average= 0.2175)
	5.0	0.83	16.75	2.0	0.33	0.4
	7.5	1.25	16.75	2.5	0.41	0.33
	10.0	1.67	16.75	4.00	0.67	0.40
	15.50	2.58	16.75	5.00	0.83	0.32
	20.00	3.33	16.75	6.00	1.00	0.30

	27.00	4.50	16.75	10.00	1.70	0.37(Average = 0.35)
	5.0	0.83	18.75	-	-	-
	7.5	1.25	18.75	2.5	0.42	0.33
	10.0	1.67	18.75	3.2	0.53	0.32
	15.5	2.58	18.75	5.0	0.83	0.32
	20.0	3.33	18.75	8.5	1.42	0.43
	27.0	4.50	18.75	10.0	1.67	0.37(Average = 0.35)
	5.00	0.83	19.65	-	-	-
	7.50	1.25	19.65	1.00	0.20	0.13
	10.00	1.67	19.65	2.00	0.33	0.20
	15.50	2.58	19.65	3.40	0.57	0.22
	20.00	3.33	19.65	3.40	0.57	0.17
	27.00	4.50	19.65	4.30	0.72	0.16(Average = 0.17)
T2	5.00	0.83	0.4	-	-	-
	7.50	1.25	0.4	-	-	-
	10.00	1.67	0.4	-	-	-
	15.50	2.58	0.4	2.00	0.33	0.13
	20.00	3.33	0.4	3.20	0.53	0.17
	27.00	4.50	0.4	3.80	0.63	0.14
	5.00	0.83	5.8	-	-	-
	7.50	1.25	5.8	-	-	-
	10.00	1.67	5.8	-	-	-
	15.50	2.58	5.8	1.50	0.25	0.10
	20.00	3.33	5.8	2.80	0.47	0.14
	27.00	4.50	5.8	3.50	0.58	0.13
	5.00	0.83	15.46	-	-	-
	7.50	1.25	15.46	-	-	-
	10.00	1.67	15.46	1.00	0.18	0.11

	15.50	2.58	15.46	2.60	0.43	0.16
	20.00	3.33	15.46	3.00	0.50	0.15
	27.00	4.50	15.46	4.00	0.66	0.15
	5.00	0.83	16.75	-	-	-
	7.50	1.25	16.75	-	-	-
	10.00	1.67	16.75	1.5	0.25	0.15
	15.50	2.58	16.75	2.6	0.44	0.17
	20.00	3.33	16.75	3.50	0.60	0.18
	27.00	4.50	16.75	5.00	0.86	0.19(Average = 0.17)
	5.00	0.83	18.75	-	-	-
	7.50	1.25	18.75	1.00	0.20	0.26
	10.00	1.67	18.75	1.30	0.21	0.25
	15.50	2.58	18.75	2.20	0.36	0.29
	20.00	3.33	18.75	2.60	0.43	0.27
	27.00	4.50	18.75	3.50	0.56	0.26(Average = 0.146)
	5.00	0.83	19.65	-	-	-
	7.50	1.25	19.65	0.75	0.08	0.10
	10.00	1.67	19.65	1.00	0.23	0.10
	15.50	2.58	19.65	1.40	0.25	0.11
	20.00	3.33	19.65	1.50	0.29	0.08
	27.00	4.50	19.65	1.80	0.30	0.06(Average= 0.09)
T3	5.00	0.83	0.4	-	-	-
	7.50	1.25	0.4	2.00	0.33	0.26
	10.00	1.67	0.4	3.50	0.58	0.35
	15.50	2.58	0.4	4.65	0.77	0.30
	20.00	3.33	0.4	6.00	1.00	0.30
	27.00	4.50	0.4	8.00	1.30	0.30(Average = 0.30)
	5.00	0.83	5.8	-	-	-

7.50	1.25	5.8	-	-	-
10.00	1.67	5.8	3.00	0.50	0.30
15.50	2.58	5.8	5.00	0.83	0.32
20.00	3.33	5.8	6.50	1.08	0.33
27.00	4.50	5.8	9.50	1.70	0.35(Average = 0.32)
5.00	0.83	15.46	-	-	-
7.50	1.25	15.46	-	-	-
10.00	1.67	15.46	3.40	0.37	0.34
15.50	2.58	15.46	5.50	0.80	0.35
20.00	3.33	15.46	7.00	0.95	0.35
27.00	4.50	15.46	10.70	1.78	0.40(Average = 0.36)
5.00	0.83	16.75	2.7	0.45	0.54
7.50	1.25	16.75	3.5	0.58	0.47
10.00	1.67	16.75	5.00	0.82	0.49
15.50	2.58	16.75	7.24	1.21	0.47
20.00	3.33	16.75	9.00	1.53	0.45
27.00	4.50	16.75	11.40	1.90	0.42(Average = 0.47)
5.00	0.83	18.75	3.00	0.5	0.60
7.50	1.25	18.75	4.40	0.73	0.58
10.00	1.67	18.75	5.00	0.83	0.51
15.50	2.58	18.75	7.80	1.33	0.51
20.00	3.33	18.75	9.80	1.63	0.49
27.00	4.50	18.75	13.00	2.10	0.48(Average = 0.53)
5.00	0.83	19.65	3.00	0.50	0.90
7.50	1.25	19.65	4.00	0.67	0.53
10.00	1.67	19.65	5.00	0.83	0.50
15.50	2.58	19.65	5.40	0.92	0.35
20.00	3.33	19.65	5.50	0.96	0.27
27.00	4.50	19.65	6.00	1.00	0.22(Average = 0.37)

Table 9: **Disk Blade Geometry**

	Diameter (cm)	Concavity (cm)	Edge Thickness Thickness	Weight (kg)	Surface Treatment
Disc I	58.80 cm	7.4	2.85	37.56	Normal
Disc II	58.75 cm	7.4	2.82	38.03	Normal
Disc III	58.60 cm	7.35	2.78	37.97	Corroded
Disc IV	58.88 cm	7.4	2.86	38.26	Corroded
Disc V	58.60 cm	7.4	2.85	38.12	Painted
Disc VI	59.00 cm	7.5	2.75	37.94	Painted
Average	58.77 cm	7.41	2.82	37.98	
Standard Deviation				0.25	
All the blades are of the same radius of curvature			=	56.2 cm	

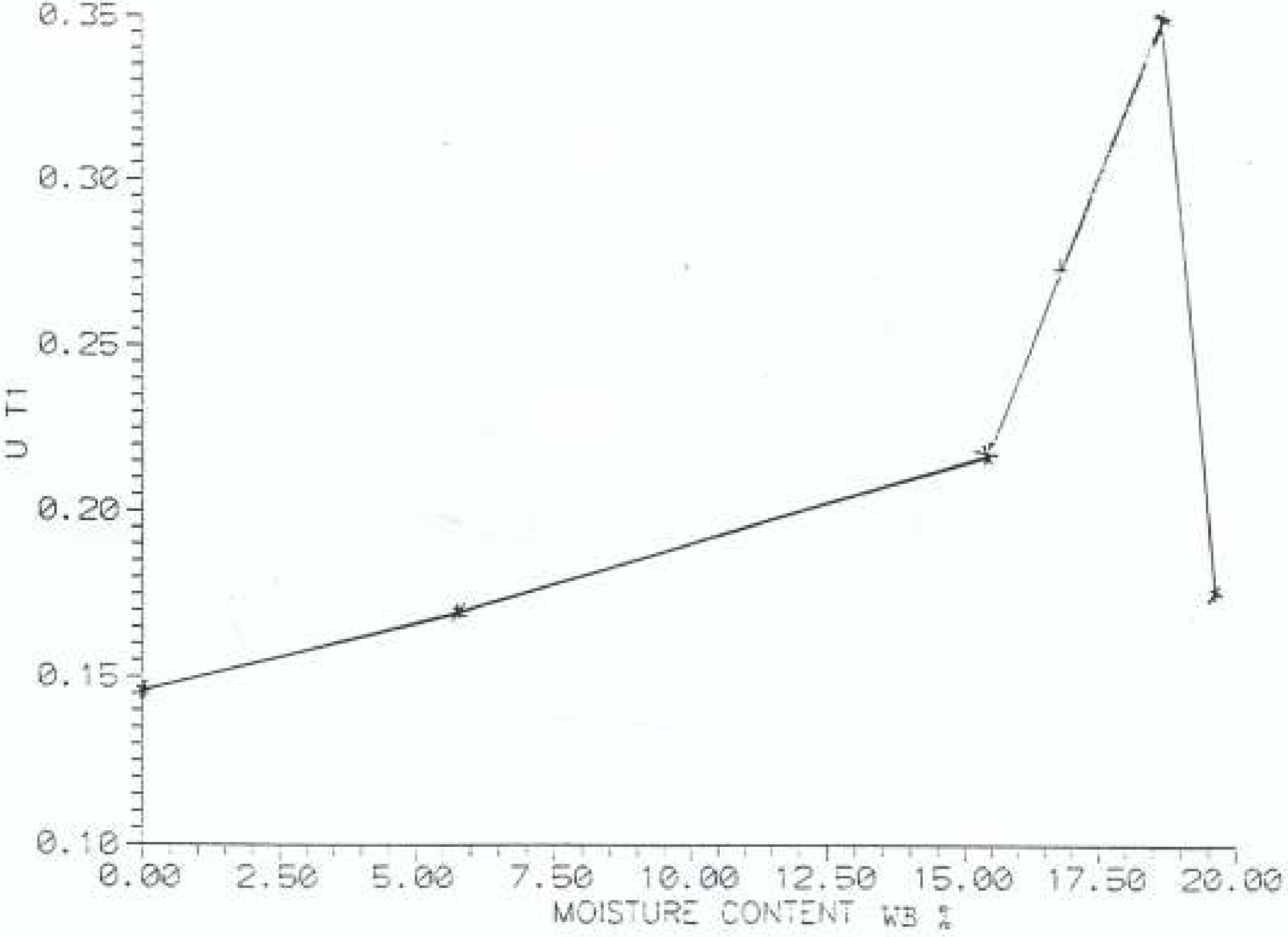


FIGURE 35 : GRAPH OF u (APPARENT COEFFICIENT OF FRICTION AGAINST MOISTURE CONTENT = W.B FOR SURFACE T1

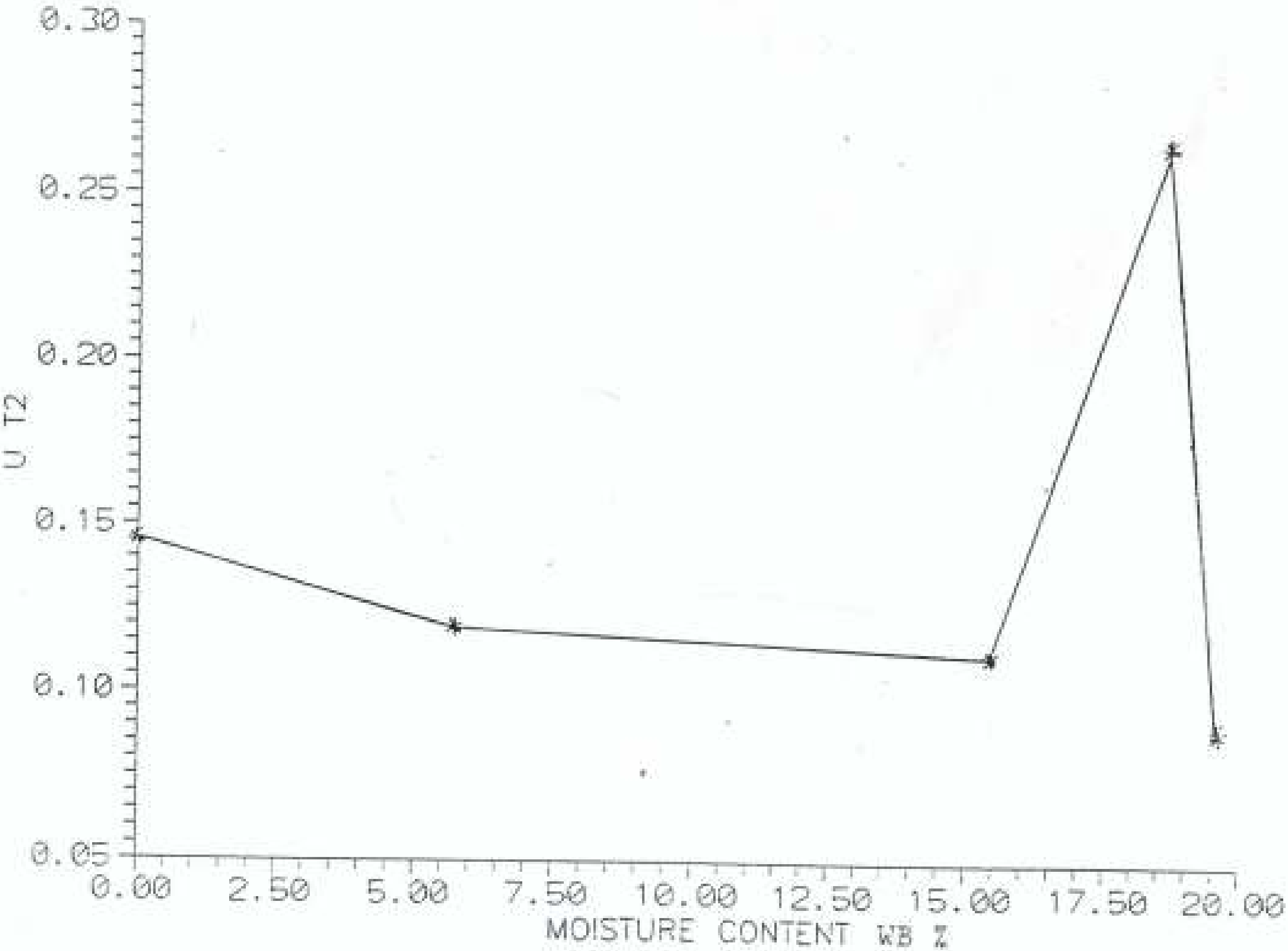


FIGURE 34: GRAPH OF U (APPARENT COEFFICIENT OF FRICTION AGAINST MOISTURE CONTENT = W.B FOR SURFACE T2

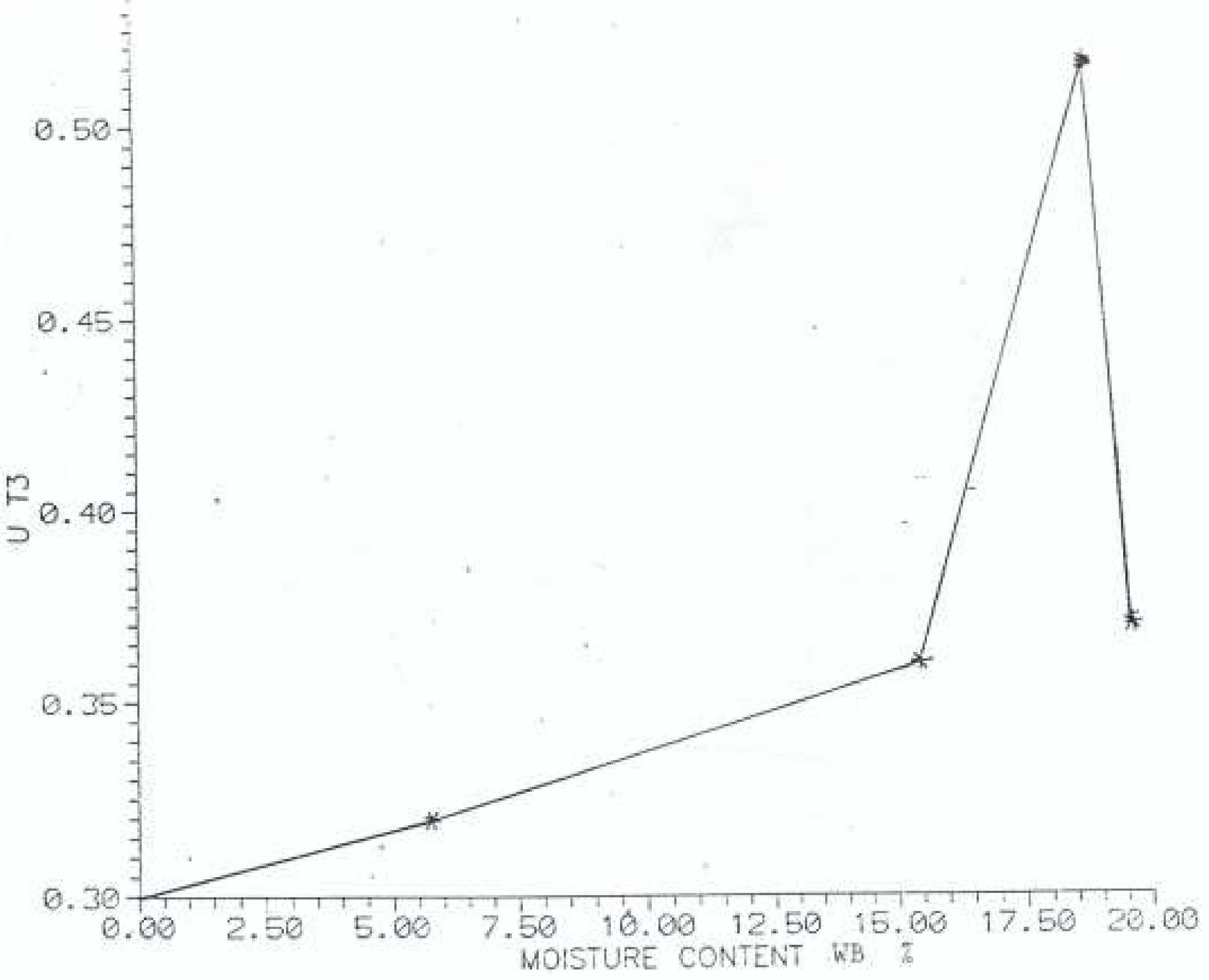


FIGURE 35: GRAPH OF U (APPARENT COEFFICIENT OF FRICTION) AGAINST MOISTURE CONTENT % W.B FOR SURFACE T3

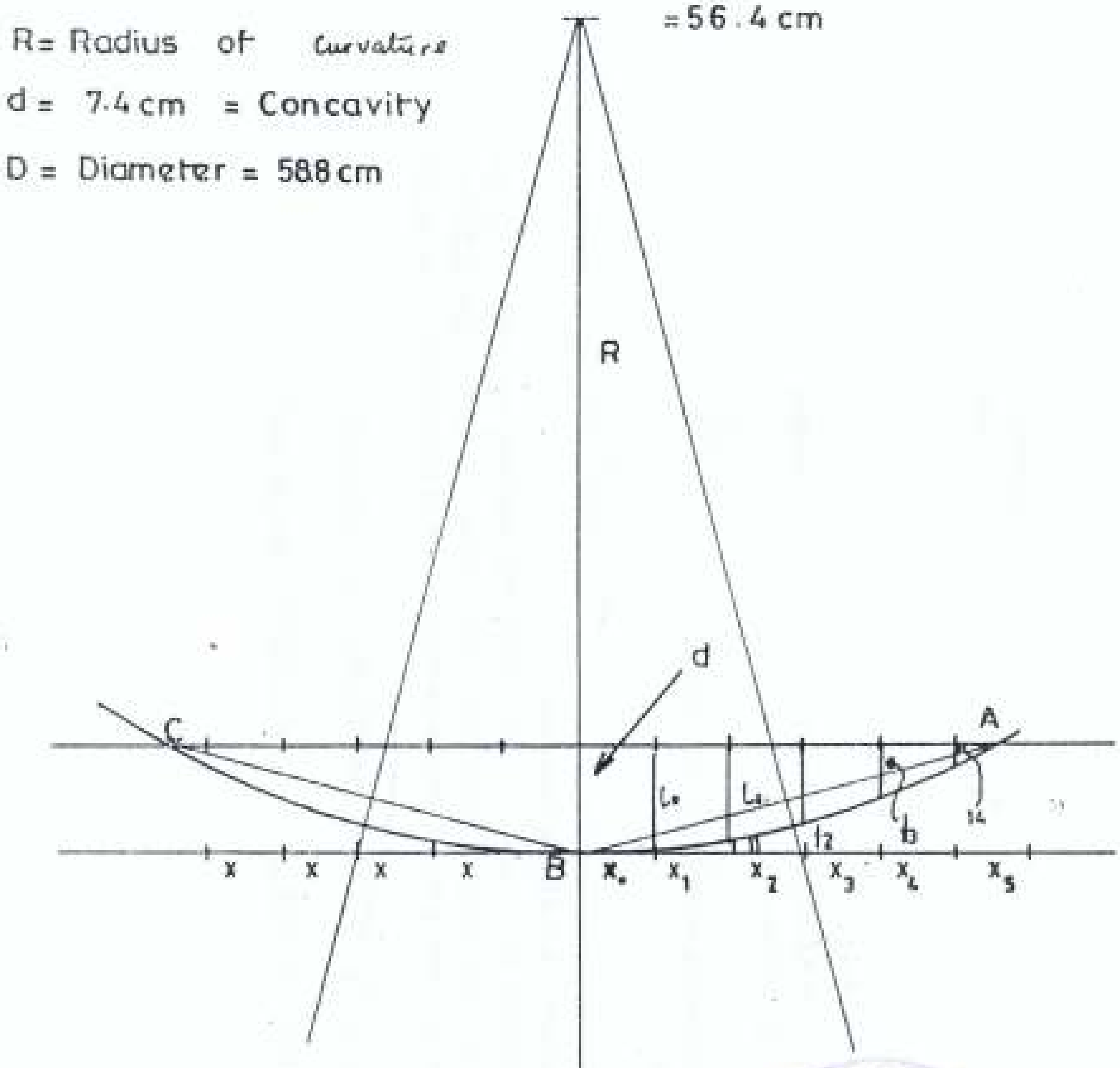


FIGURE 36 : DETERMINATION OF THE DISK RADIUS OF CURVATU

APPENDIX 3

Draught requirement of the tillage trials (Table 9 - 10)

Table 5 : **Determination of Average Spring Rate, K_s**

Weight	Spring	Extension		K	(kg/cm)	k3	Mean
(kg)	X1	X2	X3	K1	K2	K3	
29	0.32	0.31	0.31	90.61	93.55	93.55	92.57
40	0.46	0.45	0.43	87.00	88.89	93.02	89.64
52	0.61	0.57	0.58	85.25	91.23	89.66	88.82
58	0.64	0.67	0.65	90.63	86.57	89.25	88.81
69	0.74	0.77	0.78	93.24	89.61	88.46	90.44
81	0.85	0.91	0.92	95.30	89.01	88.04	90.78
92	1.03	1.05	1.03	89.32	87.62	89.32	88.75
104	1.17	1.16	1.16	88.89	89.66	89.66	89.40
110	1.26	1.17	1.17	87.3	94.02	9402	91.78
150	1.69	1.60	1.68	93.75	90.36	89.29	91.13
							90.21

Average Spring Rate k = 90.21kg/cm

Table 10: Data for Draught Requirement

S/N	Treatment combination	Spring Extension (cm) with three Replicates					k (kg/cm)		Pull (kN)
			R1	R2	R3	Average			
1	$T_1\theta_1S_1$	Tractor only	1.90	2.05	2.05	2.00	90.21		1.77
		Tractor, plough + soil	6.95	7.30	7.05	7.10	90.21		6.27
		Plough + soil	-	-	-	-	90.21		4.51
2	$T_1\theta_1S_2$	Tractor only	2.00	2.20	1.95	2.05	90.21		1.81
		Tractor, plough +soil	7.50	7.90	7.85	7.75	90.21		6.86
		Plough + Soil	-	-	-	-	90.21		5.05
3	$T_1\theta_1S_3$	Tractor only	2.25	2.00	2.00	2.08	90.21		1.84
		Tractor, plough +soil	8.00	7.85	8.60	8.15	90.21		7.21
		Plough + Soil	-	-	-	-	90.21		5.37
4	$T_1\theta_1S_4$	Tractor only	2.30	2.20	2.00	2.16	90.21		1.91
		Tractor, Plough +soil	9.30	9.40	9.05	9.25	90.21		8.18
		Plough + Soil	-	-	-	-	90.21		6.27
5	$T_1\theta_2S_1$	Tractor only	1.90	2.05	2.05	2.00	90.21		1.77
		Tractor, Plough + soil	7.50	8.00	6.52	7.34	90.21		6.50
		Plough + Soil	-	-	-	-	90.21		4.73
6	$T_1\theta_2S_2$	Tractor only	2.00	2.20	1.95	2.05	90.21		1.81
		Tractor, Plough + soil	8.40	8.50	9.00	8.63	90.21		7.61
		Plough + Soil	-	-	-	-	90.21		5.83
7	$T_1\theta_2S_3$	Tractor only		2.25	2.00	2.00	2.08	90.21	1.84

		Tractor, Plough + soil	10.00	9.00	10.00	9.65	90.21	8.54
		Plough + Soil	-	-	-	-	90.21	6.70
8	$T_1\theta_2S_4$	Tractor only	2.30	2.20	2.00	2.16	90.21	1.91
		Tractor, Plough + soil	11.00	9.50	10.58	10.36	90.21	9.17
		Plough + Soil	-	-	-	-	90.21	7.26
9	$T_2\theta_1S_1$	Tractor only	1.90	2.05	2.05	2.00	90.21	0.77
		Tractor, Plough	6.00	7.00	6.20	6.40	90.21	5.66
		Plough + Soil	-	-	-	-	90.21	3.89
		+ soil						
10	$T_2\theta_1S_2$	Tractor only	2.00	2.20	1.95	2.05	90.21	1.81
		Tractor, Plough + soil	7.00	6.90	7.25	7.05	90.21	6.24
		Plough + Soil	-	-	-	-	90.21	4.43
11	$T_2\theta_1S_3$	Tractor only	2.15	2.10	2.10	2.08	90.21	1.84
		Tractor, Plough + soil	7.50	8.00	7.40	7.62	90.21	6.74
		Plough + Soil	-	-	-	-	90.21	4.90
12	$T_2\theta_1S_4$	Tractor only	2.30	2.20	2.00	2.16	90.21	1.91
		Tractor, Plough + Soil	8.50	7.90	8.85	8.14	90.21	7.44
		Plough + Soil	-	-	-	-	90.21	5.53
13	$T_2\theta_2S_1$	Tractor only	1.90	2.05	2.05	2.00	90.21	1.77
		Tractor, Plough + Soil	7.25	7.00	7.75	7.30	90.21	6.46
		Plough + Soil	-	-	-	-	90.21	6.69
14	$T_2\theta_2S_2$	Tractor only	2.00	2.20	1.95	2.05	90.21	1.81
		Tractor, Plough + Soil	7.90	7.5	8.00	7.80	90.21	7
		Plough + Soil	-	-	-	-	90.21	5.45
15	$T_2\theta_2S_3$	Tractor only	2.25	2.00	2.00	2.08	90.21	1.84

		Tractor, Plough + Soil	8.50	8.90	8.40	8.60	90.21	7.60
		Plough + Soil	-	-	-	-	90.21	5.76
16	$T_2\theta_2S_4$	Tractor only	2.30	2.20	2.00	2.16	90.21	1.91
		Tractor, Plough + Soil	9.00	9.60	9.30	9.30	90.21	8.21
		Plough + Soil -	-	-	-	90.21	6.33	
17	$T_3\theta_1S_1$	Tractor only	1.90	2.05	2.05	2.00	90.21	1.77
		Tractor, Plough + Soil	8.75	8.50	8.25	8.50	90.21	7.53
		Plough + Soil	-	-	-	-	90.21	5.76
18	$T_3\theta_1S_2$	Tractor only	2.00	2.20	1.95	2.05	90.21	1.81
		Tractor, Plough + Soil	8.65	9.00	8.85	8.83	90.21	7.81
		Plough + Soil	-	-	-	-	90.21	6.00
19	$T_3\theta_1S_3$	Tractor only	2.25	2.00	2.00	2.08	90.21	1.84
		Tractor, Plough + Soil	9.50	10.00	8.40	9.30	90.21	8.24
		Plough + Soil	-	-	-	-	90.21	6.40
20	$T_3\theta_1S_4$	Tractor only	2.30	2.20	2.00	2.16	90.21	1.91
		Tractor, Plough + Soil	11.00	9.50	11.00	10.50	90.21	9.28
		Plough + Soil	-	-	-	-	90.21	7.37
21	T3θ2S1	Tractor only	1.90	2.05	2.05	2.00	90.21	1.77
		Tractor, Plough + Soil	9.00	7.90	10.00	8.92	90.21	7.89
		Plough + Soil	-	-	-	-	90.21	6.12
22	$T_3\theta_2S_2$	Tractor only	2.00	2.20	1.95	2.05	90.21	1.81
		Tractor, Plough + Soil	9.00	9.85	10.00	9.62	90.21	8.51
		Plough + Soil	-	-	-	-	90.21	6.70
23	$T_3\theta_2S_3$	Tractor only	2.15	2.10	2.10	2.08	90.21	1.84
		Tractor, Plough + Soil	8.50	9.00	12.50	10.02	90.21	8.87
		Plough + Soil	-	-	-	-	90.21	7.03
24	$T_3\theta_2S_4$	Tractor only	2.30	2.20	2.00	2.16	90.21	1.91
		Tractor, Plough + Soil	11.85	12.40	12.05	12.10	90.21	10.71
		Plough + Soil	-	-	-	-	90.21	8.80

APPENDIX 4

Results of final soil tilth measurement (Tables 11-12 and figure 37)

Table 11 : Data for MWD (Mean Weight Diameter)

Treatment Combination	size of seizes (mm)	D^0=Largest diameter(s) of clod retained on each seize with the mass (m) of all soil in the seize						Mean Valu
	D_i	R_1		R_2		R_3		
		D_0	M(g)	D_0	M(g)	D_0	M(g)	
$T_1\theta_1S_1$	>19	-	-	-	-	-	-	
	19-6.70	1.8	120	16	20	14	60	
	6.70-4.75	5.6	46	6.6	63	6.6	60	
	4.75-2.36	4.5	104	4.6	111	4.5	115	
	2.36-1.18	2.1	224	2.1	240	2.3	226	
	1.18-0.425	0.9	294	1.15	208	1.08	260	
	0.425-0.212	0.4	118	0.4	149	0.4	138	
	0.212-0.075	0.2	60	0.2	143	0.2	61	
	0.075-0.00	0.07	34	0.07	11	0.07	75	2.23
$T_1\theta_1S_2$	>19	-	-	-	-	-	-	
	19-6.70	13.0	61	17	60	13	80	
	6.70-4.75	6.0	24	6.2	22	6.3	10	
	4.75-2.36	4.45	129	4.55	174	4.60	115	
	2.36-1.18	1.35	246	1.20	214	1.20	238	
	1.18-0.475	1.03	302	1.1	288	1.0	342	
	0.475-0.212	0.35	126	0.35	122	0.30	98	
	0.212-0.075	0.40	71	0.2	60	0.2	75	
	0.075-0.00	0.07	41	0.07	60	0.07	42	2.06
$T_1\theta_2S_1$	>19	-	-	-	-	-	-	
	19-6.70	9.8	34	10.05	61	13.20	33	
	6.70-4.75	5.8	35	5.61	24	5.25	83	
	4.75-2.36	3.8	244	4.05	129	4.30	156	

	2.36-1.18	1.45	107	1.85	246	1.90	267	
	1.18-0.425	0.85	325	0.90	302	0.83	232	
	0.425-0.212	0.4	149	0.4	126	0.35	124	
	0.212-0.075	0.14	79	0.14	71	0.14	52	
	0.075-pan	0.04	35	0.04	41	0.04	53	1.82
T_1Q_1S4	>19	-	-	-	-	-	-	
	19-6.70	10.85	73	13.20	22	9.0	84	
	6.70-4.75	5.70	41	5.80	19	5.50	83	
	4.75-2.36	37	165	3.65	89	3.5	165	
	2.36-1.18	1.75	202	1.35	160	1.80	143	
	1.18-0.425	0.76	277	0.90	299	0.90	251	
	0.425-0.212	0.4	133	0.37	262	0.35	170	
	0.212-0.075	0.14	75	0.14	18	0.14	58	
	0.075-pan	0.04	34	0.04	49	0.04	56	
								1.64
$T_1Q_2S_1$	>19	24	50	22	45	26	55	
	19-6.70	16	112	12.35	67	14.50	22	
	6.70-4.75	6.0	45	6.63	64	6.50	83	
	4.75-2.36	4.6	107	4.2	120	4.0	133	
	2.36-1.18	2.2	220	2.3	226	2.0	232	
	1.18-0425	1.15	275	1.0	277	1.1	243	
	0.425-0.212	0.41	134	0.40	140	0.38	118	
	0.212-0.075	0.2	64	0.2	55	0.2	68	
	0.075-pan	0.07	38	0.04	20	0.07	48	3.17
$T_1Q_2S_2$	>19	-	-	-	-	-	-	
	19-6.70	13.20	61	15	102	16.8	122	
	6.70-4.75	6.25	155	6.65	98	6.60	107	
	4.75-2.36	4.50	80	4.7	186	4.6	124	
	2.36-1.18	2.00	255	2.35	305	2.25	253	

	1.18-0425	1.05	220	1.15	216	1.10	254	
	0.425-0.212	0.42	035	0.42	037	0.42	24	
	0.212-0.075	0.14	134	0.14	34	0.14	78	
	0.075-pan	0.07	60	0.07	22	0.07	38	2.83
$T_1\theta_{12}S_3$	>19	-	-	-	-	-	-	
	19-6.70	17	93	13	118	11	164	
	6.70-4.75	6.5	68	5.9	145	50	94	
	4.75-2.36	3.9	124	4.0	108	2.6	146	
	2.36-1.18	2.2	187	2.1	149	1.85	245	
	1.18-0425	7.05	200	1.10	165	0.85	104	
	0.425-0.212	0.42	200	0.42	185	0.35	162	
	0.212-0.075	0.2	94	0.14	82	0.2	43	
	0.075-pan	0.07	34	0.07	18	0.07	42	2.47
$T_1\theta_2S_4$	>19	-	-	-	-	-	-	
	19-6.70	10.85	160	9.5	111	11.5	75	
	6.70-4.75	5.5	64	5.7	82	5.8	142	
	4.75-2.36	3.7	101	3.0	95	4.0	120	
	2.36-1.18	2.0	152	1.9	167	2.1	121	
	1.18-0425	0.9	285	0.9	170	1.1	181	
	0.425-0.212	0.4	124	0.37	192	0.37	144	
	0.212-0.075	0.14	74	0.2	145	0.14	92	
	0.075-pan	0.07	42	0.04	38	0.07	34	2.3
$T_2\theta_1S_1$	>19	20	8	19	7	19	6	
	19-6.70	12	78	9.0	36.00	12.6	45	
	6.70-4.75	5.81	46	56.3	8.00	6.0	75	
	4.75-2.36	4.45	107	4.30	86	3.8	42	
	2.36-1.18	1.75	184	1.76	220	2.20	283	
	1.18-0425	0.85	237	1.10	284	0.83	197	
	0.425-0.212	0.4	186	0.40	157	0.38	190	

	0.212-0.075	0.14	118	0.14	133	0.14	127	
	0.075-pan	0.07	46	0.07	69	0.07	35	
	MWD	1.99		1.35		1.75		1.7
$T_2\theta_1S_2$	>19	-	-	-	-	-	-	
	19-6.70	16	44	11	62	9	38	
	6.70-4.75	5	45	6.7	40	5.7	60	
	4.75-2.36	4.3	125	4.6	150	4.6	61	
	2.36-1.18	2.1	210	2.0	103	1.75	233	
	1.18-0425	0.90	270	1.1	115	1.0	275	
	0.425-0.212	0.4	195	0.4	298	0.4	110	
	0.212-0.075	0.2	30	0.2	155	0.2	176	
	0.075-pan	0.04	81	0.04	77	0.04	46	
	MWD	1.72		1.67		1.54		1.64
$T_2\theta_1S_3$	>19	-	-	-	-	-	-	
	19-6.70	11	60	10.5	22	9	84	
	6.70-4.75	5.7	45	5.5	41	6.2	62	
	4.75-2.36	3.6	140	3.7	165	4.0	122	
	2.36-1.18	1.65	167	1.30	202	1.90	104	
	1.18-0425	0.85	275	0.76	299	0.54	251	
	0.425-0.212	0.37	188	0.4	262	0.4	230	
	0.212-0.075	0.14	50	0.14	75	0.14	122	
	0.075-pan	0.07	75	0.07	48	0.07	25	
	MWD	1.66		1.53		1.75		1.65
$T_2\theta_1S_4$	>19	-	-	-	-	-	-	
	19-6.70	10	21	8.5	60	7.0	43	
	6.70-4.75	6.6	38	5.6	40	5.8	27	
	4.75-2.36	2.9	67	3.0	89	3.8	75	
	2.36-1.18	1.8	87	2.0	57	1.8	268	
	1.18-0425	0.9	296	1.1	324	0.76	207	

	0.425-0.212	0.3	276	0.3	346	0.3	288	
	0.212-0.075	0.14	177	0.14	58	0.14	63	
	0.075-pan	0.07	38	0.07	26	0.07	39	
	MWD	0.98		1.34		1.45		1.20
$T_2\Theta_2S_1$	>19	-	-	-	-	-	-	
	19-6.70	14	229	16	121	9.9	41	
	6.70-4.75	6.0	59	6.0	77	6.01	137	
	4.75-2.36	4.5	105	4.6	132	4.3	98	
	2.36-1.18	2.1	101	2.0	143	1.8	165	
	1.18-0425	0.9	157	1.1	261	0.84	197	
	0.425-0.212	0.4	258	0.4	189	0.38	223	
	0.212-0.075	0.2	71	0.2	56	0.14	102	
	0.075-pan	0.07	20	0.07	21	0.07	37	
	MWD	3.41		2.94		1.85		2.73
$T_2\Theta_2S_2$	>19	-	-	-	-	-	-	
	19-6.70	10.6	115	15	130	7.4	100	
	6.70-4.75	5.9	96	6.3	92	5.8	105	
	4.75-2.36	3.6	120	2.9	90	4.0	192	
	2.36-1.18	2.0	177	1.8	156	2.2	192	
	1.18-0425	1.16	212	1.14	261	1.15	172	
	0.425-0.212	0.38	103	0.41	89	0.41	108	
	0.212-0.075	0.19	87	0.21	113	0.2	100	
	0.075-pan	0.06	90	0.03	69	0.03	108	
	MWD	2.43		2.64		2.18		2.30
$T_2\Theta_2S_3$	>19	-	-	-	-	-	-	
	19-6.70	13	79	15	35	12	40	
	6.70-4.75	6.5	57	5.4	34	5.5	67	
	4.75-2.36	4.6	247	4.2	224	3.8	140	
	2.36-1.18	1.9	235	2.2	325	2.0	277	

	1.18-0425	1.1	122	0.8	117	0.9	226	
	0.425-0.212	0.4	152	0.4	149	0.4	120	
	0.212-0.075	0.2	60	0.2	79	0.2	75	
	0.075-pan	0.07	36	0.07	48	0.07	55	
	MWD	2.47		1.97		1.78		2.07
$T_2\theta_2S_4$	>19	-	-	-	-	-	-	
	19-6.70	15	81	14	10	120	52	
	6.70-4.75	6.5	46	5.8	15	6.2	142	
	4.75-2.36	4.0	129	4.2	84	3.9	71	
	2.36-1.18	1.85	256	2.1	210	2.3	248	
	1.18-0425	0.15	177	1.10	288	0.90	264	
	0.425-0.212	0.4	126	0.4	174	0.35	87	
	0.212-0.075	0.2	123	0.14	137	0.2	80	
	0.075-pan	0.07	62	0.07	82	0.07	56	
	MWD	2.12		1.12		2.25		1.79
$T_1\theta_1S_1$	>19	19	34	20	23	21	12	
	19-6.70	14	62	18	244	16	93	
	6.70-4.75	6.5	54	6.6	87	6.4	101	
	4.75-2.36	4.7	120	4.4	122	4.3	170	
	2.36-1.18	2.3	226	2.1	147	2.3	145	
	1.18-0425	1.1	97	1.1	168	0.8	140	
	0.425-0.212	0.4	200	0.35	97	0.38	123	
	0.212-0.075	0.2	189	0.14	78	0.14	145	
	0.075-pan	0.07	31	0.07	34	0.07	43	
	MWD	2.57		4.77		2.82		3.39
$T_1\theta_1S_2$	>19	-	-	-	-	-	-	
	19-6.70	16	175	18	112	14	81	
	6.70-4.75	4.9	83	5.6	145	6.4	64	
	4.75-2.36	3.0	120	3.5	184	4.0	105	

	2.36-1.18	2.0	152	1.9	187	2.1	226	
	1.18-0425	1.1	289	0.9	162	0.9	238	
	0.425-0.212	0.4	75	0.35	121	0.38	131	
	0.212-0.075	0.2	62	0.2	55	0.2	127	
	0.075-pan	0.07	42	0.07	34	0.07	38	
	MWD	3.78		3.08		3.12		3.33
$T_3\theta_1S_3$	>19	-	-	-	-	-	-	
	19-6.70	12	175	17	123	16	143	
	6.70-4.75	6.6	106	6.65	105	6.65	104	
	4.75-2.36	4.7	119	4.5	130	4.3	121	
	2.36-1.18	1.9	142	2.1	150	2.3	141	
	1.18-0425	1.15	279	1.1	250	1.05	221	
	0.425-0.212	0.4	106	0.4	71	0.4	119	
	0.212-0.075	0.2	38	0.2	102	0.2	96	
	0.075-pan	0.07	45	0.07	68	0.07	55	
	MWD	3.21		2.98		3.08		3.09
$T_3\theta_1S_4$	>19	-	-	-	-	-	-	
	19-6.70	18	41	16	141	15	118	
	6.70-4.75	5.8	101	6.2	127	5.6	49	
	4.75-2.36	4.0	99	3.6	132	4.2	179	
	2.36-1.18	2.2	226	1.8	247	1.5	248	
	1.18-0425	1.1	234	1.1	140	1.1	234	
	0.425-0.212	0.39	159	0.39	156	0.39	22	
	0.212-0.075	0.14	100	0.14	45	0.14	56	
	0.075-pan	0.07	45	0.07	12	0.07	20	
	MWD	2.03		3.25		2.64		2.64
$T_3\theta_2S_1$	>19	23	55	25	30	27	40	
	19-6.70	18	253	18	117	18	240	
	6.70-4.75	5.0	148	56	196	6.0	175	

	4.75-2.36	4.5	106	4.5	154	4.5	157	
	2.36-1.18	2.2	183	2.1	194	2.2	053	
	1.18-0425	1.1	158	1.1	103	1.1	168	
	0.425-0.212	0.38	460	0.4	152	0.4	100	
	0.212-0.075	0.2	64	0.2	40	0.2	35	
	0.075-pan	0.07	27	0.07	14	0.07	35	
	MWD	5.94		4.32		5.62		5.29
$T_1\theta_1S_2$	>19	27	64	28	22	26	34	
	19-6.70	18	196	17	240	17	233	
	6.70-4.75	6.5	162	5.0	148	4.8	128	
	4.75-2.36	4.7	97	4.5	90	4.3	134	
	2.36-1.18	2.3	206	0.9	300	2.15	274	
	1.18-0425	1.15	168	0.175	107	1.175	154	
	0.425-0.212	0.4	45	0.4	60	0.4	21	
	0.212-0.075	0.2	35	0.2	30	0.2	10	
	0.075-pan	0.07	27	0.07	12	0.07	12	
	MWD	4.07		4.41		4.06		4.4
$T_1\theta_2S_3$	>19	20	93	23	23	-	-	
	19-6.70	17	166	18	168	16	198	
	6.70-4.75	6.1	152	6.5	87	6.6	75	
	4.75-2.36	4.7	93	4.5	122	4.7	158	
	2.36-1.18	2.2	148	2.1	147	2.0	234	
	1.18-0425	1.1	151	1.1	168	1.1	241	
	0.425-0.212	0.4	83	0.4	88	0.35	104	
	0.212-0.075	0.2	82	0.14	61	0.14	67	
	0.075-pan	0.07	27	0.07	36	0.07	23	
	MWD	5.36		3.89		3.89		4.38

$T_1e_2S_1$	>19	27	40	-	-	23	23	
	19-6.70	19	155	14	139	16	258	
	6.70-4.75	6.6	80	6.6	135	6.6	87	
	4.75-2.36	4.7	104	4.7	110	4.7	122	
	2.36-1.18	2.2	120	1.8	2.9	1.7	147	
	1.18-0425	1.1	255	1.1	203	1.1	168	
	0.425-0.212	0.4	85	0.4	86	0.4	88	
	0.212-0.075	0.14	116	0.14	89	0.14	70	
	0.075-pan	0.07	45	0.07	29	0.07	37	
	MWD		4.21		3.09		4.71	4.00

Table 12: Determination of Percentage of Water Stable Aggregates of the Experimental Site

Soil Sample	Weight of Aggregates > 0.425 mm Diameter in three replicates				Total Weight of Soil Used (gm)	WSA %
	R1 (gm)	R2 (gm)	R3 (gm)	Mean (gm)		
T1Θ1S1	21.00	20.25	18.10	19.80	50	39.6
T1Θ1S2	21.00	22.00	22.00	21.67	50	43.24
T1Θ1S3	22.00	27.00	22.00	23.67	50	47.34
T1Θ1S4	19.00	19.00	21.00	19.67	50	39.34
T1Θ2S1	20.00	30.00	24.00	24.67	50	49.34
T1Θ2S2	25.00	21.00	22.00	26.67	50	45.34
T1Θ2S3	27.00	26.00	27.00	26.67	50	53.34
T1Θ2S4	19.00	27.00	22.00	22.67	50	45.34
T2Θ1S1	36.00	30.00	24.00	29.00	50	58
T2Θ1S2	23.00	22.00	24.30	23.10	50	46.2
T2Θ1S3	23.00	21.00	22.00	22.00	50	44
T2Θ1S4	20.00	21.00	21.00	20.67	50	41.34
T2Θ2S1	26.00	21.00	25.00	24.00	50	48
T2Θ2S2	21.00	19.50	19.00	19.87	50	39.74
T2Θ2S3	25.00	18.00	20.00	21.00	50	42
T2Θ2S4	20.00	21.00	20.00	20.33	50	40.66
T3Θ1S1	23.00	19.00	20.00	20.67	50	41.34
T3Θ1S2	19.00	22.00	21.00	19.67	50	39.34
T3Θ1S3	23.00	24.00	27.00	24.67	50	49.34
T3Θ1S4	18.00	21.00	25.00	21.33	50	42.66
T3Θ1S1	20.00	22.00	74.00	22.00	50	44
T3Θ2S1	23.00	20.00	23.00	22.33	50	44.66
T3Θ2S2	19.00	21.00	23.00	21.00	50	42
T3Θ2S3	21.00	24.00	20.00	21.67	50	43.24
T3Θ2S4	20.00	19.50	24.00	21.20	50	42.4

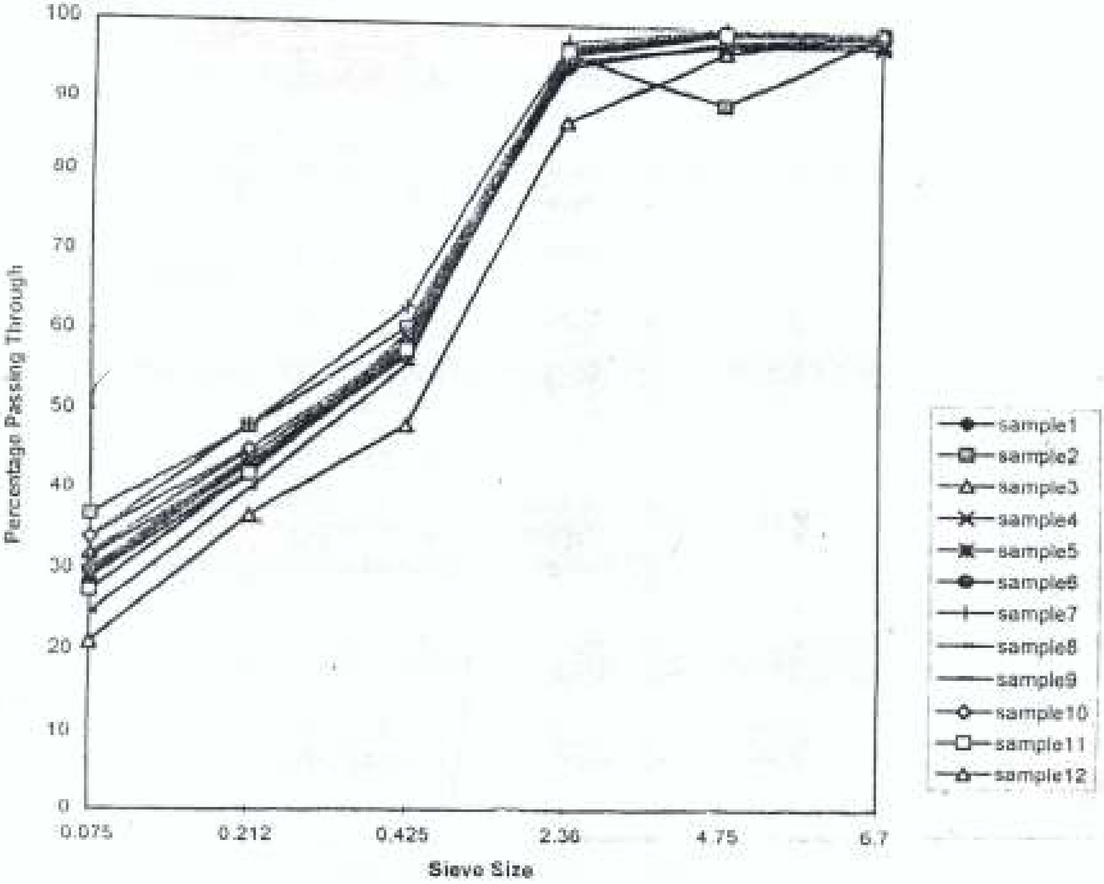


Figure 37: Graph of Soil Particle Size Distribution

APPENDIX 5

Multiple Regression Analysis of Data

R- Square = 0.8332 R-Square Adjusted = 0.7981

Variance of the estimate - Sigma** 2 = 0.47197

Standard error of the estimate-stigmas = 0.68700

Sum of squared errors-see = 8.9675

Mean of dependent variable = 3.4647

Log of the likelihood function = 22.2412

Analysis of Variance - From Mean

	SS	DF	MS	F
Regression	44.796	4.	11.199	23.728
Error	8.9675	19.	0.47197	
Total	53.764	23.	2.3376	

Variable Name	Estimated Coefficient	Standard Error	T-Ratio 19 DF	Partial P-Value Corr.	Standardized Coefficient	Elasticity At Mean
Treatment	0.11029	0.9728E-01	1.134	0.8650.252	0.2324	0.5793

Speed	-1.3320	0.4060	-3.281	0.002-0.601	-0.7258	-0.6763
Tilt	0.15903	0.1110	1.432	0.9160.312	0.2125	0.9180
Draught	1.0180	0.4060	2.507	0.9890.499	0.7724	1.7212
Constant	-1.8786	3.092	-0.6077	0.275-0.138	0.0000	-0.5422

Correlation Matrix of Coefficients

Treatment	1.0000				
Speed	0.80817	1.0000			
Tilt	0.68958	0.69979	1.0000		
Draught	-0.88939	-0.90586	-0.77538	1.0000	
Constant	-0.84654	-0.84120	-0.91741	0.81567	1.0000

Residual sum = -0.40301E-13 Residual Variance = 0.47197

R-Square between observed and predicted = 0.8332

APPENDIX 6

(ONE WAY ANALYSIS OF VARIANCE)

between

Variable DRT DRAUGHT (KN)
By Variable TRT TREATMENT

Analysis of Variance

Source	D.F.	Sum of squares	Mean squares	F Ratio	F Prob.
Between groups	42	15.486	3.875	5.359	.0326
Within groups	19	13.730	0.7224		
Total	23	29.216			

One way

Variable DRT DRAUGHT (IN)
By Variable TRT TREATMENT

Multiple Range Test

LSD Procedure

Ranges for the .050 level - 3.01 3.01

The ranges above are table ranges.

The value actually compared with mean (J)- Mean(I) is ...

.7286 *Range * Sqrt (1/N(I) + 1/N(J)

(*) Denotes pairs of groups significantly different at the .050 level

Mean	Group	TREAT 2	TREAT 1	TREAT 3
5.715	TREAT 2			
5.10	TREAT 1			
6.78	TREAT 3	*		

Homogeneous subsets (subjects of groups, whose highest and lowest means do not differ by more than the shortest significant range for a subset of that size)

SUBSET 1

Group	TREAT 2	TREAT 1
Mean	5.715	5.100

SUBSET 2

Group	TREAT 1	TREAT 3
Mean	5.1000	6.7800

APPENDIX 7

(ONE WAY ANALYSIS OF VARIANCE)

between

Variable MWD (MWD)
By variable TRT TREATMENT

Source	D.F.	Sum of Squares	Analysis of Variance Mean Squares	F Ratio	F prob
Between Groups	42	49.9769	12.4912	13.0716	.0005
Within Groups	19	3.82	0.955		
Total	23	53.7969			

<u>One Way</u>

Variable MWD MWD (mm)

By Variable TRT TREATMENT

Multiple Range Test

LSD procedure

Ranges for the .050 level - 3.01 3.01

The ranges above are table ranges.

The value actually compared with Mean(J)-Mean(I) is ...

.6880 * Range* Sqrt(1/N(I) + 1/N(J))

```
(*) Denotes pairs of groups significantly different at the .050 level

                              T       T       T

                              R       R       R

                              E       E       E

                              A       A       A

                              T       T       T

                              2       1       3

Mean    Group

2.375   TREAT  2

2.875   TREAT  1

5.1425  TREAT  3              *       *

Homogenous Subsets                    (subsets of groups, whose highest and lowest means do

                                      not differ by more than the shortest significant range for

                                      a subset of that size)

SUBSET         1

Group          TREAT  2       TREAT  1

Mean           2.375          2.875

SUBSET         2

Group          TREAT  3

Mean           5.1425
```

Appendix 8:

Analysis of Variance for the three factors factorial Experiments.

The experimental is a 3 x 4 x 2 factorial experiment design. The model for the experiment is YyKl = mi + Ai + Bj + (ABij + Ck + (AC)ik + (BC) jkl (ABC)ijk + Fijkl

where Yijkl = Individual observation

N = General mean

Ai = Effect of factor A

Bj = Effect of factor B

(AB) ij = Effect of Interaction AB

Ck = Effect of factor C

(Al)ik = Effect of Interaction AC

(ABC) jk = Effect of Interaction BC

(ABC) ijk = Effect of Interaction ABC

Eijkl = Experimental Error.

The Hypothesis

The hypothesis to be tested are those for the main effects, the first order and the second order interaction.

For factor A

H_0: The effect of factor A is not significant

H_A The effect of factor A is significant.

For factor B

H_0: The effect of factor B is not significant

H_A: The effect of factor B is significant

For factor C

H_0: The effect of factor C is not significant

H_A: The effect of factor C is significant

For Interaction AB

H_0: The effect of factor AB is not significant

H_A: The effect of factor AB is significant

For Interaction AC

H_0: The effect of interaction AC is not significant

H_A: The effect of interaction AC is significant

For Interaction BC

H_0: The effect of interaction BC is not significant

H_A: The effect of interaction BC is significant

For Interaction ABC

H_0: The effect of interactionABC is not significant

H_A: The effect of interaction ABC is significant

The table below contains data representing the MWD (in mm) for an experiment involving three Tool Surface Roughness (factor A), four levels of speed (factor B) and two levels of tilt angle (factor C).

Table 13a-MWD for the 4x3x2 factorial experiment.

	a_1				a_2				a_3			
	b_1	b_2	b_3	b_4	b_1	b_2	b_3	b_4	b_1	b_2	b_3	b_4
C_1	2.68	2.38	2.12	1.86	1.99	1.67	1.53	0.98	2.57	3.21	2.03	3.78
	1.53	1.96	1.67	1.07	1.35	1.54	1.75	1.34	4.77	2.98	3.25	3.08
	2.26	1.82	1.67	2.00	1.75	2.05	1.96	1.27	2.82	3.08	2.64	3.12
C_2	3.60	2.33	2.41	2.52	3.41	2.41	2.47	2.12	5.94	4.07	5.36	4.21
	2.96	3.05	2.72	2.03	2.94	2.64	1.97	1.02	4.32	4.41	3.89	3.09
	2.96	3.12	2.27	2.35	1.85	2.18	1.78	2.25	5.62	4.06	3.89	4.71

Correction factor (CF) is calculated from Table 14a as follows

$$CF = \frac{(\text{Grand total})^2}{rabc} = \frac{(\Sigma x)^2}{rabc} = \frac{(192.46)^2}{3 \times 3 \times 4 \times 2}$$

$$= \frac{37040.85}{72} = 514.46$$

$$\text{SS total} = \Sigma x^2 - cf$$

$$= 599.84 - 514.46$$

$$= 85.38$$

To calculate SS treatment. Table 14b shows the analysis

Table 13b - Analysis for SS treatment calculation.

	a_1				a_2				a_3			
	b_1	b_2	b_3	b_4	b_1	b_2	b_3	b_4	b_1	b_2	b_3	b_4
c_1	6.47	6.16	5.46	4.93	5.09	5.26	5.24	3.59	10.16	9.27	7.92	9.98
c_2	9.52	8.50	7.40	6.90	8.20	7.25	6.22	5.39	15.88	12.54	13.14	12.01
	15.99	14.66	12.86	11.83	13.29	12.51	11.46	8.98	26.04	21.81	21.06	21.99

$$\text{SS treatment} = \frac{\Sigma x^2}{3} - \text{CF}$$

$$\frac{1758.45}{3} - \text{Cf}$$

$= 71.69$

SS error = SS total - SS treatment

= 85.38 - 71.69

13.69

Table13c - A X B

	a_1	a_2	a_3	Total b
b1	15.99	13.29	26.04	55.32
b2	14.66	12.51	21.81	48.98
b3	12.86	11.46	21.06	45.38
b4	11.83	8.98	21.99	42.80
Total a	55.34	46.24	90.90	192.46

$$SSa \quad = \quad \frac{(55.34)^2 + (46.24)^2 + (90.90)^2}{3 \times 4 \times 2} \; - \; Cf$$

$$\frac{13463.46}{24} - Cf$$

$$= \quad 46.52$$

$$SSb \quad = \quad \frac{(55.32)^2 + (48.98)^2 + (45.38)^2 + 42.80)^2}{rac} \; - \; Cf$$

$$\frac{9350.53}{3 \times 3 \times 2} \; - \; Cf$$

$$= \; 5.01$$

$$SS(ab) = \quad \frac{(15.99)^2 + (13.29)^2 \ldots\ldots (21.99)^2}{3 \times 2} \; - \; Cf - SSa - SSb.$$

$$= \frac{3401.86}{6} \; - \; Cf \; - \; SSa - SSb.$$

$$= \quad 52.52 \; - \; 46.52 \; - \; 5.01$$

$$= 0.99$$

Table 13ii - A X C

	a_1	a_2	a_3	Total C
c1	23.02	19.18	37.33	79.53
c2	32.32	27.06	53.57	112.95
Total a	55.34	46.24	90.90	192.46

$$SSc \quad = \quad \frac{(79.53)^2 + (112.95)^2}{3 \times 4 \times 3} \; - \; Cf$$

$$\frac{19082.72}{36} \; - Cf$$

$$= \quad 15.62$$

$$SS(ac) = \frac{(23.02)^2 + (19.18)^2 \ldots\ldots\ldots\ldots\ldots (53.57)2}{rb} - Cf \quad SSa - SSc$$

$$= \quad 578.16 - \quad Cf \quad - \quad SSa - SSc$$

$$63.70 - 46.52 - 15.62$$

$$= \quad 1.56$$

Table 13e - B X C

	b_1	b_2	b_3	b_4	Total c
c1	21.72	20.69	18.62	18.50	79.53
c2	33.60	28.29	26.76	24.30	112.95
Total b	55.32	48.98	45.38	42.80	192.46

$$SSbc \quad = \quad \frac{(21.72)^2 + (20.69)^2}{ra} \ldots\ldots\ldots\ldots\ldots (24.30)^2 \quad - \quad Cf - SSb - SSc$$

$$= \quad \frac{4824.66}{9} \quad - \quad Cf - SSb - SSc$$

$$21.61 - 5.01 - 15.62$$

$$= \quad 0.98$$

$$SS(ABC) = SStrt - SSA - SSB - SSC - SSAB - SSAC - SSBC$$

$$= \quad 71.69 - 46.52 - 5.01 - 0.99 - 15.62 - 1.56 - 0.98$$

$$= \quad 1.01$$

The degrees of freedom are computed as follows:

For A, df $= a - 1 = 2$

For B, df $= b - 1 = 3$

For C, df $= c - 1 = 1$

For AB, df $= 9a - 1)(b - 1) = 6$

For AC, df $= (a - 1)(c - 1) = 2$

For BC, df = 9b - 1)(c - 1) = 3

For ABC, df = (a - 1)(b - 1)(c - 1) = 6

For Error, df = abc(r - 1) = 48

For total df = rabs - 1 = 71

Table 13f: The Anova Table

Source of Variation	d.f	SS	ms	Fal	Remark
A	2	46.52	23.26	1.70	ns
B	3	5.01	1.67	0.12	ns
C	1	0.99	0.99	3.84	ns
AB	6	15.62	2.6	0.19	ns
AC	2	1.56	0.78	0.06	ns
BC	3	0.98	0.34	0.03	ns
ABC	6	1.01	0.17	0.07	ns
Error	48	13.69			
Total	71	85.40			

Note ns: not significant at 0.01 and 0.05 significance levels.