

**EFFECTS OF TILLAGE INDUCED SOIL PHYSICAL AND HYDROLOGICAL  
PROPERTIES ON THE SOIL WATER BALANCE AND THE GROWTH OF  
SORGHUM IN THE SEMI ARID AREAS OF TANZANIA**

**GUZHA ALPHONCE CHENJERAYI**



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**ABSTRACT**

Conservation of soil water is an important management objective for crop production in the semi arid tropics. Identification of the best tillage methods to achieve this objective is thus imperative.

The integrated effects of tillage-induced soil physical and hydrologic properties on soil water balance on a sandy loam soil were evaluated. The field experiment consisted of five tillage treatments, namely tied ridging (TR), no till (NT), disc plough (DP), strip catchment tillage (SCT), and hand hoe (HH). Data measured in the field included soil moisture content, bulk density, surface roughness, infiltration, surface runoff and evaporation.

Infiltration rates and depths were higher for the tilled soils than the untilled soils. The DP treatment had the highest cumulative infiltration. TR had low cumulative infiltration not significantly different from the NT treatment. SCT and HH treatments had almost similar values for cumulative infiltration but less than DP. The Kostiakov (1932) and Phillip (1957) infiltration models were fitted to the infiltration data and gave good fit. Depression storage determined using Mitchell and Jones (1976) depth-storage model was highest in the TR treatment. The higher the surface roughness the greater the depression storage volume. Regression analysis showed that random roughness decreased exponentially with increase in rainfall. Tillage increased total porosity and the DP plots

had the highest values. However total porosity decreased with cumulative rainfall in all treatments.

Evaporation experiment results showed that a more open tillage-induced surface structure increased evaporation losses particularly during the first stages of evaporation. This resulted in higher cumulative losses for the DP and HH tilled soils than the other treatments. It therefore appeared that the acclaimed beneficial "soil mulch" effect was masked by the initial higher evaporation losses from the tilled soils under the atmospheric evaporative demands of the study area.


Mean separation of the measured soil moisture showed significantly higher levels of soil moisture in the TR plots than the other treatments. Higher soil moisture contents were associated with treatments having higher depression storage.

Field measured surface runoff after each rain storm also showed marked differences between the treatments. The tied ridged plots had the least runoff while the NT plots recorded very high runoff losses.

Saturated conductivities estimated using van Genuchten model were highest in the DP soils and lowest in the NT soils. Analysis of the pF curves revealed that tillage reduced available water content and the NT had the highest total available water among all the treatments.

**DECLARATION**

I **GUZHA ALPHONCE CHENJERAYI** do hereby declare to the senate of the Sokoine University of Agriculture that this thesis is a result of my own original work and that it has never been submitted for a degree award in any other university.

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## CHAPTER ONE

### INTRODUCTION

#### 1.1 General

In many arid and semi arid regions the paradoxical situation that often prevails is that the area suffers from both a general water shortage and destructive floods. The reason for this is the great variability of rainfall in time and space. Drought years are as common as are years when high intensity rain storms which produce floods and serious erosion damage occur. These unfavourable conditions make crop production difficult without some measures to reduce surface runoff during and after rainfall events, enhance surface storage, infiltration into the soil and minimize evaporation losses.

The remedial measures are, in the context of the present discussion, referred to as soil water conservation practices. These measures consist of some engineering solutions such as tillage. Current agricultural practices of tillage and soil management were developed through long and tedious trials, yet seldom were they analyzed and compared to discern the more successful practices, or to study possible changes of soil conditions needed for higher and more stable yields for a given combination of soil, climatic, environment and mode of management (Makungu, 1991).

## **1.2 Definition of Tillage**

Tillage is generally defined as the mechanical manipulation of the soil to achieve a desired tilth. Sipos (1978) states that "the aim of tillage is to produce such physical conditions through the controlling of the processes going on in the soil as will best provide the most optimum conditions for the production of a given crop."

Depending on the objectives, further distinction of tillage can be made, for example, primary and secondary tillage.

## **1.3 Role of tillage in soil water conservation**

The sole source of water immediately available to plants is that held within the volume of soil accessed by plant roots. The size of this reservoir, its replenishment by precipitation, and its depletion through evaporation, percolation and redistribution determine the quantity of water available to the plant. The importance of tillage in soil water conservation is underlined by the fact that it modifies the soil surface where the complex and crucial partitioning of rainfall into surface runoff, infiltration, and subsequent evaporation takes place (Mwendera, 1992).

Tillage can influence the amount of water available to the plant in the following three ways:

- (a) Improving water infiltration into soil by altering the soil porosity, creating micro relief or by creating surface conditions which minimize surface sealing or crusting by creating a cloddy surface.
- (b) Reducing evaporation losses and conserving water in the soil during the dry period
- (c) Increasing available water to plants by permitting the root system to develop better in depth and volume.

These effects are not of equal merit, nor are their results necessarily the same for different soil types, different times of the season, different climatic conditions as well as different tillage systems. The effectiveness of tillage in enhancing soil water storage depends on the physical response of various soils to different tillage operations and the way tillage induced soil physical conditions respond to the accumulated impact of rainfall energy and other natural processes. For each individual situation, the most significant factors limiting plant soil water availability need to be assessed and the most feasible means for improving the situation through tillage need to be identified.

Contrasting observations on the effects of tillage on infiltration, surface storage, runoff and evaporation have been observed. While tillage would open up the soil and enhance drying of the wet subsoil by evaporation, tillage is needed to enhance infiltration of the subsequent rains. Such contrasting observations emphasize the need for more research in order to understand the complex and important tillage-soil-water interaction under

different field and climatic conditions. The importance of being able to understand the effects of tillage on soil water dynamics and relate the tillage induced soil hydraulic changes to ultimate crop growth and yields cannot be over emphasized. Such knowledge on tillage effects on soil water conservation are important because of the following:

- (a) They allow selection of the most efficient and appropriate crop production system for a given soil and climate;
- (b) They enable agricultural advisers and farmers alike to make judicious soil and land management decisions; and
- (c) They change the emphasis of tillage studies towards appropriate practices under prescribed environmental conditions.

The importance of tillage in soil water conservation and storage is underlined by the fact that tillage modifies the soil surface where the complex and crucial partitioning of rainfall into runoff, infiltration and evaporation takes place. Water storage and transmission characteristics of the soil are influenced by soil surface structure, total porosity, pore continuity and pore size distribution.

Evaporation losses from the soil are influenced by, among other things, water transmission characteristics of the top layer and the soil surface structure. Tillage modifies most of these properties and has, therefore a major influence on the hydrology of an agricultural catchment.

Research comparing conventional-tillage and no-till systems has produced variable results, apparently depending largely on soil type and climatic conditions. Spatial and temporal variation in many soil properties further complicates data interpretation and comparisons with previous research. However, such information is essential for implementation of the most efficient soil and water conserving practices, especially on fragile and erodible lands.

These contrasting observations on the effects of tillage on soil physical and hydrological properties as well as crop growth prompted this study.

The main objective of the study was to investigate the effects of tillage induced soil physical and hydrological conditions on the soil water balance and the subsequent effects on crop growth and yield.

The specific objectives of the study were to:

- (a) evaluate effects of tillage on soil water evaporation.
- (b) evaluate the effects of tillage on the soil moisture regimes
- (c) evaluate the influence of tillage on the soil moisture release

characteristics and hydraulic conductivity of the soils.

(d) assess effects of tillage on:

- (i) total porosity and bulk density of the plough layer;
- (ii) soil water infiltration;
- (iii) surface runoff;
- (iv) surface micro topography and depressional storage

(e) assess the influence of the different tillage systems on crop growth and yield.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

#### **2.1 General overview on tillage research**

##### **2.1.1 Background to tillage research**

Tillage research can be seen to have proceeded along two distinctly separate but complimentary directions. One concentrating on the tillage operation itself (the forces involved and the soil conditions produced) and described by Hillel, (1980) as the engineering approach; The other direction involves investigating the effects of the tillage induced conditions on crop production and described as the agronomic approach. A lot of work has been done to investigate the effects of various tillage treatments on crop yields. According to Henderson (1979) much of the literature reports on studies of the effect of a tillage procedure on crop yield without providing an insight into how the procedure influenced crop growth and therefore yield. As a result of these general objectives, the results obtained were often site and year specific.

Later research was more specific in terms of objectives and the research was narrowed down to a few factors and how they influence crop growth. It was observed, for example, that tillage could have an impact on crop production if physical properties of

the soil hindering crop growth such as hard pans were removed (Marshall, 1962). Thus many subsequent studies narrowed down their objectives to specific factors, such as tillage effects on bulk density and water infiltration.

However, with this later approach, results have been contradictory and inconclusive and thus further research work on different types of soils is still being carried out. The new approach in tillage research has moved away from associating crop yield with the type of implement used to associating it with the soil conditions produced by that tillage implement. Research has also moved away from using crop yields as an indicator of the suitability of the soil conditions produced by tillage. The new dimension is to use growth factors such as soil water storage, soil temperature and mechanical impedance as indicators.

## **2.2 Soil water management aspects related to tillage**

Tillage and soil surface management play crucial roles in the management of water resources and in alleviating water related constraints to agricultural production and environmental quality. The principal aspects of water management in relation to tillage are outlined in Fig. 2.1. Appropriate tillage systems can be used to facilitate drainage in the root zone, increase infiltration to improve soil water storage, change porosity and tortuosity to influence soil water evaporation and enhance macropore flow.

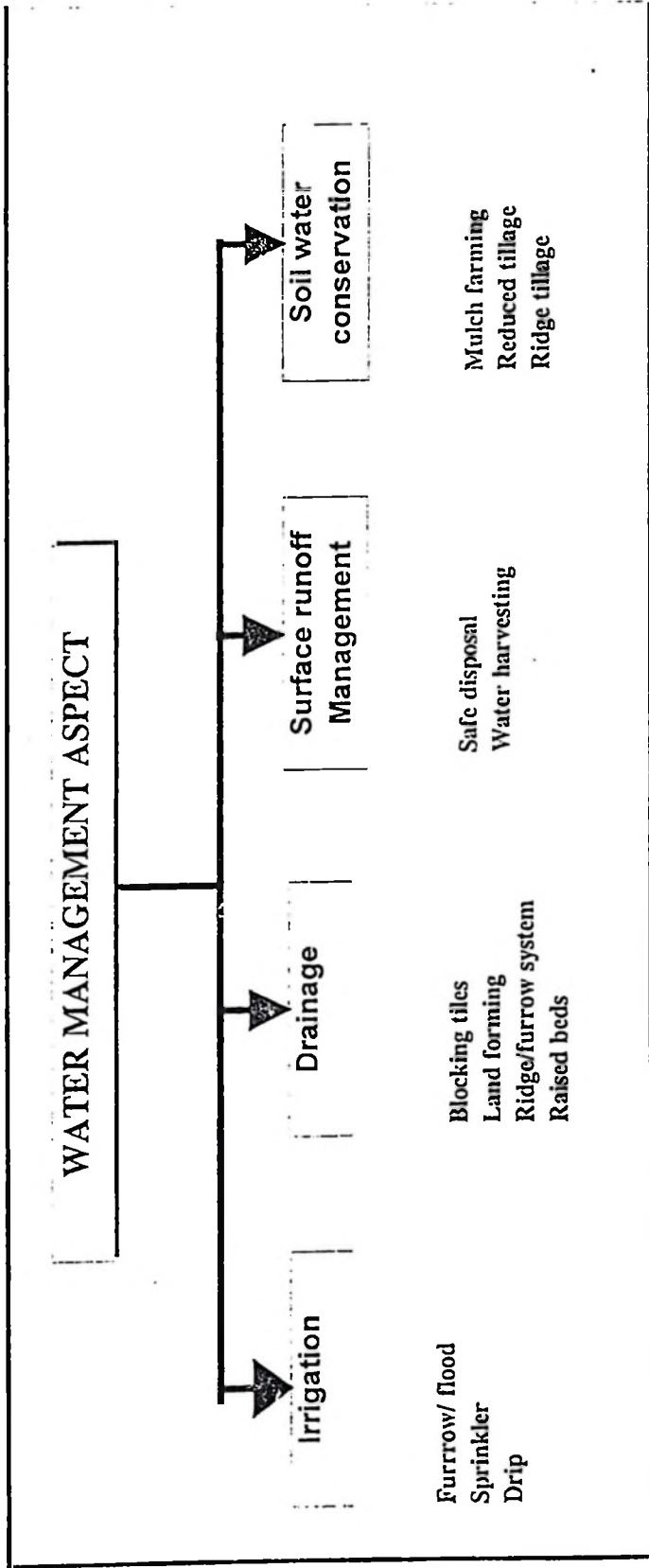


Figure 2.1 Soil water management aspects related to tillage  
(Source: Lal, 1993)

Tillage techniques are useful tools to provide an optimum soil moisture regime in the root zone by :

- (i) enhancing efficiency of irrigation;
- (ii) drainage of excess water in the root zone;
- (iii) regulating water quality;
- (iv) facilitate rainwater harvesting;
- (v) changing structural properties of the soil to provide favourable plant specific environments in the root zone.

However tillage techniques to achieve these functions differ depending on soil properties and antecedent soil conditions.

Water use efficiency for irrigation can be enhanced by (i) sub soiling to alleviate compaction (ii) ridge tillage for regulating water flow (iii) mulch based conservation tillage systems. Special tillage techniques, usually deep tillage followed by incorporation of organic amendments and gypsum are required for reclaiming salt affected soils. Conservation tillage techniques are used for decreasing runoff and conserving soil water in the root zone.

These tillage requirements also vary depending on climate. No till with crop residues would be a viable option for well drained soils in the humid and sub humid regions. Ridge tillage and subsoiling are useful systems for hard setting and easily compacted

soils of the arid and semi arid regions.

### 2.3 The soil water balance

Any attempt to control the quantity of soil water through tillage must be based on a thorough understanding and quantitative knowledge of the interrelationship between the tillage induced conditions and the dynamic balance of the water in the soil.

The factors influencing the soil water balance may be described by the following conceptual relationship:

$$Wc = f(S, E, M) \dots \dots \dots 2.1$$

where  $Wc$  = soil water content

$S$  = soil composition and condition

$E$  = environment

$M$  = management practices

$f$  = functional relationship between  $Wc$ ,  $S$ ,  $E$  and  $M$ .

It is an interaction of all the above factors which influences the amount of water in the soil. Changes in the soil water storage, or the soil water balance may be expressed as

a difference between the water gains and losses as presented in equation 2.2.

$$\Delta_s = (P + I_r + U) - (R + D + E + T) \dots \dots \dots 2.2$$

where:

$\Delta_s$  = net change in water storage

$(P + I_r + U)$  = Water gains.

$(R + D + E + T)$  = Water losses.

$P$  = Precipitation.

$I_r$  = Irrigation.

$U$  = Upward flow of water by capillarity.

$R$  = Runoff.

$D$  = Drainage

$E$  = Evaporation

$T$  = Transpiration

Without considering the irrigation and plant effects the above equation reduces to:

$$\Delta_s = P - (R + D + E) \dots \dots \dots 2.3$$

Precipitation and runoff may be combined into the following relationship :

$$I = P - R \dots\dots\dots 2.4$$

where : I = total infiltration

Hence equation 2.3 may be further simplified to:

$$\Delta_s = I - D - E \dots\dots\dots 2.5$$

The effects of tillage induced conditions on the soil water processes of infiltration, redistribution and evaporation is not uniform and may in fact in some cases be contradictory. For example, an open loose tilled soil layer at the surface may be favourable for water entry into the soil, but that soil condition may be conducive to rapid evaporative losses and the net effect may be poor water storage (Henderson, 1979). Also a tillage induced soil condition produced at the start of any cropping season may produce favourable conditions at the beginning but these conditions deteriorate fast with time and even produce worse results at the end of the season in terms of water storage. For these reasons, the best soil conditions required for optimization of soil water are often a compromise in the light of all the soil water processes involved and the changes in the soil conditions occurring within the growing season (Henderson, 1979). This is due to the fact that it is the fluctuations of the soil water content during the growing season as a whole which matters most in terms of relating crop response

to a tillage practice (Kuipers, 1984).

To describe a tillage treatment three general aspects need to be considered. Firstly, the different tillage induced conditions on the soil need to be described quantitatively and in a way that reflects their behavioral or causal relationship with the soil water hydraulic properties or water processes; Secondly, the changes of these soil conditions within the season need to be described quantitatively; and thirdly the soil hydrological processes need to be described in a way that takes into account important weather characteristics such as rainfall patterns.

However to address all these three aspects simultaneously is very difficult, partly because the effects of most tillage induced conditions on soil water have not been studied sufficiently (Makungu 1991). The difficulty also arises from the fact that most studies on tillage and soil water processes have dealt with single processes rather than deal with the whole soil water regime (Gardner et al.1970).

For these reasons, only a few tillage induced soil conditions can adequately be quantified and used to describe the soil water processes and their interactions. In the following sections, soil water flow processes and how they are affected by different tillage practices will be presented.

## **2.4 Infiltration**

### **2.4.1 Conceptual description**

Generally, infiltration is the term applied to the process of water movement into the soil. The factors that influence infiltration are varied and dynamic. Some of the factors include soil texture, soil structure, surface roughness, total porosity, pore continuity, pore size distribution and initial soil moisture (Burwell et al., 1963). At low moisture content, infiltration is governed by the gradient of the water potential between the wetting front and the soil surface. Consequently the decrease in infiltration rate is caused by the decreasing water potential gradient during the infiltration process (Baver et al., 1972). At high moisture content, saturated hydraulic conductivity determines the process. Infiltration is also controlled by interactive factors. In the case of a high rainfall event, infiltration can be reduced by surface sealing, soil air pressure beneath the wetting front and filling of macropores by detached fine particles (Ghosh, 1983).

### **2.4.2 Effects of tillage on infiltration**

Tillage modifies most of the soil properties affecting infiltration and has therefore a major influence on the infiltration characteristics of a soil. Tillage affects infiltration by increasing porosity (and hence water storage volume and water transmission) and surface roughness (and hence surface detention storage). Burwell and Larson (1969) studied the influence of tillage on rainfall infiltration for a freshly tilled bare soil surface. It was observed that during simulated rainfall, increases in tillage induced random roughness, and soil pore spaces increased water infiltration significantly before runoff began. Random roughness was found to be a significant factor accounting for the

increased infiltration on bare soil surfaces before the commencement of surface runoff. After runoff began and the rough surface had been broken down by rainfall energy, they found little difference between the tillage treatments.

Lindstrom et al.(1984) and Steichen (1984), found a higher infiltration rate in tilled clay loam soil than in no-till plots. No-till plots had low infiltration because of the impeding top layer or crust with a high bulk density which was not disturbed. Miller and Gardner (1968), showed that an impeding layer with higher bulk density caused abrupt discontinuities in water content and hydraulic conductivity at the inter-layer boundaries and cause a pronounced reduction in infiltration. Vittal et.al.(1983) also observed that infiltration rates, both initial and final, increased as tillage depth increased possibly because of opening up of the soil profile by deep cultivation.

On dense soil layers, tillage has the effect of decreasing soil bulk density, increasing soil porosity, and increasing the total infiltration relative to that of undisturbed state. A tillage operation producing water stable aggregates at the surface and open soil pores will lead to greater infiltration rates. Cumulative infiltration and rainfall energy required to initiate runoff is greater on the rough, porous surface created by, for example the disc plough than for any other tillage treatment for example hand hoeing. However, where surface seals occur, the influence of tillage induced random roughness and pore space on infiltration become overshadowed.

On the other hand, tillage can reduce infiltration by creating discontinuous pore space in the plough layer and by weakening the structure due to micro fractures (Freebairn, et al. 1989). The effect of tillage on infiltration, therefore, depends on the type and stability of the surface micro structure and pore geometry produced. This is the reason why infiltration on bare tilled fields is highly dynamic with time depending upon the previous and most recent tillage operations.

## **2.5 Soil water evaporation**

### **2.5.1 Conceptual description**

Evaporation from a bare soil is a two step phenomena involving conversion of liquid water to vapour and the loss of the vapour into the atmosphere. There are three major requisites for evaporation to occur and these are (a) continual supply of energy to vaporize the water, (b) existence of a vapour pressure gradient between the evaporating surface and the surrounding atmosphere, and (c) continual water supply to the evaporating surface (Jalota and Prihar, 1990).

Evaporation is normally described in three stages according to Lemon (1956). These stages are :

- (i) The first stage, referred to as the "constant rate stage", where the evaporation rate is governed by external conditions and equals atmospheric evaporativity (Reynolds and Walker, 1984). This is the energy limiting stage.
  
- (ii) After a threshold period, the rate of water loss from the soil lags behind atmospheric evaporativity and thus it decreases with time. This is the second stage or falling rate stage and is characterized by evaporation rate which decreases exponentially with time. Evaporation is controlled by the diffusivity function of the near-surface soil profile (Black et al. 1969).
  
- (iii) Gradually, a drier layer, or a soil mulch, develops at the surface which acts as a barrier to vapour diffusion, and the evaporation enters the third stage, the reduced evaporation rate stage. Water transfer in this stage occurs only in the vapour state by molecular diffusion and the flow is governed by the adsorptive forces acting over molecular distances at the solid-liquid interface (Lemon, 1956). According to Black et al.(1969) cumulative evaporative flux through the

soil surface during this stage is linearly related to the square root of time and hence this stage is also known as the "root-time behavior" stage.

### **2.5.2 Effects of tillage on evaporation**

Evaporation from the soil surface plays a significant role in the water loss from the soil and is a key factor in the soil water balance. The effect of tillage on soil evaporation depends on climatic conditions above the soil surface, depth of water table below the tilled layer, time and nature of tillage, nature of the tillage induced surface structure and the pore geometry of the tilled layer (Jalota and Prihar, 1990).

Tillage causes a wide range of effects on the evaporation process ranging from dramatically decreasing the rate in some situations to increasing it in others (Makungu, 1991). In general, tillage that exposes moist soil to the atmosphere will increase the evaporation rate and, hence, the cumulative evaporation from the plough layer. However such tillage may also loosen the soil near the surface, thus reducing the unsaturated water flow to the surface and, thereby, decreasing evaporative losses of deeply stored soil water.

The increased tillage induced surface roughness and air porosity decrease the albedo of the surface, increase the surface area exposed to the atmosphere, increase penetration of wind into the loose and rough structure, and concentrate heat in the surface layers. All of these will result in increase of the initial rate of evaporation from the tilled soils (Linden, 1982), relative to untilled soils. This causes the rapid formation of a dry layer because of accelerated drying of the tilled surface. As a result, evaporation rate from tilled soils will be reduced as compared to that from untilled soils. Eventually, when the drying front moves deeper into the untilled soil, the less porous surface layer permits less vapour flow compared with an equal depth of the more porous layer of the

tilled soil (Will and Bond, 1971). Consequently, the rate of evaporation loss from the tilled soil exceeds that from untilled soils.

Usually evaporation from tilled soils is compared with that from untilled soils by normalizing the tilled soil evaporation on the untilled soil evaporation. This is done by dividing evaporation from tilled soil with that from untilled soil.

The duration and magnitude of the increase or decrease in evaporation rates from tilled versus untilled soil, which determine the time course of the evaporation reduction with tillage, have been found to depend on soil type, evaporativity, time and type of tillage and their interactions (Jalota and Prihar, 1990).

Hillel(1982) reported that when external evaporativity is low, the initial constant rate stage can persist longer. This fact led to the hypothesis that hastening the development of a dry layer through tillage would induce high evaporativity which may reduce cumulative moisture loss in the long run (Lemon, 1956).

Makungu(1991) pointed out the work of Bristow et al.(1983) as demonstrating that tillage decreased the soil capillary conductivity to the surface and thereby reducing cumulative evaporation. On the other hand, Holmes et al.(1960) observed that high cumulative water losses occurred in the coarse soil tilths and was lowest in the finer tilths.

Jalota and Prihar(1976) identified water retention and transmission properties of the soil as controlling evaporation during the soil limiting phase. First stage evaporation is assumed to occur as long as soil moisture content at the surface can meet atmospheric demand. When this demand cannot be met, evaporation moves into stage two. Tillage induced soil conditions which cause a decrease in the rate of soil water flow may act to prolong the duration of first stage. On the other hand, soil conditions which result

in higher water transmission would hasten the drying on the surface and hence shorten stage one.

On the whole, the net effect of tillage on the cumulative evaporation is difficult to predict and depends on the interplay among many factors (Makungu, 1991).

## **2.6 Influence of tillage on surface runoff**

Water loss in the form of surface runoff is one of the major ways in which water from cultivated fields is lost. The development of a better understanding of the effects of tillage on the amount of runoff is needed to make appropriate recommendations on tillage. Several studies (Romkens et al., 1973; Johnson and Moldenhauer, 1979) have shown less runoff with conservation or minimum tillage than with conventional tillage, while others (Moldenhauer et al., 1921; Lindstrom and Onstad, 1984) have shown the opposite. Differences in runoff volumes among tillage treatments have been attributed to the varying effects of tillage on surface conditions and residue cover (Romkens et al., 1973). A tillage treatment that increases the surface roughness will reduce the volume of surface runoff as most of the water will be trapped in the surface depressions will infiltrate into the soil with time. Smoother surfaces will on the other hand, cause higher amounts of surface runoff. Conservation tillage in which crop residues are left on the surface will reduce the amount of runoff by inhibiting lateral water flow and promoting infiltration. On the other hand, conservation tillage involving minimum tillage with no crop residues on the surface will generate a large amount of runoff. Results obtained by Hatibu et al.(1995) show that tied ridging produced the least amount of surface runoff while the zero tillage plots and strip cultivated plots (conservation tillage systems) produced the highest run off yields on average in all rainfall events. There was also a high correlation between rainfall intensity and runoff yield.

Romkens et al.(1973) also observed that the effect of tillage on the volume of runoff was dependent on the antecedent soil moisture level and the time of the runoff event. When soil moisture content was high (less than six days since last rain) runoff was higher from the no till plots than from the conventionally tilled plots. The reverse was true when the last rainfall was more than seven days before a runoff event. The rainfall pattern and initial soil moisture were found to have significant influence on cumulative runoff yield.

## **2.7 Soil hydraulic properties and hydrologic processes**

Soil hydraulic properties include saturated and unsaturated hydraulic conductivity, soil water retention, and soil water diffusivity (Klute, 1982). These properties, in turn, affect the soil hydrologic processes such as water flow through the soil matrix, drainage, infiltration and evaporation. Tillage operations affect these hydraulic properties in a variety of ways as explained in the following sections.

### **2.7.1 Effect of tillage on soil moisture release characteristics**

The soil water release characteristics are an important property used to quantitatively describe most of the soil water processes. Tillage indirectly influences the soil water flow processes. Soil texture, bulk density, and organic carbon have been shown to affect the soil water release characteristics of a soil. These properties are altered by tillage and therefore it implies that tillage has an effect on the soil water release characteristics. The effects of bulk density changes on the soil water release properties are not uniform across the whole moisture content range of the release function of the soil. Decreasing bulk density increases amount of water held at low suction heads and decreases the amount held at high suction heads (Unger, 1975; Klute, 1982).

Soil water retention is controlled by total porosity and pore size distribution. Hence changes in these two properties resulting from tillage operations cause a change in water retention. Porosity and pore size distribution are changed whenever bulk density is changed by tillage. Tillage can cause large changes in the bulk density of the plough layer and hence significant changes to the soil water release characteristics (Luttrell, 1963). Decreasing the bulk density increases total porosity and hence increases the amount of water held at high soil water potentials and decreases the amount held at lower soil water potentials (Elrick and Tanner, 1955).

However the responses depend on soil textural characteristics. For example, Klute (1978) showed that disrupting the natural structure decreased the water retention of coarse textured soils and increased the retention of fine textured soils relative to that of natural soil cores at a matric potential of -0.033 MPa. At matric potential of -1.5 MPa, disturbed soil samples of all textures retained slightly more water than undisturbed samples, but the percentage change was greater for coarse than for fine textured soils. The same results were also obtained by Unger (1975).

Tillage also influences water retention if it alters the distribution of sand, silt and clay in the soil by mixing these particles from different soil horizons (Harper and Brensing, 1950).

### **2.7.2 Effects of tillage on soil hydraulic conductivity**

Tillage operations change the soil conditions and the hydraulic conductivity of the soil (Allmaras et.al., 1966). Alteration of the soil pore size distribution by tillage changes the hydraulic conductivity of the soil (Unger and Cassel, 1991). The relationship between the unsaturated hydraulic conductivity and the soil moisture content (the hydraulic conductivity function) is influenced by both textural class and tillage affected soil properties such as bulk density (Gardner, 1983).

Loosening the soil increases saturated hydraulic conductivity, but compaction by wheel trafficking during or after a tillage operation decreases saturated hydraulic conductivity relative to its value before the tillage operation. Compaction by wheels at soil depths below that of the shallow tillage may reduce saturated hydraulic conductivity in the soil below the tillage zone. Cassel and Nelson (1985) reported position effects on saturated hydraulic conductivity for conventional, chisel plough, and subsoil bed tillage on a Norfolk loamy sand that had a tillage pan.

### **2.7.3 Effect of tillage on soil bulk density**

Soil bulk density has a major impact on soil water relationships and root development and consequently on crop growth and yield. Soil bulk density has an influence also on soil hydraulic conductivity, soil porosity and soil moisture retention characteristics among other soil water properties. Most tillage operations are performed to decrease soil density within the disturbed zone.

However, bulk density often varies temporarily and spatially. This is because of undisturbed zones within the soil, compaction and reconsolidation due to traffic, subsequent tillage operations and breakdown of unstable soil aggregates due to the impact of raindrops.

## **2.8 Surface roughness**

### **2.8.1 Definition**

Surface roughness is the surface configuration of the soil caused by the randomly oriented arrangement of soil clods. Tillage implements can produce two types of roughness; oriented roughness and random roughness ( Allmaras et. al, 1966). The

second type of roughness is caused by the random occurrence of peaks and depressions resulting from soil clods and organization of aggregates which cannot be attributed to oriented roughness resulting from tillage tool marks or general slope effects.

### **2.8.2 Random roughness**

Random roughness is a very important property of tilled soils in terms of soil water storage. Infiltration, evaporation and runoff retardation are closely associated with random roughness. Burwell et al., (1969) have shown highly significant correlations of infiltration capacities prior to the start of runoff with a roughness index. Falayi and Bouma (1975) also reported such a correlation and showed that differences can only occur due to the nature of the sealed or crusted layer formed at the soil surface.

Allmaras et al., (1977) observed higher evaporation rates from rough surfaces; however these soils also had increased porosity, which may increased infiltration.

### **2.8.3 Random roughness and depression storage**

The water stored in the surface depressions caused by surface roughness of the soil surface is termed depression storage. It has been found that there is a positive correlation between the surface roughness and the depression storage. The rougher the soil surface, the greater the amount of depression storage during a rainfall event.

### **2.8.4 Partitioning of rain water into the various phases of depression storage during a hypothetical rainfall event**

Depression water storage process during a rainfall event may be described by four distinct phases as follows;

- (i) Depression storage is zero until some rainfall excess is generated (rainfall

- exceeds infiltration) which allows the depressions to begin filling with water.
- (ii) Small depressions begin to fill with water, some of which may be continuously interconnected so that they are contributing to runoff. All depressions, however, are not necessarily interconnected and some water is held as temporary storage in these isolated depressions.
  - (iii) The depressions in the soil surface are filled with water so that the entire ponded surface is interconnected and the rainfall excess generated at every point is contributing to runoff. An increase in temporary storage of water on the surface at this time is more correctly termed detention storage since it will eventually run off at the cessation of the rainfall event.
  - (iv) Rainfall ceases and depressional storage declines as the water in storage infiltrates into the soil profile. Detention storage declines rapidly when rainfall ceases because it is contributing to runoff.

#### **2.8.5 Estimating depressional storage from surface roughness data**

Work has been done on how to measure depression storage and predict storage values using different models that consider surface roughness (Linden, 1979; Onstad, 1984). Huggins and Monke (1966) developed an empirical storage depth relationship through regression analysis for determining depression storage. Seginer (1971) developed a model to predict both drainage pattern and surface storage capacity of the cultivated surfaces taking into account the slope of the field, direction of the furrows and roughness of the field. Mitchell and Jones (1976) developed models which use geometric models of the surface configuration. These models use complex computer algorithms to simulate the rate at which water accumulates at the surface during a rainfall event.

However most of these initial models are complex and very laborious. Their empirical nature often limit their use in estimating depression storage. Onstad (1984) developed a simpler model using regression analysis. This model can be presented as;

$$D_s = 0.112 R_r + 0.031 R_r^2 - 0.012 R_r S \dots\dots\dots 2.6$$

where :

$D_s$  = maximum depression storage (cm);

$R_r$  = random roughness (cm);

$S$  = slope steepness (%);

Mitchell and Jones (1976) also developed another simpler depth storage model which can be expressed as:

$$S = aD^b \dots\dots\dots 2.7.$$

where:

$S$  = Water storage (cm)

$D$  = Depth above the lowest point on the surface (cm)

$a, b$  = fitted equation parameters.

Mitchell and Jones (1978) processed micro relief meter data to obtain depth storage values on the assumption that each point measurement was the centre of a 2.5 cm square level surface. The method can be represented as shown in equation 2.8 below:

$$S_r = \sum_{i=1}^n \sum_{j=1}^m (H_r - H_a) \dots\dots\dots 2.8$$

where  $S_r$  = surface depressional storage (cm);

$i, j$  = rows and columns of point measurements respectively;

$H_r$  = reference height (cm);

$H_a$  = point measurement (cm);

The selection of appropriate methods for use needs careful consideration and the selection of any one single model depends on the purpose of the calculation and the objectives of the investigation (Makungu, 1991). Different models partition the surface water from excess rainfall into various components. A distinction is made between those models which include detention storage and those which do not. Models which include detention storage are termed surface storage models while those which do not are termed depression storage models. The two types of models present different levels of detail on what eventually happens to rainfall excess. In studies where an accurate estimate of the runoff component is a major objective, surface storage models would be ideal to use. On the other hand, where the interest is for the excess rainfall component which eventually contributes to infiltrated water, depression storage models would suffice.

#### **2.8.6 Role of Depressional storage in the soil hydrologic processes**

Depression storage is a component in the infiltration runoff process on the soil. It is a means by which ponded water from rainfall is kept on the surface and allowed to infiltrate. When the rainfall rate is higher than the infiltration rate runoff begins when all the depressions are filled with water. The amount of runoff depends on the roughness of the surface. Rougher surfaces take more time before runoff is initiated because rougher surfaces store more water in the surface depressions. Smoother surfaces have less depressional storage volume and thus runoff is generated at a faster rate (Linden, 1979).

## 2.9 Dynamic nature of tillage induced soil physical conditions

The initially tillage induced soil conditions have been found to decline as time progresses (Zoebeck and Onstad, 1987). The major cause of the decline is normally cumulative rainfall. A rough cloddy surface will gradually slake and be smoothed by raindrop energy. Dexter (1977) measured the random roughness of the soil and related it to cumulative natural rainfall occurring during a year in Australia. He observed both linear and exponential relationships between random roughness and cumulative rainfall. Johnson et al., (1979) and Zoebeck and Onstad (1987) also observed a similar exponential decay of the form shown in the Equation 2.9

$$RR = \alpha RR_o e^{-\beta P} \dots\dots\dots 2.9$$

where :

RR = Random roughness on any day;

RRo = initial random roughness;

P = cumulative rainfall;

e = exponent;

$\alpha$ ,  $\beta$  = regression coefficients representing rate of decline in random roughness and the shape of the exponential curve.

Burwell and Larson (1988) observed that much of the random roughness and total pore space created by tillage was decreased significantly by the time runoff began in all treatments. Similarly, porosity decreases when freshly tilled soils are exposed to wetting and raindrop action (Allmaras, et al., 1966). Onstad et al. (1984) related changes in bulk density on freshly tilled soils with the cumulative water applied. They found bulk density changes (increases) to be very rapid at the beginning and gradual at later stages of water application.

### **2.10 Influence of tillage on crop growth**

Spomer and Hjelmfell (1984) noted that inadequate soil moisture has an adverse effect on crop yield because plant growth is dependent on adequate water supply. Most reported yield increases with conservation tillage systems have been attributed to increases in soil moisture (Moddy et al., 1963; Blevins et al., 1971).

Conservation tillage systems increase soil moisture by improving soil hydrological properties such as profile water recharge by increasing water infiltration and transmission. Almarras et al. (1972) observed increases in soil hydraulic conductivity with increased depth of chisel plough.

The findings of Allen et al. (1980) indicate increased fallow season soil water storage for conservation tillage which resulted in higher wheat and sorghum yields. Wittmus and Yazar (1980) found greater profile moisture for minimum tilled soils than in the conventionally tilled soils and they got higher maize yields on the no till plots. Crop yield increases have also been obtained in Kenya in trashlines which help to conserve soil moisture besides improving the fertility status of the soil (Kiome and Stocking, 1992). Shumba et al. (1993) found no significant difference in maize yield in conventionally tilled soils and conservation tillage treatments on sandy soil possibly due to the low and erratic rainfall in the southern part of Zimbabwe.

### **2.11 Synthesis of Literature review**

The preceding literature review shows that tillage causes changes in soil physical and hydrological properties. Such changes can lead to significant changes in the soil water balance and storage which in turn affects crop yields. Experience from the semi arid regions shows that the presence of rougher soil surfaces increases surface detention of rain water and soil water storage while there is an effective decrease in surface water

runoff. This leads to more water being available to the crops, which then results in increased crop yields. There is relatively little information available on the effects of major tillage operations on the soil water balance and crop yields in the semi arid tropics.

Although the tilling of soils to bring land into agricultural production is socially and economically a desirable activity in view of the need for economic development, there is need however to ensure that this is done in such a way that a long term sustainable productive system is created. Thus it is important that basic data is obtained on the changes of the different parameters which occur as a result of tillage operations. The extrapolation of data from the humid tropics to the semi arid tropics is of limited application and hence the need to undertake basic research in these semi arid regions. The principal objective of this study is to narrow down the knowledge gap by obtaining basic information on changes occurring in soil physical properties, hydrologic properties and crop yields when different tillage operations are performed.

## CHAPTER THREE

### MATERIALS AND METHODS

#### 3.1 Location, soils and weather

##### 3.1.1 Location

The research work was conducted at Hombolo Agricultural Research Institute (ARI) in Dodoma, central region of Tanzania. The institute is located 58km North east of the Dodoma town, at 5°53'S latitude and 35°55'S longitude. The altitude is 1097m above sea level. Fig. 3.1a shows the location of Hombolo Bwawani village in Dodoma while Fig. 3.1b shows the location of the research site at the research station.

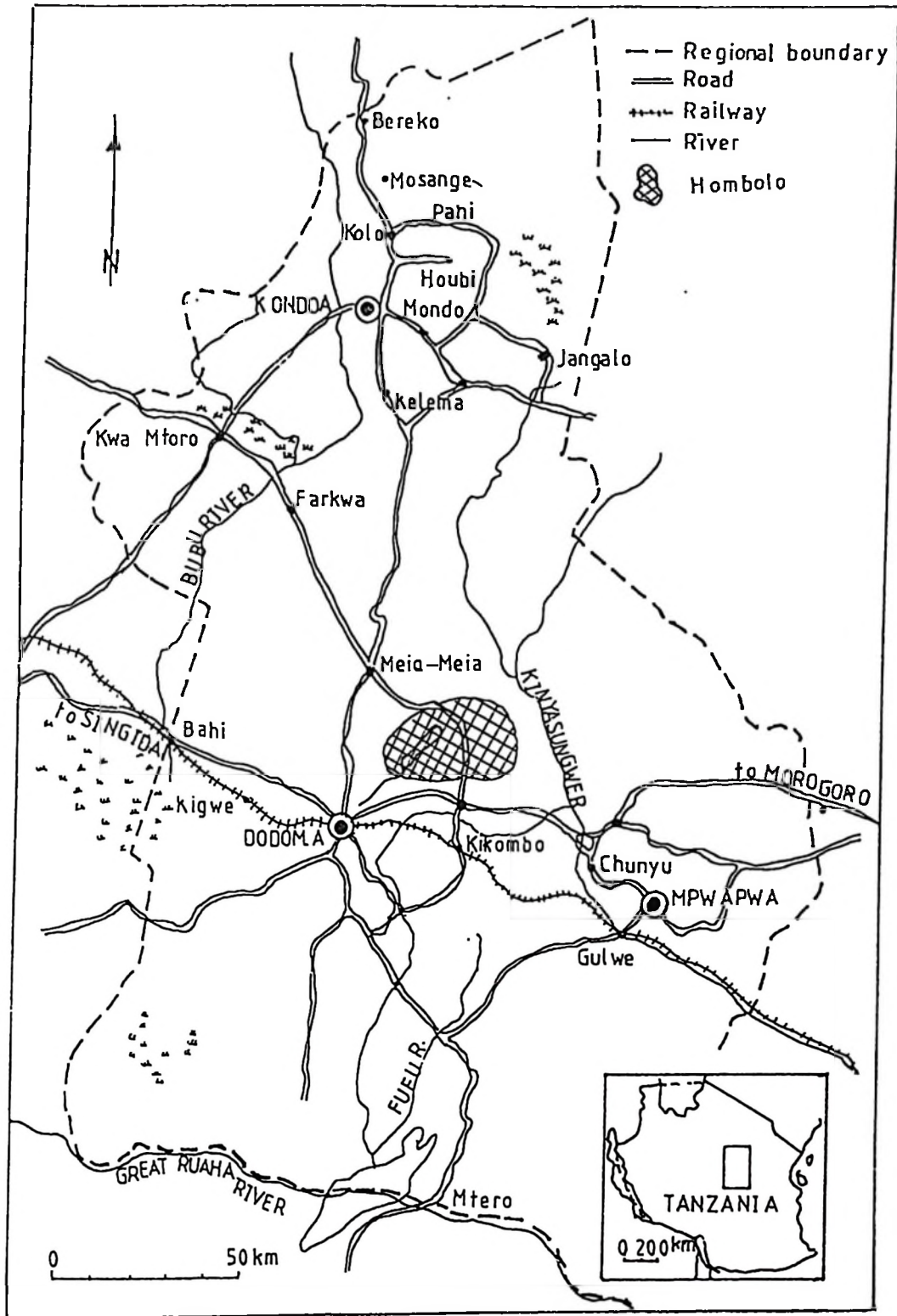


Figure 3.1.a: Location of Hombolo Research station.

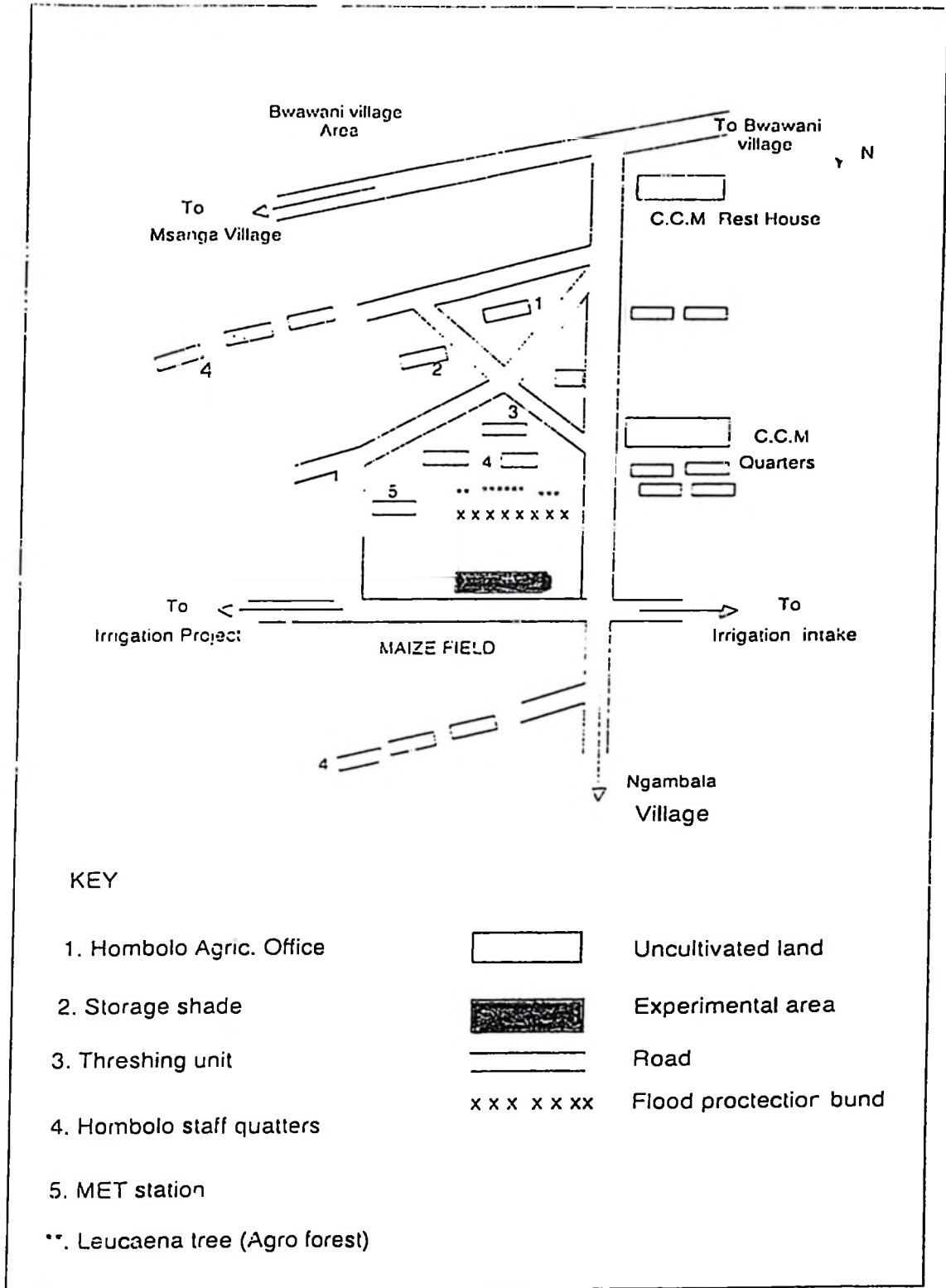


Figure 3.1b Location of experimental site in Hombolo Bwawani village

### **3.1.2 Soils**

Most of central Tanzania is made up of plateau peneplains with gently undulating topography or almost flat land with isolated hills and inselbergs. Under these conditions the movement of soil particles through erosion and soil creep is slow enough to allow the soil forming processes. Thus the development of a sequence of characteristic soil types along the slopes takes longer. In principle, the soils on the upper slopes, that are formed directly from the underlying parent rock, are normally red, well drained and deeply weathered zonal soils. Rock outcrops, may occur on the hill tops. On the lower slopes an accumulation of both transported, dissolved material in the soil and of coarser particles like sand on the soil takes place. The soil type is thus formed on material originating from higher up the hills (colluvium). In the flat valley bottoms, clays and bases (like calcium) dissolved in the drained water accumulate. These dark clay soils, locally called "Mbugas", are very characteristic for depressions in much of central Dodoma. These soil toposequences along slopes occur in a recurrent pattern over vast areas with similar climate, topography and parent material. They are called "Catenas" and are of greater significance in land use planning because of the very different characteristics of the soils within small distances on different positions along the slopes. Hardpans are often formed in the section of material accumulation on the lower slopes, often where the drainage is impeded. Some types of accumulation and processes give rise to so called laterites.

### **3.1.3 Soils of Hombolo experimental site**

Based on colour and texture the soils are fairly uniform based on colour and texture (Hatibu et al., 1995). The soils are generally sandy clay loam soils which are easy to

work and do not form very stable aggregates. Crusting takes place on the surface. Appendix A shows the profile description for the research site done by Mahoo and Kaaya (1991).

### 3.1.4 Climate

#### 3.1.4.1 Rainfall

The general rainfall pattern in the study area is influenced by the movements of the Inter Tropical Convergence Zone (ITCZ) between the northern and the southern hemispheres. The year is divided into two distinct seasons; a dry season between May and November and a rainy season from December to March.

Table 3.1 below shows the average monthly rainfall distribution at Hombolo meteorological station from 1974 to 1992.

Table 3.1 Monthly averages of rainfall at Hombolo Met station for the period 1974 to 1992.

Month	A	S	O	N	D	J	F	M	A	M	J
Rainfall (mm)	0	0	7	37	14	118	118	107	63	8	9

(source: Lameck, 1994)

The average annual rainfall is 589 mm. However the annual distribution of the rainfall is highly variable. It is interesting to note that although Dodoma is in the semi arid region, the rainfall intensity is just as high as in other humid coastal places like Dar es Salaam on the Indian ocean coast (Table 3.2). The high rainfall intensity coupled with the limited vegetation cover in the area partly explains why land degradation becomes pronounced in these areas.

Table 3.2 Maximum rainfall intensities (mm/hr) at various durations and return periods for Dodoma region.

Duration(min)	Return period (Years)				
	2.2	5	10	25	50
10	51	100	135	175	205
20	17	51	73	102	122
30	25	63	88	120	145
60	29	57	75	97	115

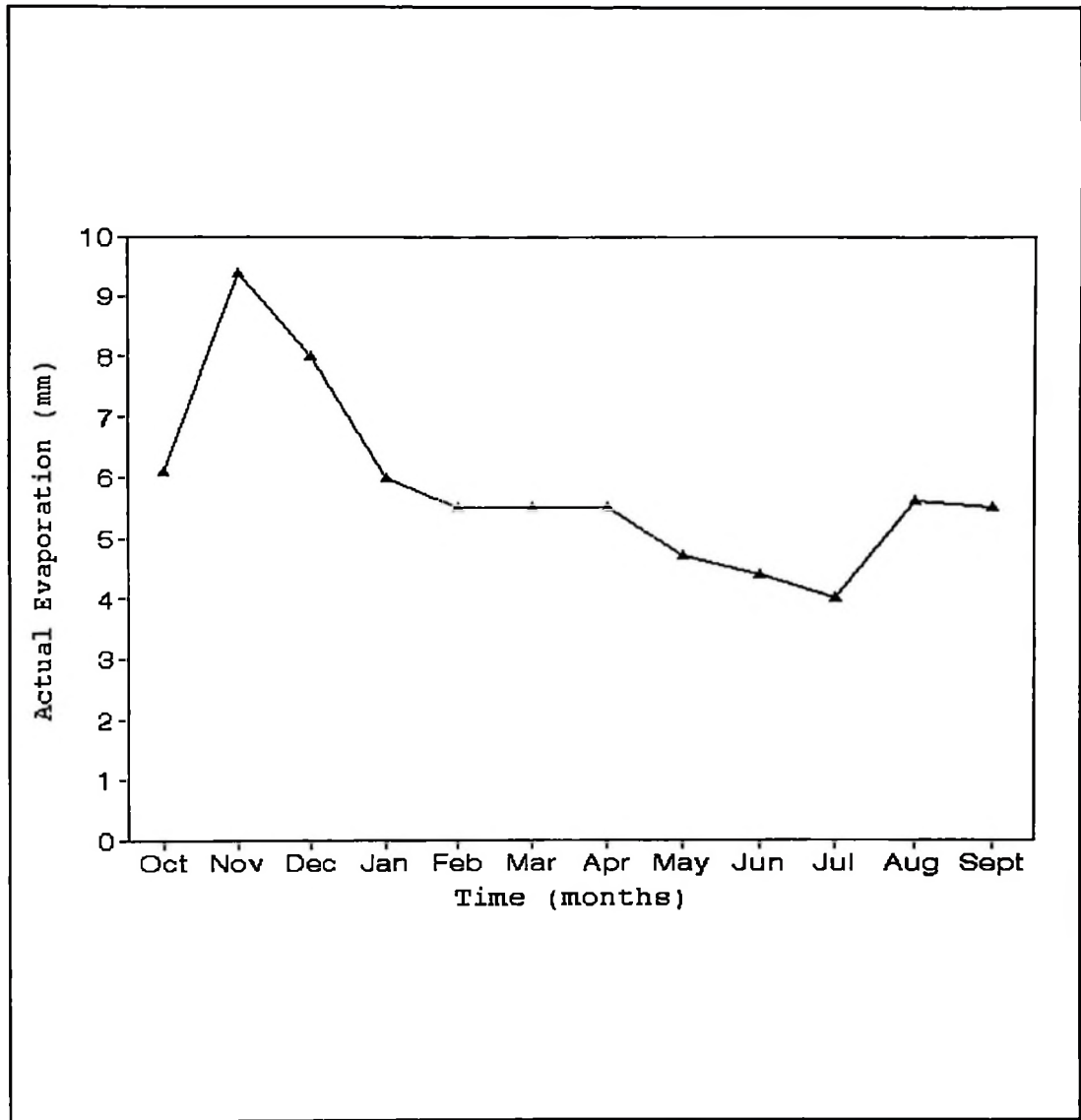
(source: Ngana, 1993)

#### **3.1.4.2 Temperature**

The mean temperature shows seasonal variation although the transition is not sharply marked. In July to August it is relatively cooler than the rest of the year and July is the coolest month with an average temperature of 19.6°C. November is the hottest month when temperatures soar up to as high as 35°C. The average annual temperature is 22.7°C.

#### **3.1.4.3 Evaporation**

As in most semi arid regions potential evaporation is normally high and it reaches its peak in November due to the high insolation and high wind speeds. Average annual potential evaporation is 2123 mm (Christianson, 1981). The actual evaporation is 650mm and on very few occasions the rainfall meets the evapotranspiration demand. Fig. 3.2 shows the average monthly daily actual evaporation for Hombolo.



**Figure 3.2** Average daily actual evaporation amounts (mm) for Hombolo

#### 3.1.4.4 Relative humidity

The high daytime temperature and low night temperature results in the huge fluctuations in relative humidity. Early morning relative humidities of 84% to 93% are common but in the hot afternoon average mid day relative humidity is 34%. The daily fluctuations in relative humidity are shown in Fig 3.3.

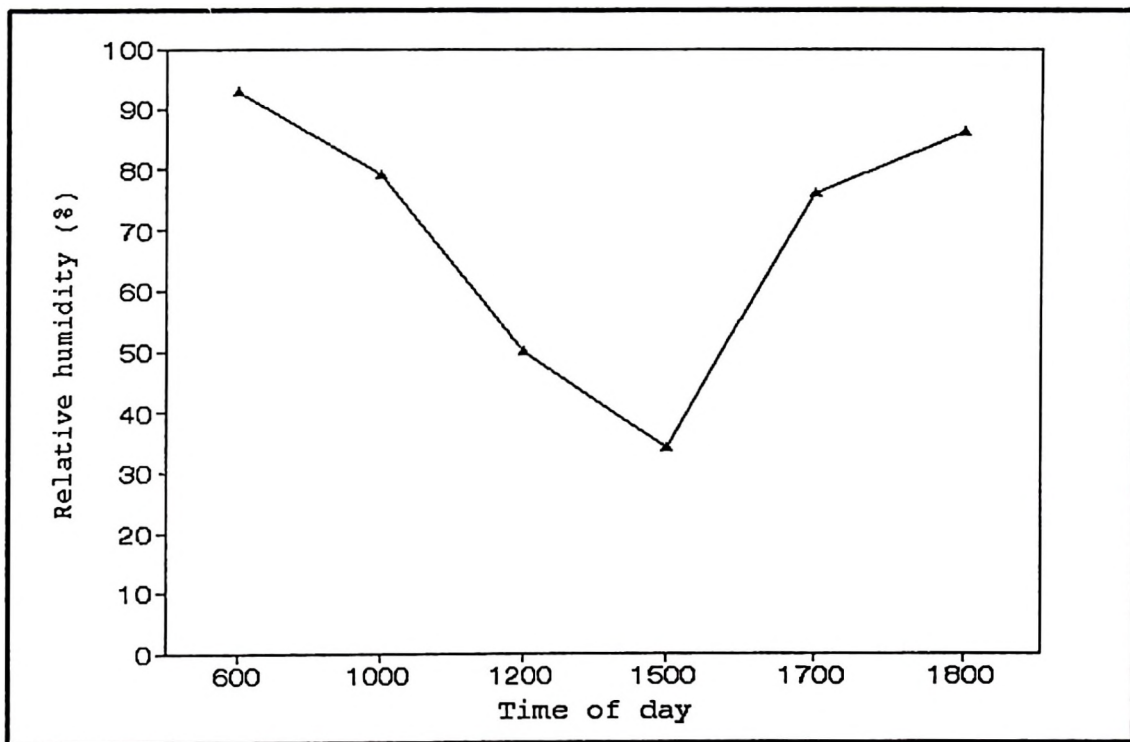


Figure . 3.3 Diurnal fluctuation in relative humidity (%)

## **3.2 Hydrology**

### **3.2.1 Drainage**

Central Dodoma belongs to the Internal drainage basins which have no external runoff hydrologically. The central part of Tanzania is drained to internal lakes on the eastern branch of the Rift Valley which include the Bahi Depression complex. The Bubu, Mponde and Kunganira are seasonal rivers draining into the Bahi Depression. The large semi-arid central plateau depends almost entirely on ground water sources.

### **3.2.2 Runoff**

Surface runoff from small control areas like erosion plots in some areas of Central Tanzania have been reported by Staples, 1938, Van Rensburg, 1955, Hatibu et al., 1995. Rapp et al (1972) concluded that runoff from semi-arid pediment areas of East Africa with poor vegetation cover can reach 30-40% of the rainy seasons precipitation for catchment areas a few square kilometres in size.

However, in larger catchments, proportionally more of the precipitation is infiltrated into the large areas of sandy rivers, sandy fans and "mbugas". From there, it is partly lost by evaporation during the dry season, which reduces the percentage of runoff.

### **3.3 Experimental design and layout**

To facilitate statistical analyses and interpretations of the data collected a completely randomised experimental design was used. There were five tillage treatments, No till (NT), Disc plough (DP), Strip Catchment Tillage (SCT), Hand Hoe (HH) and Tied Ridging (TR). The five tillage treatments were replicated three times thus a total of 15 field plots 20 m long and 5 m wide were used. The length of all the plots were parallel to the direction of the slope and the general slope average was 4%. Plots were separated by pathways of 1 m wide each. The schematic plan of the plot layout is shown in Figure 3.2.

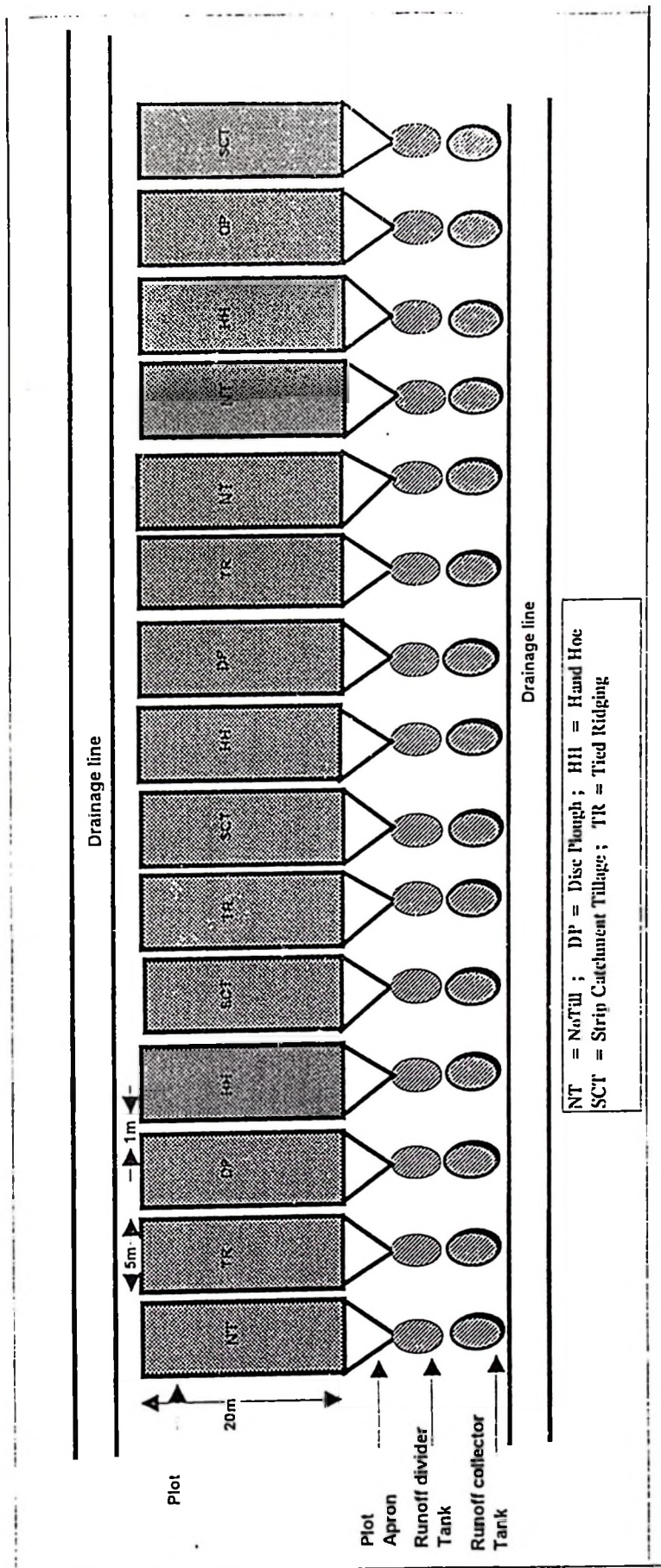


Figure 3.5 Experimental plot layout

### **3.4 Tillage treatments**

The tillage treatments used in the experiment are described below:

**(i) No Till (NT)**

Soil remained undisturbed throughout the season. The only disturbance was during planting when the hand hoe was used to dig the holes for the seeds. There were no crop residues in the plots.

**(ii) Hand Hoe (HH)**

Flat cultivation with a hand hoe which involved digging across the slope to a depth of 10 cm. It produced uniform sized clods and a relatively rougher surface configuration.

**(iii) Disc Plough (DP)**

Involved a three furrow disc plough, pulled by a 50 HP tractor ploughing at a depth of 15 cm. It resulted in partial soil inversion of the soil with less pulverisation and a very rough surface was produced.

**(iv) Strip Catchment Tillage (SCT)**

Involved digging to 10 cm depth with a hand hoe a strip in which planting of the seed was done and minimal disturbance of the soil occurred and surface roughness was relatively low.

**(v) Tied Ridging (TR)**

Top soil was heaped in a series of bunds forming ponds on the surface. The ridges were 0.75 m apart and tied at 1.5 m intervals. The ridges had average dimensions of 450mm by 450 mm and 250 mm deep. Plate 1 in Appendix C shows the tied ridging system.

The different tillage implements used were selected for some specific reasons. The disc plough was selected because of the ever increasing tractor mechanised farming in tropical Africa. Disc ploughing (DP) represents one of the most common methods of seedbed preparation in tractor mechanised farming in a large part of Africa. It was therefore found to be important to compare it with the other treatments in terms of its effects on the different factors investigated herein. Hand hoe(HH) was selected because it is the most predominant method of seedbed preparation among most peasant farmers

especially those in marginal areas. Strip catchment tillage (SCT) is a reduced tillage method which creates minimal disturbance of the soil structure and probably improve soil water storage. Tied ridging (TR) is a method being advocated for because of its advantages on water conservation. No till (NT) treatment was used in order to provide some kind of a control treatment in which the soil would remained undisturbed.

### **3.5 Planting**

Sorghum (*sorghum bicolor* var Tegemeo) was planted at a spacing of 0.75 m between rows and 0.3 m within rows. A plant population of about 45000 to 46000 plants per hectare was obtained.

### **3.6 Instrumentation and measurements**

#### **3.6.1 Meteorological data records**

The meteorological data which was recorded in the field consisted of rainfall (amount and duration) and open pan evaporation. These measurements were obtained daily from the meteorological station within the study area.

Rainfall was measured using a standard rain gauge and an automatic recording rain gauge.

Open pan evaporation was measured using a Class 'A' evaporation pan.

Daily records of minimum and maximum temperatures, wind speed and direction were also recorded at the meteorological station using minimum and maximum thermometers, cup anemometer and wind vane respectively.

### **3.6.2 Measurement of Infiltration**

Infiltration was measured using a double ring infiltrometer which consists of an inner ring (27.8 cm diameter), surrounded by an outer ring (54.5 cm diameter) as shown in Plate 4 in Appendix C. The infiltration measurements were done at the beginning of the season after the tillage operations.

### **3.6.3 Determination of soil moisture retention characteristics**

Soil cores for laboratory determination of water release characteristics on tension table (Clement, 1966) and pressure plates (McIntyre, 1973) were taken from all the five tillage treatment plots at 10 cm increments to a depth of 30 cm. Suctions were applied at 0.1, 0.3, 0.6, 1.0, 3.0, and 15 bars, and the soil moisture contents were determined at each suction level.

In order to investigate the effects of changes in bulk density caused by tillage and subsequent soil subsidence the water release characteristics were also determined using the van Genutchen(1980) model. This was for the purpose of comparing the measured and estimated curves to gain a better understanding of the variations in the curves with different tillage systems.

van Genutchen (1980) concluded from analysis of numerous experimental data sets that an accurate estimate of soil water content as a function of pressure head can be made using the equation below :

$$q(h) = q_s [ 1 + \text{abs}(ah)^n ]^{-m} \dots\dots\dots 3.1$$

with

$$\theta_e = (\theta - \theta_r) / (\theta_s - \theta_r) \dots\dots\dots 3.2$$

Mualem (1976) derived the following equation for calculating parameter m;

$$m = 1 - 1/n \dots\dots\dots 3.3$$

- where :  $\theta$  = soil water content;
- $\theta_s$  = relative saturation;
- $h$  = pressure head (-cm);

$\theta_s$  = saturated water content ( $\text{cm}^3/\text{cm}^3$ );

$\theta_r$  = residual moisture content ( $\text{cm}^3/\text{cm}^3$ ) and was  
taken as zero;

$\alpha$ ,  $n$ ,  $m$  = parameters determining shape of curve;

The parameters  $\alpha$ ,  $n$  and  $\theta_s$  in the van Genuchten relationship were derived from Veerecken et al., (1989) regression equations. These equations consider soil textural data, bulk density and organic carbon in the determination of the van Genuchten parameters as shown below :

$$\alpha = \exp(-2.486 + 0.025\text{Sa} - 0.351\text{Om} - 2.617\text{Bd} + 0.001\text{Cl}) \dots \dots \dots 3.4$$

$$\theta_s = 0.81 - 0.283\text{Bd} + 0.001 \text{Cl} \dots \dots \dots 3.5$$

$$n = \exp(0.053 - 0.009\text{Sa} - 0.013\text{Cl} + 0.0001\text{Sa} * \text{Sa}) \dots \dots \dots 3.6$$

where;

Sa = sand percentage;

Si = silt percentage;

Cl = clay percentage;

Om = Organic matter percentage;

Bd = bulk density ( $\text{g}/\text{cm}^3$ );

### 3.6.4 Determination of soil hydraulic conductivity

The hydraulic conductivity (saturated and unsaturated) of the soils was determined using the indirect method developed by Gardner and Fireman (1958). The procedure uses the van Genuchten model parameters.

Gardner et al (1958) developed the following closed form equation for predicting the hydraulic conductivity of unsaturated soils (K(h)):

$$K(h) = K_s \{1 - (ah)^n [1 + (ah)^n]^{-m}\}^2 / [1 + (ah)^n]^{m/2} \dots\dots\dots 3.7$$

where  $K_s$  = saturated hydraulic conductivity.

$K_s$  was determined/estimated using the regression equation of developed by Vereecken et al.(1990) which relates saturated hydraulic conductivity to bulk density and particle size distribution as shown in Equation 3.8 below.

$$K_s = 20.62 - 0.956 \ln(Cl) - 0.66 \ln(Sa) - 0.46 \ln(Oc) + 8.43(Bd) \dots\dots\dots 3.8$$

where :

Cl = clay fraction in the soil;

Sa = sand fraction in the soil;

Oc = organic carbon fraction in the soil;

Bd = Bulk density of the soil;

### 3.6.5 Measurement of soil moisture.

Measurement of soil moisture was done periodically using core samplers. Samples were collected randomly from each plot at three different depths per hole: 0 - 15 cm, 15 - 30 cm, 30 - 45 cm. On each of the nine sampling dates a total of 45 samples were collected and well sealed before being taken to the laboratory for drying.

The standard gravimetric method where soil samples were dried in an oven at 105<sup>o</sup>c for 24 hours was used in determining soil moisture content. The soil moisture content was expressed as a percentage of the dry weight of the soil. The gravimetric moisture content was then converted to volumetric moisture contents as shown in equation 3.9:

$$\theta_v = \theta_g * \frac{Bd}{dW} \dots\dots\dots 3.9$$

where:

$\theta_v$  = volumetric moisture content;

$\theta_g$  = gravimetric moisture content;

Bd = soil bulk density;

dW = density of water;

Volumetric moisture content measurements from the three depths were calculated. Each of the three values was assumed to represent an average value in a section of the profile of thickness 15 cm. The volume (in units of depth) contained within the soil profile was calculated as follows:

$$W_d = \sum [150 * (W_{ci}/100)] \dots \dots \dots 3.10$$

where:

$W_d$  = water content depth contained (mm) in a 45 cm deep profile;

$W_{ci}$  = volumetric moisture content at layer i (%);

i = soil layer (1,2,3);

### 3.6.6 Measurement of Surface roughness.

Measurement of surface roughness was done using a micro relief meter. The micro relief meter used in this study was similar to the one used by Kuipers (1957). The main

parts of the instrument are illustrated in Figure 3.4. It consists of a 130cm by 90cm main frame of aluminium bars. Across the middle of the frame is a needle locking string. The string is designed to hold 23 needles which slide up and down. Each needle is fitted with a small foot to prevent it from penetration the soil.

For height measuring, the whole device was placed horizontally with the needles locked up. The instrument was levelled by means of a spirit level and adjusting the support pins. The needles were then allowed to slide down until their feet touched the soil surface (measuring position). Once all needles had touched the ground, the needles were then locked in that position. Then the height of each needle above the top of the frame was measured with a ruler. Then the needles were pulled up again, locked and the meter moved to the next measuring position.

There were two metre positions for each plot on each measurement day. Measurements were done five times on a thirty day interval with two measurements done immediately before and after tillage.

The surface roughness was determined as the standard deviation of the pin height measurements.

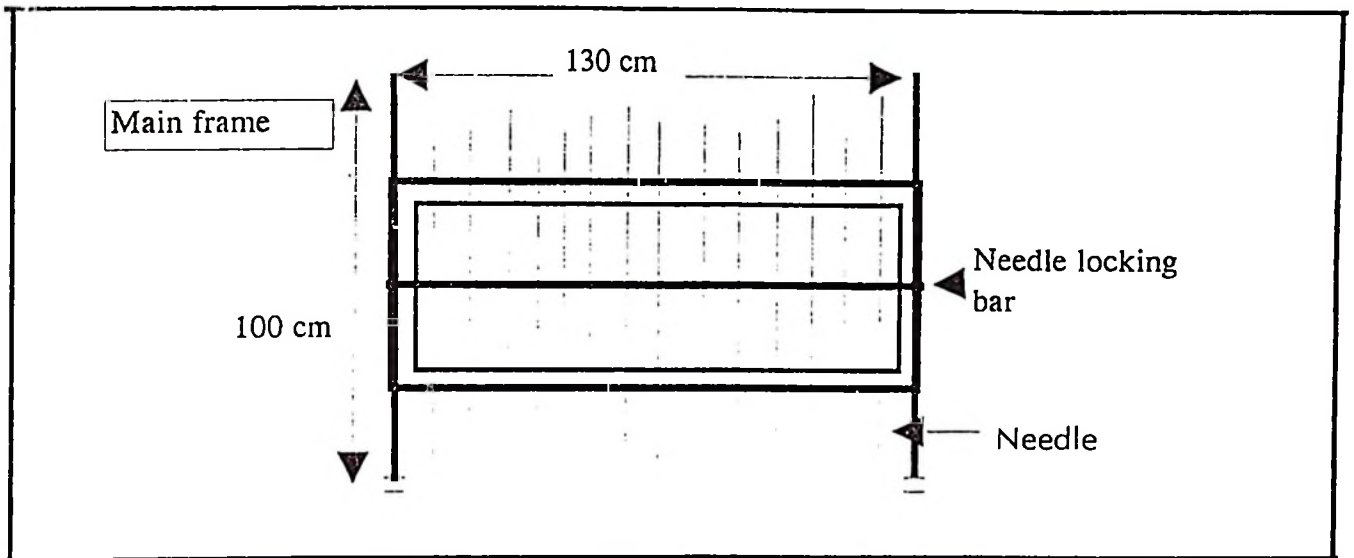


Figure 3.3 Schematic drawing of the micro relief meter

### 3.6.7 Calculation of depression storage

The Mitchell and Jones (1978) method represented by the Equation 2.8 was used in this study to determine depression storage. However in this study only rows were considered and thus the equation was modified to:

$$S_r = \sum_{i=1}^n (H_r - H_a) \dots \dots \dots 3.11$$

For the tied ridge plots depression storage was determined by covering a pond with a plastic sheet and measuring the volume of water required to fill the pond.

### 3.6.8 Measurement of bulk density and porosity.

Measurement of bulk density was done periodically during the season. Undisturbed soil samples were taken in each plot at depths of 0 - 15 cm, 15-30 cm, and 30 - 45 cm using sampling cores. The samples were oven dried at 105°C for 24 hours and weighed. Bulk density was then calculated as the ratio of the dry mass of the soil to the core volume and total porosity was calculated from the bulk density and the particle density of the soils as follows:

$$TP = 1 - \frac{Bd}{Pd} \dots\dots\dots 3.12$$

where: TP = Total Porosity;

Bd = Bulk Density; Pd = Particle density;

### 3.6.9 Measurement of soil evaporation.

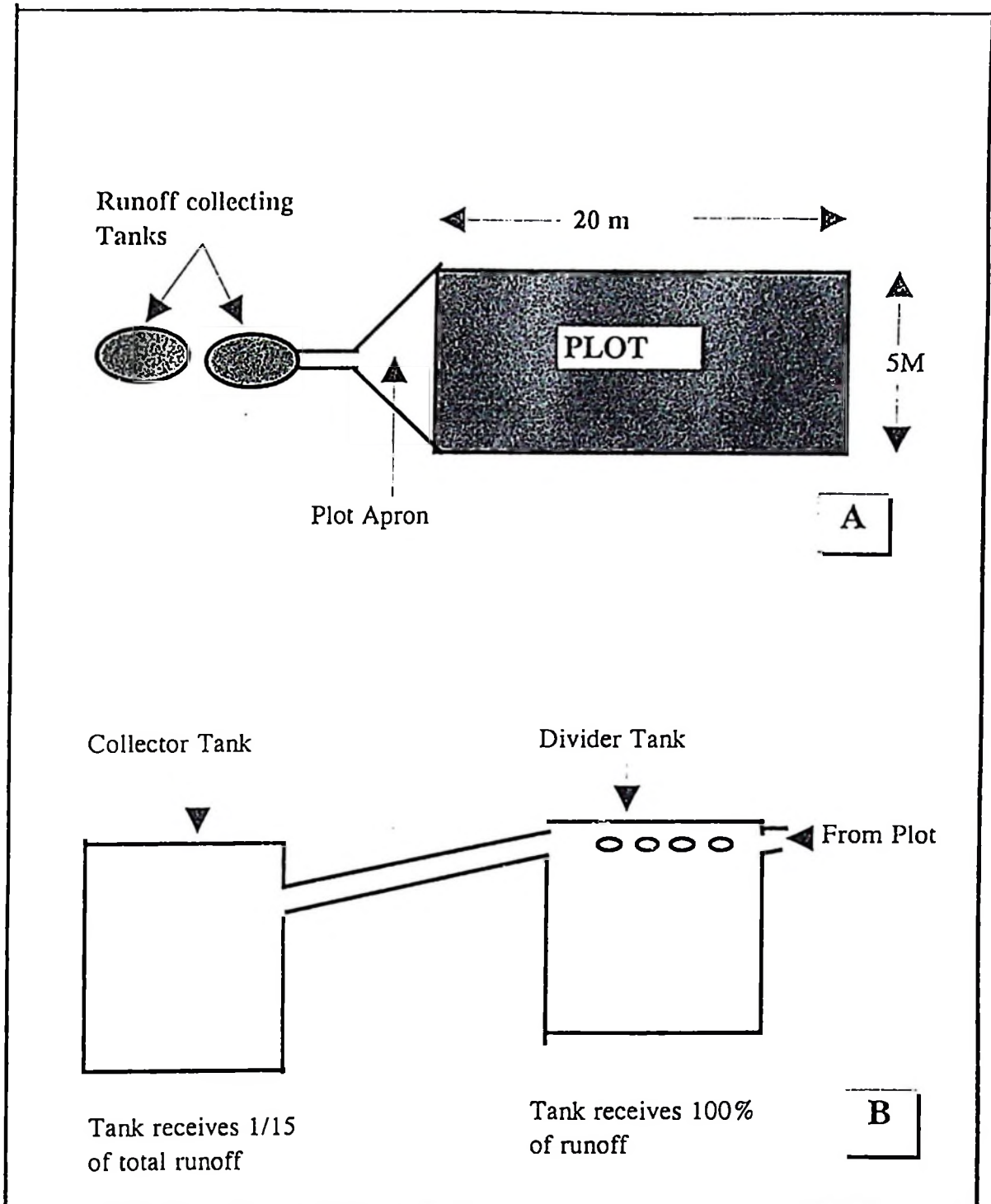
Undisturbed soil cores, micro lysimeters, were collected in cylinders constructed from 100mm (I.D). and 3.0 mm thick PVC pipe cut into pieces of 200mm lengths with the bottom edges tapered to allow easy insertion into the soil. Plate 3 in Appendix C shows the monoliths used in the experiment. The monoliths were wetted and buried in the field plots representing the five tillage treatments used. Each cylinder was measured periodically to determine the water loss by evaporation. The duration of the evaporation run was 15 days.

### 4.6.10 Measurement of surface run-off

Each plot was surrounded with metal sheets driven to a depth of 15 cm on the sides and the upslope edge. The run-off measurement data were recorded from the run-off

collection tanks (Fig.3.3). Plate 2 in Appendix C show the runoff collection systems as well.

The collection system consisted of a divider drum with 15 outlet pipes of diameter 1.91 cm. The central pipe was connected to the collector drum thus the overflow volume draining into the collector drum was 1/15 of the total overflow. Calibration of the runoff collection system was done in order to obtain the actual average ratio of the overflow that drained into the collector drum. This ratio and the apron surface area were used in the calculations of the total run-off volume from the plots. After each rainfall event, the total run-off volume entering the divider and collector drums was determined from depth of run-off, apron surface area, and over flow ratio of both divider and collector drums. A depth to volume calibration curve established for each drum was used to calculate the depth of runoff recorded.



**Figure 3.4**

**A: Overall view of plot**

**B: Schematic cross section of runoff tanks**

### **3.11 Crop growth measurements**

Plant growth was monitored by measuring plant height of four randomly selected plants in 1m<sup>2</sup> areas in each of the cropped plots. The measurements were taken at 20, 45 and 90 days after emergence. This was done in order to compare the differences in the crop growth possibly due to differences in soil moisture storage under the different tillage treatments, because all other factors like fertility were the same in all plots. At the end of the season the final crop yield in terms of grain yield for each treatment were determined and compared.

## CHAPTER FOUR

### RESULTS AND DISCUSSION

#### 4.1 Introduction

This chapter presents the experimental results and discussion in the following sections.

The results are presented in the form of tables and graphs.

#### 4.2 Effects of Tillage on Infiltration

Infiltration data was used to:

- (i) compare effects of the different tillage treatments on the cumulative infiltration.
- (ii) compare fitted parameters for the Kostiakov (1932) and Phillips (1957) infiltration models.

The results are shown in the following sections.

For all the tillage treatments, graphs of two hour cumulative infiltration were plotted as shown in Fig. 4.1.

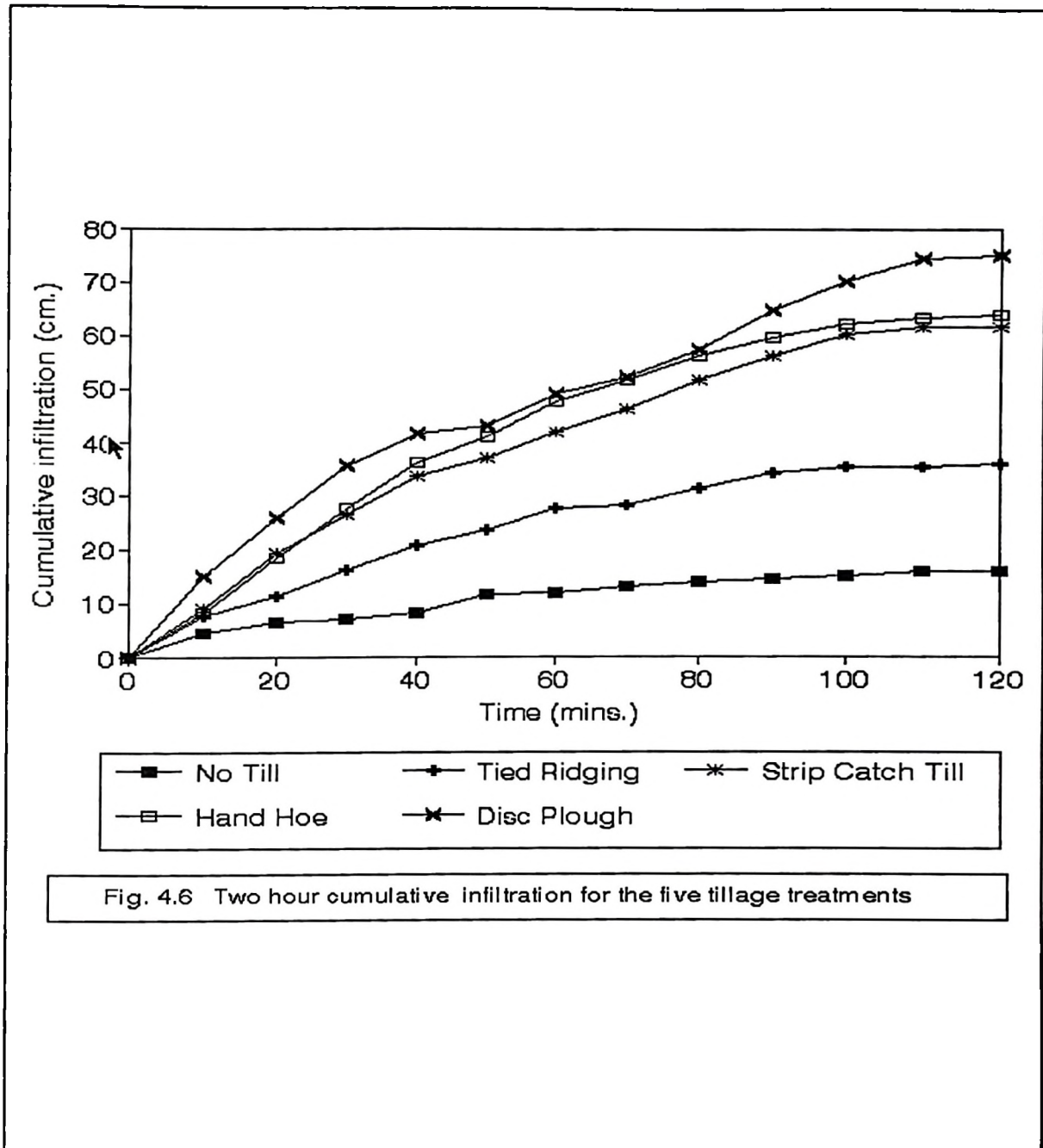


Figure 4.1 Two hour cumulative infiltration for the five tillage treatments

Tilling the soils was found to cause an enhancement in infiltration rates. Infiltration rates were significantly higher in the DP treatment than the SCT treatment. This is probably due to the higher random roughness in the DP than the SCT treatment. Higher random roughness values in the DP treatment maintains higher infiltration rates under natural rainfall due to an increased ponding depth at the surface.

The tilled plots had very high values of the initial infiltration rates, but the rates rapidly declined with time. This is probably due to rapid structural deterioration caused by slaking and dispersion. The large proportion of medium sized clods, which easily broke down and accelerated crust formation might be the major cause.

Infiltration rates were significantly low in the TR treatment than in the tilled soils. This is probably due to the fact that the infiltration tests were done in the furrows where the soil was scooped to form the ridges thus exposing less porous sub soil strata. However the advantage of tied ridging lies in the fact that the ponds created in the field will capture most of the rain water and allow it to infiltrate into the soil with time, and very little water is lost as runoff. The no till treatment had very low infiltration rates but not significantly different from tied ridging. The lower macroporosity associated with notill relative to tilled soils could be the major cause of such low infiltration values for the no till treatment.

### 4.3 Phillip (1957) Kostiakov (1932) models fitting to infiltration data

Infiltration data was analysed according to the following two models by fitting straight lines to the plots of infiltration rate (i) against the square root of cumulative time ( $t^{1/2}$ ) and log I (cumulative infiltration) against log t (time).

#### 4.3.1 Philip (1957) model

$$I = St^{1/2} + At \dots\dots\dots 4.1$$

where:

I = cumulative infiltrated water (cm);

S = soil water sorptivity;

A = Transmissivity;

t = time (min);

The equation above was fitted to the actual infiltration data to obtain values of the constants A and S.

The mean values of parameters S and A as well as the correlation coefficients and significance tests are shown in the Table 4.1.

Table 4.1 Phillips model parameters and correlation coefficients for the five tillage treatments and their significance tests.

Tillage Method	Phillips parameters		R <sup>2</sup>
	S mm/hr <sup>1/2</sup>	A mm/hr	
TR	10.73a	2.08e	0.95
NT	12.27a	2.60e	0.95
DP	50.74b	14.17f	0.90
SCT	23.24c	5.86g	0.92
HH	37.43d	9.37h	0.90

Means with the same letter in the same column are not significantly different at the 5% level of the Duncan's Multiple Range Test.

Parameter S (sorptivity parameter) indicates the capacity of a soil to absorb water and theoretically it is supposed to decrease with a reduction in the water storage capacity of the soil. It controls the initial infiltration rate.

In contrast, equilibrium infiltration rate is governed by the transmissivity parameter, A.

As time (t) increases then the second term (At) in the Phillips equation is the predominant factor governing infiltration rate or equilibrium infiltration rate.

The data showed significant differences in S of most of the treatments. Average S in the DP treatment was about seven times larger than in the NT and TR treatments and about twice that of the SCT and HH treatments. The high sorptivity values for the tilled plots imply that tillage improves the soils initial water intake ability. Trends in A were

also different among the five treatments. The A values increased with the level of soil disturbance. Again the disc plough treatment had the highest significant values of parameter A. This would imply that tillage improved the transmissivity of the soil. Similar results were obtained by Mwendera (1992) working on a silty loam soil. Lal et al. (1989) however obtained negative values for the transmissivity parameter on plow tillage treatments. Taylor and Ashcroft (1972) attributed these negative values to the heavy texture of the soils in which Lal et al. (1989) were working on.

#### 4.3.2 Kostiakov model (1932)

$$I = \alpha T^\beta \dots\dots\dots 4.2$$

I = cumulative infiltration (cm);

T = time (min);

$\alpha, \beta$  = empirical constants;

The equation was also fitted to the infiltration data to obtain values of the empirical constants,  $\alpha$  and  $\beta$ .

Taking logarithms on both sides, the equation becomes:

$$\log I = \log \alpha + \beta \log T;$$

This means that a plot of log I versus log T would be a straight line with intercept equal to log  $\alpha$  and a slope of  $\beta$ . The magnitude of  $\alpha$  indicates the initial cumulative infiltration

and  $\beta$  its rate of increase. The values of  $\alpha$  and  $\beta$  of the Kostiakov equation were calculated by performing a log transformation on the curvilinear data and calculating the linear regression on the log values. The results are shown in Table 4.2.

Table 4.2 Kostiakov parameters and correlation coefficients for the five tillage treatments and their significance tests.

Tillage method	Kostiakov constants		R <sup>2</sup>
	$\alpha$	$\beta$	
TR	#3.13a	0.205d	0.96
NT	3.25a	0.240d	0.83
DP	15.02b	0.728e	0.79
SCT	10.18c	0.414f	0.90
HH	10.48c	0.505f	0.88

# Means with the same letter in the same column are not significantly different at the 5% level of the Duncan's Multiple Range Test.

According to Kutilek et al. (1988) the parameter  $\alpha$  represents infiltration rate at the first time unit, or like sorptivity parameter (S) in the Phillips equation, the coefficient represents the initial infiltration rate (Lal et al., 1989). The exponent  $\beta$ , represents the magnitude of decline in infiltration rate with time and thus it reflects the changes in soil structure caused by wetting.

The mean values of the parameter  $\alpha$  for the DP, SCT, and HH were significantly higher than those for the NT and TR treatments. This is an indication of the enhanced effects

of tillage on water infiltration. Similar results were also obtained by Mwendera (1992) and Lal, et al (1989).

The mean values of the parameter  $\beta$  was highest for the DP treatment. This suggests a more rapid decline in infiltration rates for the DP treatment than the others. Mean values for the SCT and HH were not significantly different. The low values in the exponent for the NT and TR treatment showed that structural degradation due to cumulative water was less and thus the infiltration rates declined less sharply. The results contrast with those obtained by Lal et al.,(1989), probably due to soil texture because they were working on a poorly drained mollic ochraqualf in NW Ohio. For their work the values of the exponent, $\beta$ , were greater for the no-till treatments than the tilled treatments.

#### **4.4 Effects of tillage on Available Water Capacity**

The soil moisture release characteristic data was used to plot the pF curves and hydraulic conductivity functions for soils from each of the five tillage treatments.

The results are shown in the Figs. 4.2 to 4.7.

The average amounts of water held at pF values between 0.0 and 4.2 as well as estimated values of Permanent wilting Point (PWP), Macroporosity (MP), and Total available water (TAW) in the soils immediately after tillage are shown in Table 4.3.

Table 4.3 Estimated values of Permanent Wilting Point(PWP), Macroporosity(MP), and Total Available Water (TAW) from the moisture retention curves.

Tillage Treatment	PWP			MP	TAW
	$\theta_{0.0}$	$\theta_{2.0}$	$\theta_{4.2}$	$\theta_{0.0} - \theta_{2.0}$	$\theta_{2.0} - \theta_{4.2}$
	-----cm/cm <sup>3</sup> -----				
DP	0.395a	0.264c	0.037g	0.131h	0.227k
SCT	0.410a	0.275d	0.033g	0.135h	0.243l
HH	0.392a	0.264c	0.034g	0.128h	0.230k
TR	0.362b	0.287e	0.036g	0.075j	0.251m
NT	0.363b	0.300f	0.037g	0.063j	0.264n

Means with the same letter in the same column are not significantly different at the 5% level of the Duncan's Multiple Range Test.

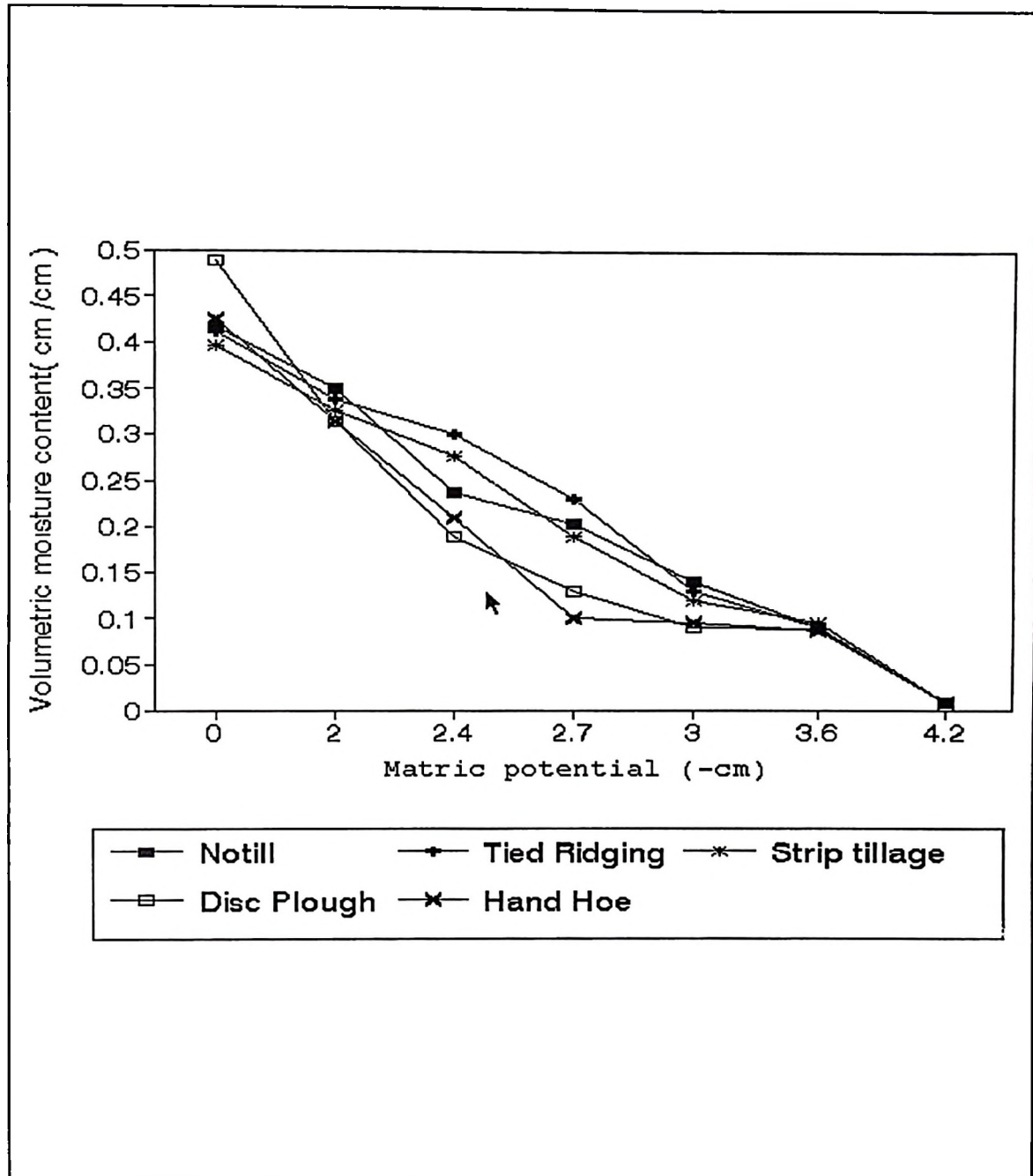


Figure 4.2 Measured soil moisture release curves for the five tillage treatments

The results show that tillage significantly increased soils moisture content at pF 0.0, and the increase was highest in the DP treatment followed by the SCT soil (although there was no significant difference between the two treatments). There was no significant difference in moisture content at the permanent wilting point. The results also showed that tillage reduced moisture content at pF 2.0. Thus there was a significant reduction in total available water as a result of tillage. The NT treatment had the largest value of total available Water.

#### **4.5 Effects of tillage on soil Hydraulic conductivity**

The hydraulic conductivity was determined using the Gardner model (Gardner et. al., 1958). Values of saturated hydraulic conductivity (Ks) were obtained immediately after the tillage operations and the results are shown in Table 4.4.

Table 4.4 Saturated hydraulic conductivity and their significance test for the five tillage treatments.

Tillage method	Ks ---cm/day---
NT	26.419a
TR	30.739a
DP	76.727b
SCT	72.001b
HH	74.702b

Means with the same letter in the same column are not significantly different at the 5% level of the Duncan's multiple range test.

The results show that tillage significantly increased Ks.

The highest values of Ks were found in the DP and the HH treatments. Similar results were reported by Cassel and Nelson (1985) although they concluded that the results were more dependent on the position for a given tillage treatment than on which of the tillage treatments was imposed. However these results contradict with those obtained by Mahboubi et al. (1967), who noted that continuous cultivation led to lower saturated conductivity than that of the no-till plots.

For the five tillage treatments hydraulic conductivity functions were plotted at different values of matric potential and the results are shown in Fig. 4.3.

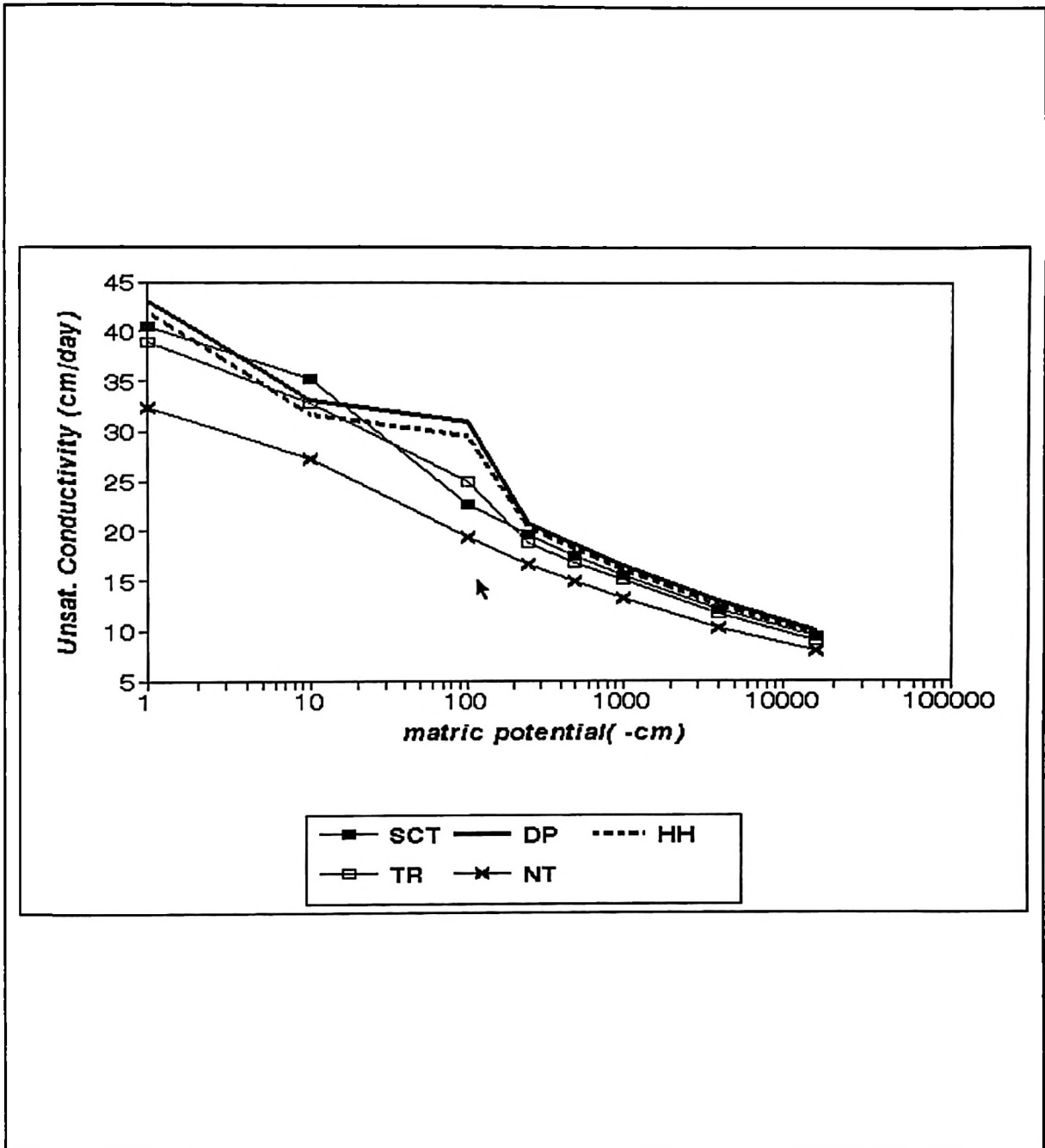


Figure 4.3 Hydraulic conductivity functions for the five tillage treatments

The variations in the  $K(h)$  functions shows the effects of the different tillage treatments on the hydraulic properties of the soil. It would appear that saturated conductivity was very much affected by tillage. Although the  $K(h)$  curves for all the tillage treatments were almost similar in the drier sections, the curves for the DP and HH were steeper in the wetter sections than for the NT, TR and SCT. The graphs show that the soils began to desaturate abruptly after a certain critical soil moisture tension ( $h$ ) had been reached. The critical soil moisture tension varied among the treatments. The almost similar  $K(h)$  curves for the DP and HH treatments suggest similar macropore size distribution for the two treatments. In the NT and TR the hydraulic conductivity changed more gradually as the soils became drier. This is an indication that the pore size distribution was more uniform in these soils.

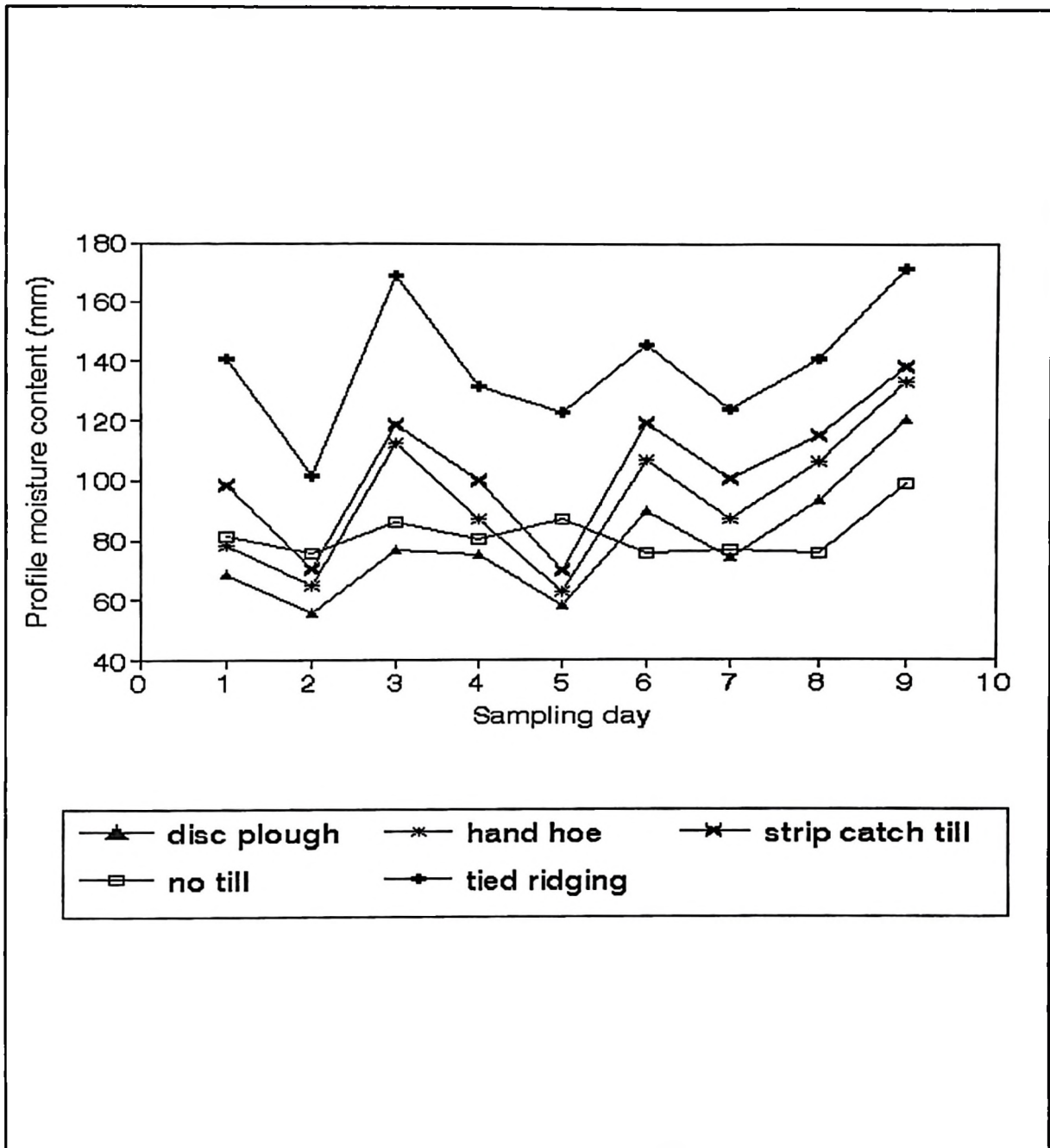
#### **4.5 Influence of tillage on soil moisture regimes**

In order to facilitate comparison of soil moisture storage performance among the different experimental treatments, average profile moisture content of the soil profile to a depth of 45 cm was calculated for each sampling day and for each treatment. Analysis of variance was used to evaluate the influence of tillage method on soil moisture storage. The results are shown in Table 4.5 and Fig. 4.4.

Table 4.5 Profile soil moisture content at different sampling times for the five tillage treatments and their significance tests

sampling day	Tillage method				
	DP	HH	SCT	NT	TR
	-----Profile moisture content (mm)-----				
1	46.89a	47.02a	56.53a	43.03a	88.63b
2	23.6c	26.33c	31.73d	28.37c	45.20e
3	72.72f	70.73f	75.67fg	83.70g	96.93h
4	72.77i	69.77i	61.67j	53.23k	74.2i
5	15.23im	9.47i	18.57m	18.03m	73.7n
6	88.92o	81.56o	73.37o	16.20p	71.73o
7	41.13q	49.30r	35.90q	19.03s	54.13r
8	69.92t	68.63t	78.77u	71.90t	95.73v
9	71.38w	70.37w	76.76x	100.68y	119.4 z

Means with the same letter on the same day are not significantly different at the 5% level of the Duncans Multiple range test



**Figure 4.4** Profile soil moisture content (mm) for the five tillage treatments

These results show that the effect of tillage method on the soil profile moisture content were highly significant.

Theoretically, treatments which produced higher depressional storage values would have higher values of profile moisture content. The results obtained from this study consistently agreed with the theoretical expectations. The TR treatment had significantly the highest values of profile soil moisture content because of the significantly high values of depressional storage. The depressions kept water for longer periods and allowed it to infiltrate into the soil profile. The tied ridging treatments had the highest values of soil moisture at all times. This agrees with the results obtained by Kayombo and Lal (1992) who noted that in relation to either open ridging or flat cultivation, tied ridging increased soil water content, soil water retention, and available water capacity, decreased surface runoff, and surface bulk density.

The SCT and DP treatments had high values of depressional storage but these were significantly lower than those of the TR treatment and, thus, they had lower soil moisture content than TR. Theoretically, higher values of bulk density are normally associated with low levels of soil moisture, and vice versa. In this study, on several occasions, treatments with higher values of bulk density also had significantly higher values of profile water content. On the whole, the results from the experiment did not clearly show a distinct pattern of behaviour for the effects of bulk density on the profile soil moisture content.

Early in the season NT treatment had significantly higher levels of profile soil moisture

than the HH, SCT and DP plots, although bulk density was higher for the NT treatment than the rest of the treatments and also depressional storage was low for the NT than the rest of the treatments.

This is contrary to what would be expected. However, results showing relatively high profile moisture contents under no till in comparison to other tillage methods have been noted in several other studies (Kayombo et al., 1991, McFarland et. al., 1991). McFarland et al (1991) attributed the high moisture content in the NT treatment to improved infiltration rates under no till as a result of a more stable structure and existence of a more continuous pore system from dead roots and worm activity which are often lacking in the conventionally tilled soils.

The merits of notill system, including soil moisture retention, in biostructurally active soils has been documented for some tropical regions (Lal, 1985).

#### **4.6 Effects of tillage on surface random roughness**

Random roughness was determined as the standard deviation of the pin height measurements of the relief meter. Analysis of variance was used to compare the differences in random roughness caused by different tillage treatments. The data for random roughness was also fitted to the Zobeck and Onstad (1987) equation.

Generally initial random roughness values were significantly higher on tilled plots than

untilled plots. The results are shown in Table 4.6

Table 4.6 Mean values and significance tests of field measured Random roughness of the four tillage treatments.

Cumulative rainfall (mm)	Tillage Method			
	NT	SCT	DP	HH
	---- Surface roughness (cm) ----			
0	0.69a	3.34b	8.33c	4.80d
142.4	0.60e	2.87f	6.33g	1.85h
315.4	0.59i	1.66j	5.28k	1.5 j
407.6	0.54l	1.15m	4.77n	1.9 o
637.4	0.54p	0.56p	1.63q	0.6 p

Means with the same letter on the same day are not significantly different at the 5% level of the Duncan's Multiple Range test.

There was no consideration of the tied ridging treatment because making tied ridges creates oriented roughness while all the other treatments had random roughness. Thus there was only consideration and comparison of those treatments which produced the same effect but at different extents.

Data obtained in this study was fitted to the Zoebeck and Onstad (1987) equation which relates random roughness to cumulative rainfall as shown in Equation 2.9

The derived regression equations for the tillage treatments used in this experiment are shown in Table 4.7

Table 4.7 Fitted Zobeck and Onstad (1987) equations  
for random roughness decline.

Tillage treatment	Equation	$r^2$
DP	$RR = 9.39RR_0e^{-0.00265P}$	0.96
HH	$RR = 3.72RR_0e^{-0.00277P}$	0.95
SCT	$RR = 3.47RR_0e^{-0.00205P}$	0.96
NT	$RR = -0.37RR_0e^{-0.00104P}$	0.91

The equations predicted relatively well the decay in random roughness except for the NT where an  $r^2$  of 0.91 was relatively poor.

Random roughness declined rapidly with small amounts of rainfall and approached a steady rate of decline with additional rainfall. The initially high rate of decrease could probably be due to sloughing and breakdown of soil clods as a result of wetting. Subsequent rate of reduction is checked by deposition into the depressions and the shear resistance of the individual soil clods. The regression coefficients show the relative decline in each treatment. The high  $\beta$  value for the DP showed a more rapid decline in the DP than the other treatments. Rate of decline in the SCT and HH were almost the

same. The reduction in random roughness has a great significance in the soil water storage capacity. The slow and steady decline in the SCT and HH treatments mean that more water would be held in the depressions at any time than in the DP where the roughness would have declined more significantly. This could partly explain the greater amount of soil moisture in the SCT and HH treatments at times than in the DP.

The relatively low regression coefficient and negative value of  $\beta$  for the NT suggests that the variation of random roughness as described by the above equation does not truly characterise the changes in actual physical conditions on the NT surface. A number of rills were developed by rainfall on the NT surface which increased with cumulative precipitation and created some oriented roughness which gave a picture of increase in random roughness with precipitation.

From these results it would appear that the decline in random roughness and its residual value depends to a greater extent on the initial surface conditions, which is contrary to what Dexter (1977) reported. Dexter (1977) reported that random roughness reduction due to rainfall was independent of the initial random roughness and the surface conditions.

The reduction in random roughness which occurs with soil pulverisation increases susceptibility of soil to wind erosion because a smoother surface is less effective in reducing wind velocity. A smoother surface does reduce wind turbulence, but the effect of the decreasing turbulence has on reducing wind erosion usually does not compensate entirely for the increased surface wind velocity (Chepil and Milne, 1941). The

considerable turbulence which would occur over a rougher surface at higher wind velocities might be expected to enhance water vapour loss from the soil. The susceptibility of the smoother surfaces to crust formation would be greater, than for rougher surface. At the end of the season, SCT, HH and NT had random roughness' which were not significantly different.

#### **4.8 Influence of tillage on depressional storage**

The values of actual elevations (measured) and line of best fit (LOBF) obtained by simple regression analysis were plotted against distance between measuring points. All points below the LOBF were taken as depressional storage as described by Mitchell and Jones (1976).

Depressional storage was determined at different times during the rainy season to observe the influence of cumulative rainfall on the depressional storage produced by each tillage treatment. The results are shown in the following sections.

##### **4.8.1 Effect of tillage method on depressional storage**

Average values for the tillage treatments for all the measurement periods and their significance tests are shown in Fig. 4.5.

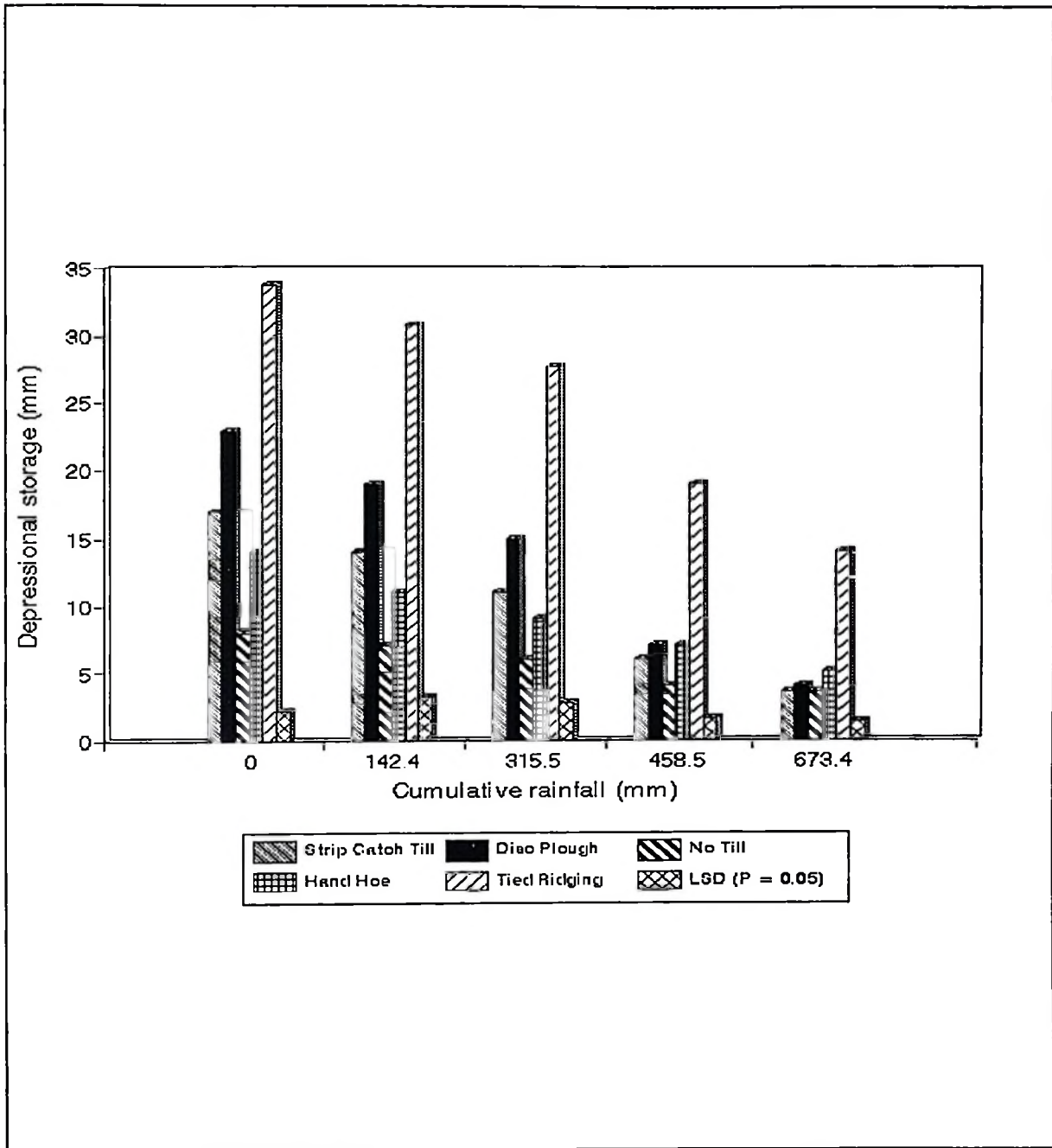


Figure 4.5 Depressional storage for the five tillage treatments

The TR treatment had the highest values of depressional storage throughout the season while the NT treatment had the least values. The pulverisation of the soil clods caused by the hand hoe resulted in lower depressional storage for the HH than the SCT treatment. Soil tilth with larger clods always gave higher depressional storage values. These observations are consistent with observations by other researchers (Makungu, 1991; Burwell and Larson, 1969) who observed that different tillage methods produced substantially different random roughness values and thus depressional storage.

#### **4.8.2 Effect of cumulative rainfall on depressional storage**

It was observed that the volume of the tied ridges were eroded after intense storms as well as silting of the ponds. As a result the depressional storage got reduced significantly with time. The effect of the raindrop impact on the soil clods in the HH and DP plots resulted in a sharp decline in depressional storage. Such an observation would be expected since the random roughness in these treatments also declined rapidly with cumulative rainfall. This decline in depressional storage has a great impact on soil water storage. Lower levels of depressional storage mean less water is kept on the soil surface and allowed to infiltrate. The decline in depressional storage would result in an increase in surface roughness which is undesirable in semi arid regions where rainfall is unreliable.

#### 4.9 Influence of tillage on total porosity

In all treatments, the initial tillage-induced total porosity was significantly higher than of the untilled soil. The harrowed soil had the highest initial porosity although it was not significantly different from that of the DP and HH as shown in Table 4.8.

Table 4.8 Mean values and significance test of total porosity for the five tillage treatments.

Tillage method	Cumulative rainfall (mm)				
	0	142.4	315.4	407.6	637.4
	----- Total porosity -----				
DP	0.53a	0.46c	0.45d	0.45e	0.44f
SCT	0.51a	0.46c	0.44d	0.43e	0.42f
HH	0.52a	0.45c	0.44d	0.43e	0.42f
TR	0.46b	0.45c	0.44d	0.43e	0.41f
NT	0.45b	0.43c	0.43d	0.42e	0.41f

Means with the same letter on the same day are not significantly different at the 5% level of the Duncan Multiple Range test.

Generally total porosity of the ploughed soils was highest throughout the season although there was no significant difference between the values. According to these results, the significance of ploughing was to increase total porosity. Similar results were obtained from ferruginous sandy loam soils of Botswana (Willcocks, 1981) and Kikuyu red loam soils of East Africa (Hosegood, 1964). However these results are contrary to those

obtained by Lal (1979b) and Armon (1980), who found notill to be superior to tilling in maintaining a high total porosity in the soil. This disparity could be due to differences in initial soil conditions, climate, soil type and machinery used as well as the cropping history of the area prior to the experiments.

Total porosity was found to decrease with depth for all the treatments as would be expected because of the increase in bulk density with depth.

#### **4.10 Influence of tillage on soil Bulk Density**

Table 4.9 shows the measured bulk densities for all the treatments at different cumulative amounts of rainfall during the season.

Table 4.9 Bulk density values for the five tillage treatments at different cumulative rainfall amounts

Tillage method	Depth	Cumulative rainfall (mm)					
		Bdo	0	142.4	315.4	407.6	
637.4							
-----Bulk density (g/cm <sup>3</sup> )-----							
NT	0 - 5	1.51	1.51	1.51	1.53	1.54	1.56
	5 - 10	1.52	1.52	1.53	1.55	1.58	1.58
	10 - 15	1.52	1.52	1.52	1.56	1.59	1.61
TR	0 - 5	1.43	1.40	1.44	1.46	1.48	1.51
	5 - 10	1.46	1.46	1.46	1.48	1.51	1.56
	10 - 15	1.47	1.50	1.51	1.56	1.57	1.60
HH	0 - 5	1.48	1.42	1.44	1.47	1.48	1.53
	5 - 10	1.48	1.43	1.46	1.49	1.52	1.53
	10 - 15	1.53	1.48	1.50	1.54	1.57	1.61
DP	0 - 5	1.51	1.41	1.44	1.44	1.43	1.45
	5 - 10	1.52	1.41	1.45	1.45	1.46	1.47
	10 - 15	1.52	1.45	1.47	1.48	1.48	1.49
SCT	0 - 5	1.48	1.40	1.42	1.46	1.49	1.53
	5 - 10	1.49	1.43	1.44	1.48	1.49	1.52
	10 - 15	1.51	1.49	1.51	1.52	1.53	1.56

Note:

NT= No till; TR = Tied ridging; HH = Hand Hoe;  
 DP = Disc Plough; SCT = Strip Catchment Tillage;  
 Bdo = bulk density measured before tillage.

Tillage was found to decrease soil bulk density and the DP treatment had the lowest bulk density after tillage. The complete inversion and structural breakdown associated with the disc plough is the cause of this low bulk density as compared to the SCT treatment where disturbance is only along some defined parts of the field.

Increase in Bulk density was significantly high in the SCT, than in the DP and HH soils. The relatively low increase in the DP and HH, despite low initial bulk density, is probably due to the presence of large clods which behaved like the untilled soil. Significantly higher repacking and re-settlement of soil aggregates which occurred in the harrowed soil resulted in higher increases in bulk density with cumulative rainfall.

#### **4.11 Influence of tillage on evaporation**

The cumulative evaporation amounts for the different tillage treatments were obtained and analysis of variance was used to compare the obtained values. Table 4.10 and Fig. 4.6 shows the results for mean separation and a plot of cumulative evaporation with time respectively.

Table 4.10 Mean values of cumulative evaporation (Es(mm)) from soil monoliths.

Tillage method	DAYS				
	3	6	9	12	15
-----Cumulative Evaporation (Es)-----					
(mm)					
NT	32.42a	51.88c	57.54d	62.39e	67.41g
DP	37.54b	49.96c	60.80d	67.93f	71.97h
SCT	36.81a	56.36c	60.98d	67.28f	69.88h
HH	34.20b	53.15c	59.69d	63.20e	66.20g

Means with the same letter on the same day are not significantly different at the 5% level of the Duncan's Multiple Range Test.

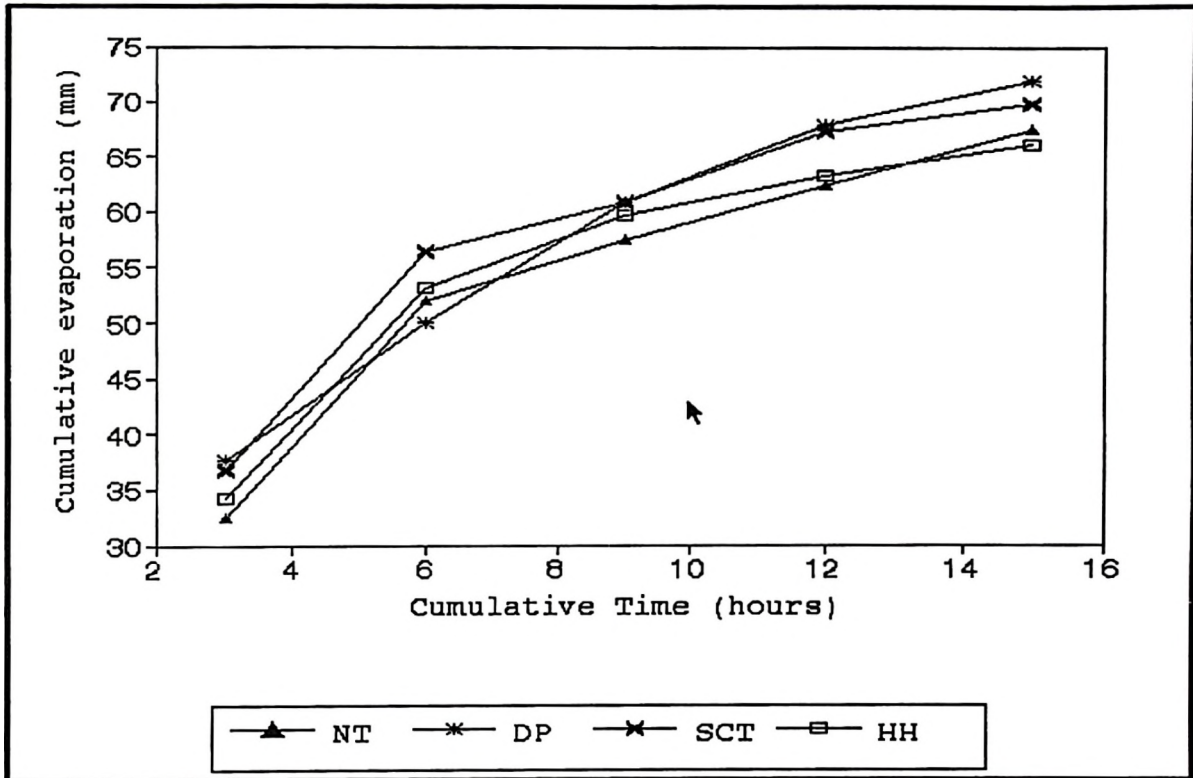


Figure 4.6 Cumulative evaporation for four tillage treatments

From Table 4.10 it can be seen that evaporation losses from tilled soils were higher than losses from untilled soils. There was no significant difference in cumulative evaporation between the DP and SCT soils, but both soils had significantly higher losses than the HH and NT tilled soils. This may be an indication of increased "forced" evaporation effect on the rougher and looser surfaces.

The higher cumulative losses for the Disc Plough and the Hand Hoe soils were probably due to the effect of forced evaporation caused by increased surface areas of soils exposed to the atmosphere and greater penetration of wind, both of which are conducive to an increase in evaporation. Evaporation rates were higher in the DP and HH soils. This is probably due to turbulent transfer of water due to forced or thermal convection out of the large holes between the large clods created by the disc plough and the stripping. It is also possible that the rougher surfaces created a larger effective evaporative surface.

The data for the evaporation losses for the treatments were also normalised on the no till data. This was done by dividing the evaporation from each of the tillage treatments by that from the NT treatment. Graphs are shown in Fig. 4.7.

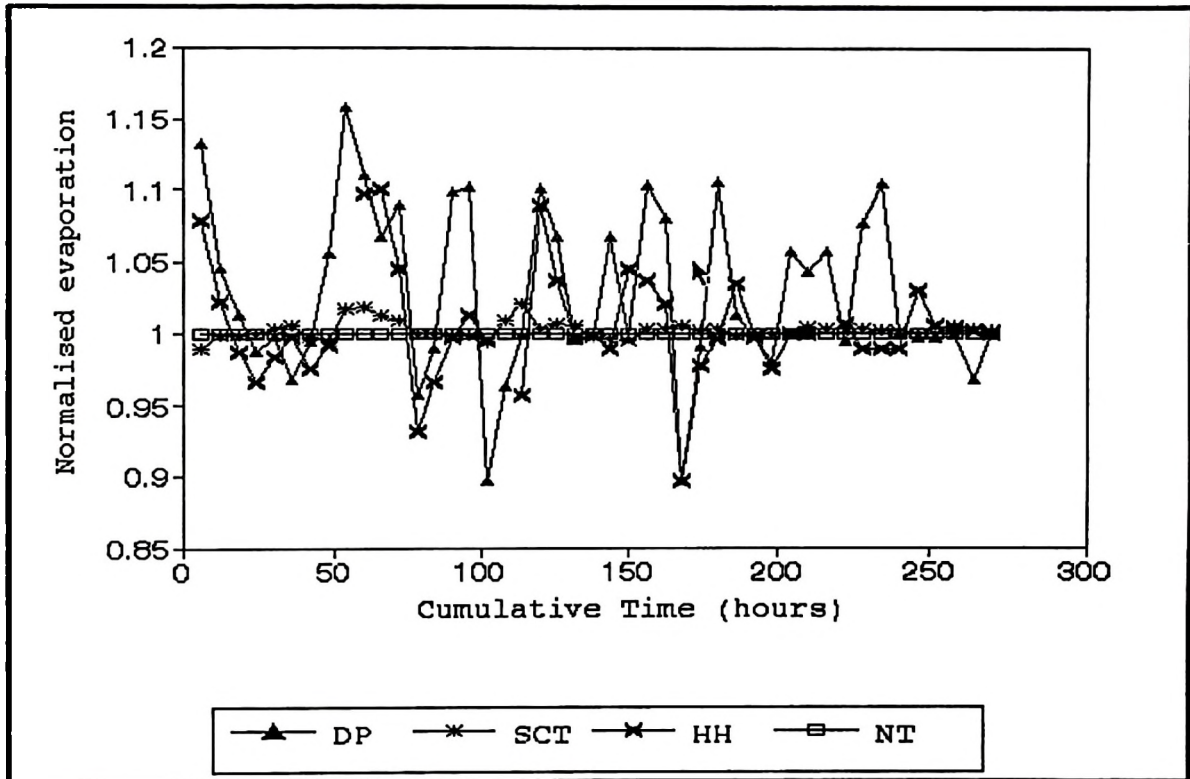


Figure 4.7 Normalizes evaporation for DP, SCT, HH and NT treatments

The normalized graphs all followed a cyclic pattern. The cyclic pattern was more pronounced in the DP and HH soils. The cyclic pattern could probably be a manifestation of the "soil mulch" effect. Thus the "soil mulch" effect was more pronounced on the DP and HH soils. It can be deduced from the graphs that stage 1 evaporation rates were higher for the DP and HH soils than the SCT soils. After some time the presence of a dried top layer reduced evaporation to levels below that for the NT soils as shown by the reduced cyclic nature of the normalised graphs.

#### 4.12 Influence of tillage on surface runoff

Table 4.11 shows the measured amounts of surface runoff generated in each treatment.

Table 4.11 Effects of tillage in generated surface runoff

Date	Rainfall amount (mm)	NT	DP	HH	SCT	TR
9/12/95	9.4	0.60	00.33	00.31	00.21	00.15
22/12/95	31.6	7.30	14.40	17.68	16.00	00.82
27/12/95	7.4	0.12	00.00	00.07	00.04	00.00
29/12/95	10.6	1.40	00.63	01.10	01.00	00.50
06/01/96	61.2	**	**	**	**	13.20
13/01/96	15.3	2.30	0.90	1.60	1.20	00.60
26/01/96	26.5	7.70	8.60	8.10	8.30	0.69
31/01/96	13.8	2.60	6.79	4.24	4.07	0.29
01/02/96	34.0	15.30	11.6	16.6	14.7	2.70
03/02/96	24.1	5.20	15.6	9.50	9.30	0.60
06/02/96	32.3	7.20	6.3	11.3	11.9	2.10
07/02/96	17.9	3.60	7.09	5.24	5.07	0.76
09/02/96	24.1	4.70	14.4	7.60	11.3	0.62
12/02/96	13.8	2.30	2.21	1.94	1.51	0.21
15/02/96	27.3	4.50	4.00	3.51	4.16	0.71
18/02/96	14.6	2.90	2.07	1.68	2.64	0.14
22/02/96	20.3	3.10	8.36	7.91	5.63	1.10
25/02/96	29.2	4.70	2.07	2.35	1.10	0.61
11/03/96	20.1	2.40	6.63	7.54	4.92	0.21
14/03/96	7.7	0.30	0.92	0.87	0.59	0.06
16/03/96	15.5	2.90	1.07	1.70	2.64	0.08
26/03/96	15.1	3.20	2.45	3.10	2.82	0.13
27/03/96	16.8	4.76	2.93	4.12	3.00	0.67
02/04/96	56.3	**	**	**	**	9.56
09/04/96	10.8	0.53	1.2	0.61	0.87	0.03

Note: \*\* Runoff was in excess of the capacity of the measuring system

Tied ridging produced the least runoff as expected while NT and HH and DP treatments produced higher runoff yields on average in most of the rainfall events.

The results also show the interaction between surface roughness and generated surface runoff. Initially there was less runoff in the DP and SCT plots than in the NT plots because of the rougher surfaces under DP and SCT which facilitated water ponding in the surface depressions and runoff would only begin after a certain critical depressional storage had been satisfied. However due to the deterioration in the surface roughness with cumulative rainfall, runoff generation was almost beginning at the same time and the amounts of runoff were almost insignificantly different.

Most experiments involving a no till treatment would normally include crop residues in the no till plots. This would help to reduce the loss of water as surface runoff. However in this experiment there were no crop residues in the no till plots and that is the reason why the NT plots had relatively high values of surface runoff.

4.13 Tillage effects on sorghum growth and final yield

4.13.1 Effect of tillage on plant growth

Plant height measurements were done at 20, 60 and 90 days after emergence (DAE) The results are shown in Fig. 4.8.

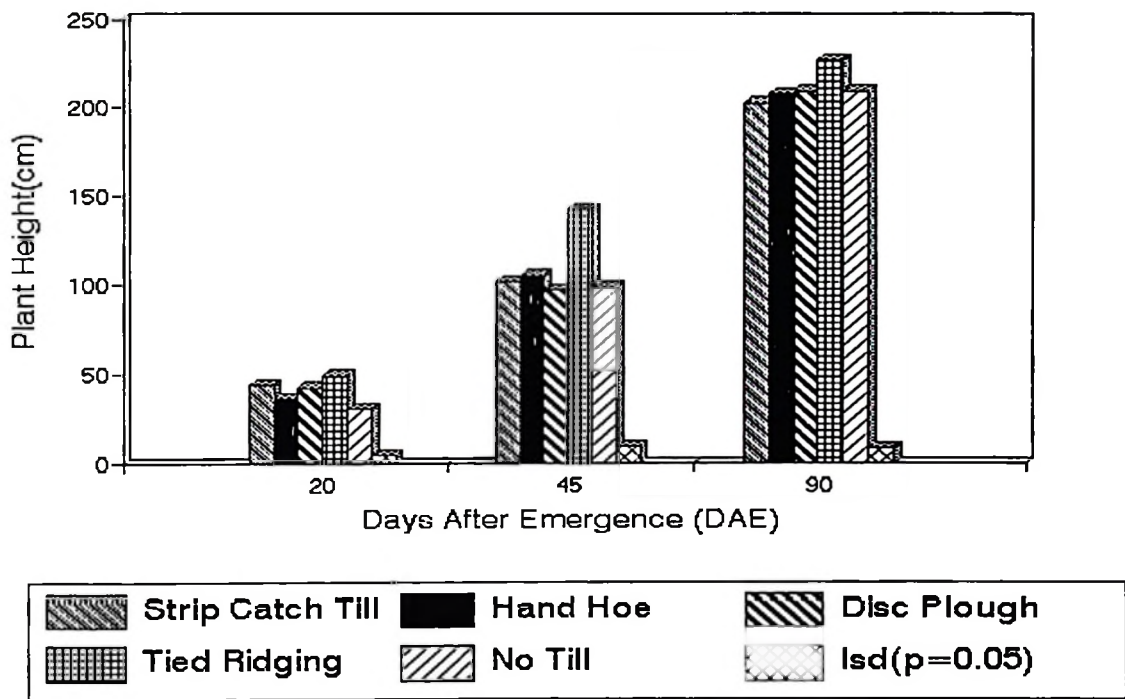


Figure 4.8 Sorghum plant height for the five tillage treatments at 30, 60, and 90 DAE

Figure 4.14 shows that the tied ridging plots generally had plants which were growing well. A more favourable soil moisture regime at most times during the season could be the reason because the only source of variation was the tillage treatment. The NT plots had plants whose height was lagging behind all the other treatments throughout. However there was no significant difference between the plant heights for the SCT, HH, and DP 60 days after emergence.

#### 4.12.2 Effect of tillage on final grain yield

Analysis of variance was used to compare the grain yield from each treatment. Appendix b4 shows the ANOVA and table 4.12 shows the mean yields obtained for each experimental treatment and their significance tests.

Table 4.12 Effect of tillage method on final grain yield of sorghum and the significance test

Tillage treatment	Yield (kg/ha)
HH	2143.53a
SCT	2262.39b
TR	2406.79c
DP	2162.39a
NT	2038.46d

Means with the same letter are not significantly different at the 5% level of the Duncan's range test.

Most experiments involving a no till treatment have often shown increased yields in the no till treatment relative to all the other treatments. However this was not the case in this experiment. This is most probably due to the influence of crop residues. Most no till treatments often have crop residues from the previous season and this helps to store soil moisture, reduce evaporation and runoff as well as providing plant nutrients as the residues decompose. In this experiment all the crop residues from the previous season had been removed and this could probably be the reason why the no till treatment had relatively low yields.

The tied ridging had the highest yield most probably due to the high water retentivity associated with tied ridging. The SCT treatment also produced relatively higher yields. These results agree with results obtained by other researchers discussed earlier on. Mahoo et. al, (1995) working on the same soils in the same area also obtained similar results.

In Ohio, Dick et. al, (1991) found higher maize yields under NT than conventionally tilled soils in a 25 year experiment. However they observed that such an advantage of the no till system was only pronounced as the experiment proceeded. In the initial years there were no significant advantages of the no till system. This could be the reason why in this work the no till system had lower yields than the yield from conventionally tilled soils.

**CHAPTER FIVE****CONCLUSIONS AND RECOMMENDATIONS****5.1 Conclusions**

From the study carried out the following conclusions can be drawn:

- (a) Within the range of the results obtained, it can be concluded that tillage increases water holding and transmitting properties of the soil. The more open the tillage induced structure, the greater is the increase. However with increased cumulative rain, the effect of tillage in enhancing surface water storage is undermined by structural breakdown of the surface layer which results in greatly increased surface runoff. The finer the tillage induced surface structure, the more vulnerable it is to structural damage from the impact of rainfall.
- (b) The effect of tillage on soil water evaporation is highly dependant on the surface structure. More evaporation will occur from rougher surfaces which are more open than the smoother surfaces.
- (c) The results indicate that a high degree of random roughness and total porosity created by tillage results in increased soil water infiltration during raining.

- (d) Treatments associated with high values of depressional storage had higher soil moisture contents at throughout the season.
- (e) Tied ridging reduced the amount of surface runoff as compared to all the other treatments. However in places of frequent heavy rainstorms, the dykes would normally be destroyed and thus they would need rehabilitation at least twice during the growing season.
- (f) There were significant yield differences among the tillage treatments indicating that tillage induced soil conditions affected the yield. A more favourable soil moisture regime in the tied ridging plots resulted in higher yields.
- (g) Tillage resulted in substantial increases in saturated and unsaturated hydraulic conductivities for the top 25 cm of the soil. Conductivity was ranked in the following order:

$$\text{DP} = \text{HH} = \text{SCT} > \text{TR} > \text{NT}.$$

- (h) Random roughness and depressional storage was of the order:

$$\text{TR} > \text{DP} > \text{SCT} > \text{HH} > \text{NT}.$$

TR had the highest values of depressional storage because of the oriented roughness associated with tied ridging. With cumulative rainfall, however,

random roughness deteriorated drastically, and at the end of the season the values were almost the same for all treatments.

- (i) Bulk density decreased after tillage for all the treatments. However with cumulative rainfall the density increased. Porosity variation was simply a mirror image of the bulk density variation for all the tillage treatments.

## **5.2 Recommendations**

From the study the following recommendations can be made:

- (a) There is need to extend the study to other soils and different tillage treatments. This will broaden the base of information on the influence of tillage on the soil properties investigated in this study.
- (b) Under natural rainfall conditions, changes in the water intake properties of a soil may be caused by soil weathering (i.e. changes in surface characteristics due to repeated wetting and drying, rainfall action and thixotropic changes). It is, therefore, necessary that the influences of such changes on infiltration can be considered in future tillage infiltration studies.

- (c) Tied ridging should be adopted by small scale farmers for soil moisture conservation. However tied ridges should be regularly maintained because with time and rainfall they easily get eroded and silted.
  
- (d) The results presented here are not conclusive since it has been observed elsewhere that tillage depth also plays a major role in influencing the effectiveness of tillage in reducing evaporation rates (Gill and Prihar, 1983). Thus it is recommended that future studies should include the combined effects of tillage type and tillage depth on different soils and atmospheric evaporative demand on the drying characteristics of the soils.
  
- (e) Understanding the effects of tillage on infiltration and depressional storage is necessary in applications of irrigation, drainage and hydrologic modelling on a field scale. Additional experimental designs are recommended to account for unequal plot slopes, unequal residue cover and unequal initial soil moisture content that exist in the field experiments. These factors affect infiltration and depressional storage and may obscure the tillage effects. Alternative statistical analysis such as Analysis of Covariance (ANACOVA) can be used so that those factors could be considered as covariates while analysing tillage effects on infiltration and depressional storage.

Generally the study confirmed that it is difficult to make generalisations about tillage effects on soil physical and hydrologic properties as well as crop growth because the response of the soil to tillage system depends on soil type, climate and cropping sequence.

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## APPENDICES

## Appendix A

**Profile description**

**Ap 0-12 cm :** Brown (7.5YR 5/4) moist and light brown (7.5 YR6/4) dry, sandy loam; moderately weak medium crumb; slightly sticky, slightly plastic (wet), very friable (moist) and slightly hard (dry);,many very fine to fine random pores; common very fine roots; abrupt, smooth boundary.

**AB 12 -28 cm :** Brown to dark brown (7.5 YR 4/4 ) moist and brown (7.5 YR 5/4) dry, sandy loam; strong coarse granular; slightly sticky, slightly plastic (wet), very friable (moist) and hard (dry); very few medium and common fine and very fine random pores; few very fine roots ; clear smooth boundary.

**Bu1 28 - 46 cm** Strong brown (7.5 YR 5/80 moist and reddish yellow(7.5 YR6/6) dry , sandy clay loam; moderately weak medium sub angular blocky , non sticky, non plastic (wet), very friable (moist) and hard (dry); common fine and very fine random pores ; gradual smooth boundary.

**Bu2 46 -102 cm** Reddish (5 YR 6/8) moist and reddish yellow (5 YR 7/8) dry, sandy clay loam; moderately weak medium sub angular blocky; non sticky non plastic (wet); very friable (moist) and hard (dry); common fine and very fine random pores; gradual

smooth boundary.

**Bu3 102- 158 cm** Reddish yellow (5 YR 6/8) moist and reddish yellow (5 YR 7/8) dry, sandy clay loam; moderately weak fine and medium sub angular blocky; slightly sticky, slightly plastic (wet), very friable (moist) and hard (dry) common fine and very fine random pores; clear smooth boundary.

**Bgcs 158 178 cm** Light brown( 7.5 YR 6/4) moist and pink (7.5 YR 7/4) dry, common fine faint clear strong brown (7.5 YR 5/6) mottles slightly gravelly sandy clay loam; moderately coarse sub angular blocky sticky and plastic (wet), firm (moist) and very hard (dry); few fine to medium pores; very few angular quartz gravel (2 - 4 mm) very few large ( 1.0- 1.5 cm) slightly soft irregular dark red iron stone nodules, abrupt smooth boundary.

**Ccs 178 - 184 cm** Pinkish gray (7.5 YR6/2) moist and pinkish gray ( 7.5 YR 7/2) dry; common medium distinct clear strong brown mottles, slightly gravelly sandy clay loam ; massive; sticky and plastic (wet), firm moist and extremely hard (dry); few fine pores; very few large ( 1.0 - 1.5 cm) slightly soft irregular dark red ironstone nodules.

## Analytical data of soil profile

Horizon	Ap	AB	Bu1	Bu2	Bu3	Bgcs	Ccs
Depth (cm)	0-12	12-28	28-46	46-102	102-158	158-178	178-200
Clay	16.0	17.0	22.0	23.0	32.0	27.0	24.0
Silt	5.0	5.0	4.0	5.0	2.0	4.0	2.0
Sand	79.0	78.0	74.0	72.0	66.0	69.0	74.5
Textural class	SL	SL	SCL	SCL	SCL	SCL	SCL
1:2.5 water pH	5.4	5.1	5.2	6.0	5.5	5.4	5.3
1:2.5 kcl pH	4.2	4.0	3.8	3.8	3.8	3.7	5.8
Organic C (%)	0.60	0.36	0.33	0.16	0.16	0.20	0.11
Organic m (%)	1.03	0.62	0.57	0.28	0.28	0.34	0.19
Total N (%)	0.05	0.03	0.04	0.02	0.030	0.03	0.02
Available P (mg/kg)	11.6	5.6	2.8	2.8	2.8	2.5	2.8

## APPENDIX b1

Analysis of variance for Phillips(1932) parameter S

Source	DF	Sum of squares	Mean squares	F ratio	F prob
Treatments	4	5052.9908	1263.2477	74.4491	0.000
Error	10	254.5189	16.9679		
Total	14	5307.5098			

Analysis of variance for Phillips(1932) parameter A

Source	DF	Sum of squares	Mean squares	F ratio	F prob
Treatments	4	305.1676	76.2919		
Error	10	.0000	.0000		
Total	14	305.1676			

Analysis of variance for Kostiakov (1932) parameter  $\alpha$ 

Source	DF	Sum of squares	Mean squares	F ratio	F prob
Treatments	4	477.5908	119.3977	61.4192	0.000
Error	10	19.4398	1.9440		
Total	14	497.0306			

Analysis of variance for Kostiaikov (1932) parameter  $\beta$

Source	DF	Sum of squares	Mean squares	F ratio	F prob
Treatments	4	0.4279	0.1070	4.2338	0.0292
Error	10	0.2527	0.0253		
Total	14	0.6806			

Analysis of variance table for saturated hydraulic conductivity

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Treatments	4	7256.8929	814.2232	218.3156	.0000
Error	10	83.1010	8.3101		
Total	14	7339.9938			

## APPENDIX B3

Analysis of Variance for profile soil moisture on first sampling date

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Tillage treatments	4	4187.7947	1046.9487	5.1322	.0165
Error	10	2039.9797	203.9980		
Total	14	6227.7744			

Analysis of Variance for profile soil moisture on second sampling date

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Tillage treatments	4	856.9173	214.2293	28.5259	.0000
Error	10	75.1000	7.5100		
Total	14	932.0173			

Analysis of Variance for profile soil moisture on third sampling date

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Tillage treatments	4	1373.6107	343.4027	13.0697	.0006
Error	10	262.7467	26.2747		
Total	14	1636.3573			

## APPENDIX B3 (cont.)

Analysis of Variance for profile soil moisture on fourth sampling date

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Tillage treatments	4	925.3427	231.3357	35.6523	.0000
Error	10	64.8867	6.4887		
Total	14	990.2293			

Analysis of Variance for profile soil moisture on fifth sampling date

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Tillage treatments	4	8213.8840	2053.4710	132.8133	.0000
Error	10	154.6133	15.4613		
Total	14	8368.4973			

Analysis of Variance for profile soil moisture on sixth sampling date

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Tillage treatments	4	9996.9424	2499.2356	19.4040	.0001
Error	10	1288.0026	128.8003		
Total	14	11284.9450			

Analysis of Variance for profile soil moisture on seventh  
sampling date

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Tillage treatments	4	2231.6600	557.9150	32.1565	.0000
Error	10	173.5000	17.3500		
Total	14	2405.1600			

Analysis of Variance for profile soil moisture on eighth  
sampling date

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Tillage treatments	4	1500.7293	375.1823	23.0100	.0000
Error	10	163.0517	16.3052		
Total	14	1663.7810			

Analysis of Variance for profile soil moisture on ninth  
sampling date

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Tillage treatments	4	5590.4007	1397.6002	245.3293	.0000
Error	10	56.9683	5.6968		
Total	14	5647.3690			

## APPENDIX B4

Analysis of Variance for final grain yield

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Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Treatments	4	231912.0698	57978.0175	3748578.71	.0000
Error	10	.1547	.0155		
Total	14	231912.2245			

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APPENDIX C



Plate 1 : Tied ridging system;

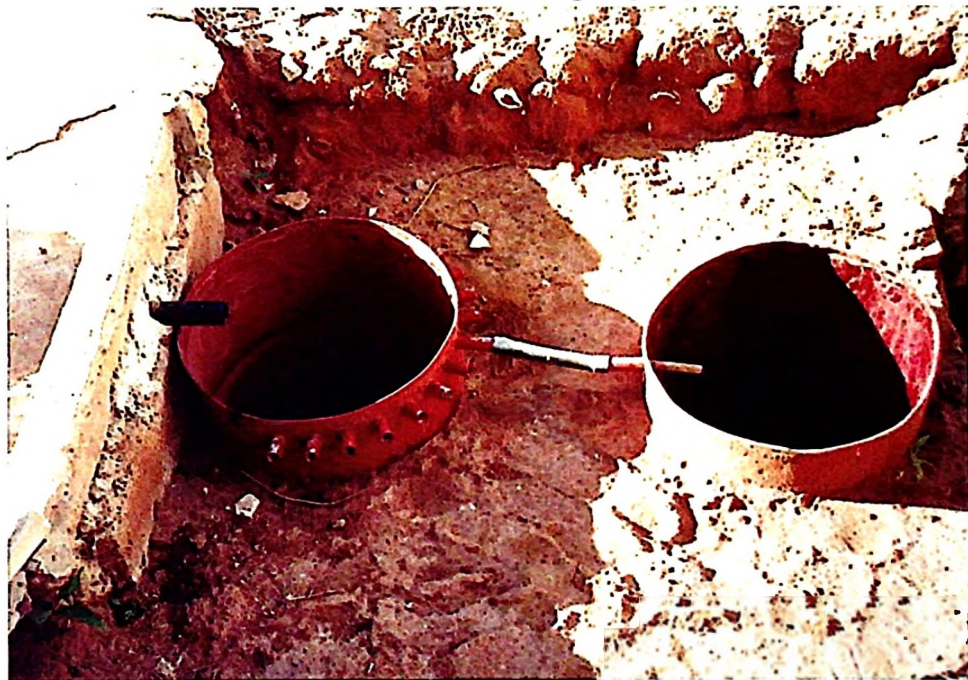


Plate 2: Runoff collection tanks opened



Plate 3 : Evaporation experiment monoliths