

**EFFECTS OF RESIDUAL TIED RIDGES ON SOIL PHYSICAL FACTORS
AND SORGHUM YIELD IN SEMI-ARID CENTRAL TANZANIA.**

BY

RAMADHANI BAKARI MSILAGI MWALIKO.

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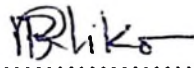
ABSTRACT

With the increasing use of conservation tillage, many questions have been raised on the viability of using residual tied-ridging system. The reported field study was conducted in semi-arid central Tanzania on a continuing three year old tillage trial comprising No-till (T1), Shallow tied ridges (T2) and deep tied ridges (T3) to study the effect of residual tied-ridges on soil physical and hydrological properties as well as sorghum grain yield. Land preparation involved the removal of crop residues from the previous season and a minimum maintenance of residual ridges. The test crop was sorghum cultivar Tegemeo. Investigated parameters include dry bulk density and cumulative infiltration which were determined before planting, at mid season and after harvest. Gravimetric soil moisture determinations at different soil depth were made on weekly basis. Measurements on soil surface roughness were made before and after every field operation and after every heavy rainstorm. Bulk densities were significantly ($p=0.05$) different between T1 and other treatments only at mid season within 0-10 cm soil layer. Total porosity values were not significantly different among tillage treatments during the study period. Weekly gravimetric soil profile moisture content (mm) in 0-50 cm soil layer was significantly ($p=0.05$) different between treatments on the 4th, 8th, and 17th week after planting. Profile moisture content variations of between 40.4 to 59.4 mm, 48.4 to 77.7 mm and 57.5 to 85.5 mm for T1, T2 and T3 respectively were observed during the growing season. However, T1 had significantly ($p=0.05$) higher cumulative infiltration than T2 and T3 by 134.8 and 172.8 mm before planting, 764 and 845.5 mm at mid season and by 355 and 437 mm at harvest respectively. Tillage significantly ($p=0.05$) affected the soil surface

roughness indices (SSRI) among treatments. SSRI variations of between 68.7 to 106.3 for T1, 152.8 to 169.2 for T2 and 173.2 to 180.0 for T3 were observed. Moreover the SSRI decreased during the growing season. Percentage seedling emergence was significantly ($p=0.05$) higher in T1 by 5.7 and 14.2% than in T2 and T3 respectively. Nevertheless the crop stand at harvest was lower in T1 by 15.1 and 4.1% than in T2 and T3 respectively. T2 and T3 had significantly ($p=0.05$) higher grain yield by about 0.85 and 1.06 t/ha respectively. Grain yield was more than doubled by residual tied-ridges compared to the control which had a yield of 0.64t/ha. Residual tied ridges are thus a viable tillage system which can reduce tillage and ridging cost as well as increase sorghum grain yield in semi-arid areas.

DECLARATION

I, RAMADHANI BAKARI MSILAGI MWALIKO, do hereby declare to the Senate of Sokoine University of Agriculture that the work presented here is my original work and has not been submitted for a higher degree award in any other University.

Signature:.....

Date:..... 13 - 06 - 2001

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DEDICATION

To my parents who have encouraged, prodded and loved me through every venture and upon whose interest I can ever depend.

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LIST OF SYMBOLS AND ABBREVIATIONS

CEC	Cation exchange capacity
°C	Centigrade degree
CV	Coefficient of variation
L	Soil layer
DAP	Days after planting
$R_{(k)}$	Roughness index
Θ_g	Gravimetric water content
Θ_p	Profile water content
Θ_v	Volumetric water content
DMRT	Duncan multiple range test
SSRI	Soil Surface Roughness Indices
FAO	Food and Agriculture Organisation
UNESCO	United Nations Educational, Scientific and Cultural Organisation
DAE	Days after emergence

CHAPTER ONE

1. 0. INTRODUCTION

Semi-arid zones occupy about one third (295000km²) of the total land area of Tanzania and extend NE/SW across the central part of Tanzania (Hatibu *et al*, 1995). In semi-arid regions, soil management is often dominated by considerations of water supply to the crop. While the potentials for increasing crop water supply is limited, small increases in available water often result in large relative increases in crop yields (Henderson, 1979). The supply of water by natural precipitation is occasional and irregular in occurrence (Hillel, 1977) and much of the rain in semi-arid zones is lost through runoff. It is estimated that run-off losses from the field can account for 30 to 35% of the storm rainfall (Hoogmoed *et al.*, 1984).

Most crops grown in the semi-arid zones usually experience water stress at some stage during the growing period. Consequently, any significant variation in the temporal and spatial distribution of rainfall usually results in serious food availability problem and a worsening poverty trap for those whose very livelihood directly depend on farming (Ngana, 1993). Furthermore, the low crop yields are mainly due to inappropriate tillage practices. Most farmers in central semi-arid areas of Tanzania prefer zero tillage (kuberega) practice, which is the technique involving manual slashing of the bare ground

(Hatibu *et al.*, 1995). Conservation of moisture is the primary concern in the management of agriculture in semi-arid areas in order to ensure a sustainable food production (Hillel, 1977).

This can be achieved through the use of conservation tillage and application of organic matter. The ridging system is not practiced for crops such as sorghum and pear millet because planting operations for sorghum and millet usually start prior to the onset of rain season when making ridges is not feasible due to soil being too dry to work.

Various conservation tillage methods have been developed, namely tied ridges, contour bands, terraces and rainfall multiplier (Hudson, 1995). There is a considerable evidence that tied ridging systems is the most effective method of increasing crop yield in regions of low unreliable rainfall (Hulugale *et al.*, 1988; Jones and Clarke, 1987). Tied ridging system is considered to be very effective in soil moisture conservation and to increase crop yield (Wright *et al.*, 1995). The labour requirements for building ridges and ties is however a major limitation to the adoption of tied ridging system in semi-arid areas of Tanzania. There is a need therefore to develop methods that could minimize the labour requirement for constructing ridges and ties. This could be achieved through the use of residual tied ridges. This system is widely practiced in some countries like Zimbabwe where it is known as no till tied ridging system (Elwell *et al.*, 1988).

There is a body of evidence indicating that manuring increases the range of plant available water (Tisdale, 1982; MacLean and More, 1979; Kramer, 1995). However, the large amount of manure needed per hectare, its limited supply and lack of means of transportation of manure to the farms are bottlenecks to the adoption of the practice. There is a need therefore to develop affordable moisture conservation tillage technique which will subsequently alleviate labour bottlenecks and increase crop yield above the current low yields levels.

Although tied-ridging is economically a desirable practice, it should be used in such a way that a long-term and productive system is created. Thus, basic data is required on changes in different parameters which occur as a result of long term use of no-till on tied ridges in order to come up with a sound recommendation package on their use.

This study had a main purpose of obtaining some basic information on changes in soil physical and hydrological properties of soil including crop yields when no-till tied ridges without manure are practiced on long term basis.

The main objective of this study is to evaluate the long term effect of tied ridges on soil water, soil compaction and sorghum crop performance in semi-arid areas of Hombolo, in Dodoma region, Tanzania.

The specific objectives are as follows:

1. To evaluate the effect of residual tied ridges on seasonal soil profile water content
2. To determine the effect of residual tied ridging on infiltration rate
3. To assess the effect of residual tied ridges use on soil compaction (Bulk density).
4. To determine the effect of residual tied ridges on crop establishment and yields of sorghum.

CHAPTER TWO

2. 0. LITERATURE REVIEW.

2. 1 Soil Moisture.

Conserving soil moisture in the soil profile is very important for crop production. In dryland areas there are long intervals between rainfall events which affect the germination and emergence of sown seeds. This limits the plant population and restricts early growth as observed by Aujilla and Cheema, (1983). Apart from poor distribution of rains there are also factors which affects soil moisture storage. They include evaporation rate, tillage and soil depth.

With regard to evaporation, Gill *et al* (1977) observed that the initial high rate of evaporation from untilled soils tends to decline sharply after a few days under high evaporation rate while it continues at a steady rate for a much longer period under low evaporation rate. They also revealed that since the rate of vapour loss from the soil is directly proportional to the potential evaporation, then the rate of loss through the tilled layer become less than that from untilled soil and cumulative soil moisture conservation increases significantly.

Different tillage systems have been reported to influence soil moisture differently. For example, Lyle and Dixon (1977) found that tied ridging offered a promising solution to soil moisture conservation for cotton in Israel. The improvement was attributed to the presence of adequate soil moisture trapped within the ridges. The alteration of soil pore volume and pore size and their distribution by soil cultivation has an important effect on soil aeration, infiltration and soil moisture retention. Van Ouwerkerk and Boone (1970) suggested that it is the alteration of pore size distribution during tillage that caused loss of large pores and a predominance of small pores which influence moisture retention after ploughing. Gravimetric field soil moisture results for a comparatively wet growing season and dry season by Goss *et al.*, (1978) suggested that ploughed soil can retain more soil moisture during wet season, than during the dry season.

2.1.1 Soil Water Conservation.

Conservation of soil water is one of the most important soil management aspects (Cook, 1962). When water infiltrates and is stored in the soil it increases the amount of water available to crops for their growth and development and it preserves soil productivity by preventing soil degradation by erosion (Lal, 1989). In an effort to achieve the above benefits in various situations, different methods have been developed and tested (Unger *et al.*, 1991).

Among them are tillage methods (Aina *et al.*, 1991), mulch farming (Nye, 1952, Pierrier, 1987, Lal, 1991), agroforestry (Kang *et al.*, 1981 and Lal, 1989), terracing, contour

cultivation and grass strip (Hudson, 1981). The most important way is increasing water absorbing power of the soil (Prentice, 1946). Use of tied ridges is one of the engineering method with considerable success. The method has been developed from the modification of locally used ridges. The method has been widely tested in West Africa, Sudan Savannah (Hulungalle, 1990), the semi-arid tropics of Burkina Faso (Perrier, 1987) and in the Central great plains of USA (Jones and Stewart, 1990).

2.2 Soil water management aspect related to tillage.

Tillage and soil surface management play crucial roles in the management of water resources and alleviating water related constraints to agricultural production and environmental quality (Lal, 1993). The principal aspect of water management in relation to tillage are outlined below.

Table 1. Water management techniques in relation to tillage.

Water management aspect			
Irrigation	Drainage	Surface-runoff management	Soil-water conservation
- Furrow/flood	- Blocking	- Safe disposal	- Mulching
- Sprinkler	- Land forming	- Water harvesting	- Reduced tillage
- Drip	- Raised -beds		- Ridge tillage
	- Ridge system		

(Source: Lal, 1993)

However, tillage techniques differ depending on soil properties and antecedent soil conditions. A study by Meickle (1972) revealed that tied ridging technique is very effective in improving moisture infiltration and storage in the soil. Tied ridging is also known to significantly reduce soil loss and run-off (Meickle, 1972). Clark and Jones (1981) in their study observed that water conserved by tied ridging system increased sorghum grain yield from 1420 to 1650 kg/ha. Increased soil water content and crop yields were also reported from Botswana by ODA (1980). Tied ridges resulted in more water in the soil throughout the growing season than open furrow and increased sorghum yield 550 to 800kg/ha.

2. 3 Traditional Ridging Systems in Tanzania.

The traditional ridging system is still being practiced by a substantial percentage of farmers in Tanzania. In the Southern Tanzania, the Matengo tribe dig circular or semi-circular pits (locally called (ngoros) for the purpose of increasing storage of water into surface depressions and hence reducing soil loss and storm runoff (Stenhouse, 1944; Allan, 1965; Jones and Stewart, 1990). This system of cultivation acts as a water harvesting technique (microcatchment water harvesting technique) (Ben-Asher and Boers, 1982). The raised ground surrounding the pits act as a seedbed on which millet and sorghum are planted (Basehart, 1973).

On the Ukara Island - Tanzania, Ludwig (1968) reports of terracing, tied ridges and stone embankments being used to conserve soil and water. Furthermore, the Nyiha tribe in Mbozi Tanzania use mounds and ridges where sorghum, finger millet and maize are the main crops grown. Finally, Dagg and Marcarney (1968) working on Oljoro area in Arusha, Tanzania with calcarous clay, clay loam and sand loam soils demonstrated the potential of tied ridges on runoff reduction.

2. 4 Tie Ridging

The tie ridge system is an improved version of the traditional ridging. The ties are at a lower elevation (5 to 10cm lower than the main ridge and connects two adjacent main ridges at right angles). A series of basins created by the ties hold surplus water and allow

more time for it to infiltrate into the soil (Lawes, 1966, Dagg and Marcartney, 1968; Hulugalle, 1987; Day, 1988). Research conducted with tie ridges on upland alfisols in Sudan showed lower runoff collection, at 0 - 15% of the seasonal rainfall whilst 20-45% of the seasonal rainfall was collected on open ridges. The low runoff from tied ridges promoted high water use efficiency by the crop leading into significant sorghum yields (Hulugalle, 1987). Dagg and Macartney (1968) also reported significant increase in yields of cotton, sorghum and maize planted in tied ridges compared to those grown on flat surface in Sukumaland in Tanzania. Day (1988) reported an increase in infiltration (2 to 4 times) leading to higher food production (60 - 90%) on tied ridges than on flat cultivation on alfisols in Mali.

2.5 No-till tied ridging.

In the recent years interest in conservation tillage systems has increased in response to need to promote water conservation and at the same time to limit erosion (Hulugale *et al.*, 1986; Unger *et al.*, 1988). Conservation tillage is a concept of farming designed to minimize tillage operations thereby reducing energy requirements and it has been found to have a great potential benefits in the semi-arid regions where rainfall is erratic and soils are highly variable. Conservation tillage also means few trips over the field which should reduce energy, time and labour inputs (FAO, 1990). Similarly, several studies in the United States and elsewhere have found conservation tillage superior and more cost

effective than conventional tillage (Fregley, 1983; Underwood *et al*, 1984; Stonehouse, 1991).

No-till tied ridging has been developed as means of overcoming high labour and draft power required in the ridges and ties making in Zimbabwe. In this method land is ploughed so that the ridges and ties can be built and in the subsequent years the land is not ploughed, ridges and ties are maintained at proper size and shape (Elwell and Norton, 1988). Studies from various experimental stations in Zimbabwe have shown that the system is effective in water storage in farmers managed trials and it has been widely adopted (Nyamudeza *et al*, 1993). The advantages of no-till tied ridging system have been investigated in Zimbabwe (Vogel, 1991). The study was carried out in two sites with two rainfall regimes (450 to 650mm and 750 to 1000mm annual rainfall) on granitic sand soils. The results indicated that no till tied ridging significantly reduced soil loss and run-off to very low level compared to conventional annual ploughing, hence promote high water use efficiency by the crop leading into higher crop yield (Hullugale, 1988).

Due to the advantages occurred from the use of tied-ridges, investigations into their applicability on long term basis under local semi-arid conditions are important.

2. 6 Effect of Tillage on Physical and Hydrological Soil Parameters.

Tillage is generally the mechanical manipulation of the soil surface in order to modify soil conditions so as to promote good crop establishment, growth and increased yield (Lal, 1982). In all tillage operations, a mechanical force which is applied to the soil tends to modify the state and behavioural properties of the soil. Tillage operations affect physical and hydrological properties of the soil through loosening the soil, compaction, crushing, shattering, shearing and inverting the soil (Lal, 1979; 1982, Adeoye, 1982; Cassel and Nelson, 1985; Kayombo, 1986; Griffith *et al.*, 1986; Benjamin *et al.*, 1990; Arora *et al.*, 1990; Aina *et al.*, 1991; Cresswell *et al.*, 1991; Datiri and Lowery, 1991). Different parameters such as dry bulk density, soil strength and particle size distribution have been used to describe the different tillage induced soil conditions (Larson, 1964; Malik *et al.*, 1985). Moreover the relationship between hydraulic conductivity and soil moisture content is influenced by tillage affected soil properties such as bulk density (Klute, 1982).

2. 6.1 Effect of tillage on Bulk Density.

The effect of tillage on bulk density has been investigated by a number of scientists in recent years (Adeoye,1982, Cresswell *et al.*, 1991, Cassel and Nelson,1985, Kayombo,1986 and Agenbag and Maree,1991). In all these studies, it was observed that bulk density of the soil increased with depth depending on the degree of pressure exerted by different tillage systems. Most tillage operations are performed to decrease soil bulk

density within the disturbed zone. However, bulk density often varies temporarily and spatially (Allmaras *et al.*, 1966). This is because of undisturbed zone within the soil, compaction and reconsolidation due to subsequent tillage operations and breakdown of unstable soil aggregates due to raindrops impact (Macartney *et al.*, 1971; Willcocks, 1981).

2. 6.2 Effect of tillage on Soil Strength.

Increase in soil strength in compacted soil has been associated with high bulk density. According to Williams and Shykewich (1971), bulk density has some functions on tension and its resultant influence on tension is superimposed on the tension-strength relationship. Taylor and Gardner (1963) found an increase in soil strength as bulk density increased. The bulk density soil strength relationship has influence on root penetration. Taylor and Gardner (1963) reported a decrease in root penetration by 30% in a soil with a bulk density of 1.55 g/ cm³ and a 70% decrease in root penetration in a soil with a bulk density of 1.75g/ cm³. Tillage loosens the soil and reduces the soil strength. Reduced soil strength means that plant roots face less resistance to penetration into the soil. On the other hand, compaction increases soil strength, which restricts root growth (Macartney *et al.*, 1971; Willcocks, 1981).

2. 6.3 Effect of tillage on Aggregate Size Distribution.

It is possible to separate soil aggregates into groups and characterize the soil in terms of relative proportions of its aggregate size groups (Hillel, 1980). These groups may differ from one another in aggregate size as well as in mineral composition that largely determine the manner a given soil interacts with water, its degree of strength (penetration resistance) and compressibility (Hillel, 1980). The size of the aggregates produced during seedbed preparation have an impact on germination and subsequent emergence of the seeds, first through seed-soil water contact for imbibition and second the easiness or difficulty for the emerging shoot to push through (Larson, 1964). A study by Schneider and Gupta (1985) found that there was delayed maize emergence in large aggregates (11mm) due to poor seed-soil contact. Schneider and Gupta (1985) also observed that aggregate size distribution with a diameter 1 to 6.8mm provide conditions favourable for early emergence.

2. 6.4 Effect of Tillage on Moisture Conservation.

Spomer and Hjelmfell (1984) noted that the influence of crop stress due to inadequate soil moisture in the semi-arid tropics has an adverse effect on crop yield because crop growth is dependent on an adequate supply of moisture throughout the growing season as well as other factors such as soil fertility. 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 system increase soil moisture by

improving soil hydrological properties such as profile water recharge by increasing water infiltration and transmission. Almaras *et al.*, (1977) observed increase in soil hydraulic conductivity with increased depth of ploughing.

Willcocks (1981) studied tillage of clod forming sand loam soils in the semi-arid climate of Botswana. In this study, it was observed that maize (*Zea mays*) grain yields from 0.3m deep tilled plots were 700kg/ha where as yield from 1m deep tilled plots were 790kg/ha. In constrast the differences were less obvious in a wet year.

The findings of Gerik and Morrison (1984) indicate that profile soil water content were not significantly different between the tillage treatments on their study on the effect of no-till (NT) and conventional tillage (CT) on growth and development of grain sorghum (*sorghum bicolor*), however there was a significant differences in grain yields. Also McFarland *et al.* (1991) attributed the higher moisture content in the no-till treatment to improved infiltration rates as due to more stable soil structure and existence of a more continous pore system from dead roots and worms activity which are often lacking in the conventionally tilled soils. The merits of no-till system, including soil moisture retention in biostructurally active soils has also been documented for some tropical region (Lal, 1993).

A significant rise in crop yields has also been obtained in Kenya in no-till with mulch which helps to conserve soil moisture besides improving the fertility status of the soil (Kiome and Stocking, 1992).

2.6.5 Effect of Tillage on Infiltration.

Tillage affects infiltration by increasing porosity and surface roughness. 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, increase in tillage induced random roughness and soil pore spaces increased water infiltration significantly before runoff began. Kayombo (1986) reported that manually cleared plots had higher infiltration rates averaging 10cm/h whilst the plots cleared by tractor drawn implements induced compaction which reduced the infiltration rate to 0.5cm/h. 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 significantly as tillage depth increased possibly because of opening up of the soil profile by deep cultivation.

Nicou and Chopart (1979) evaluated the effect of four tillage methods that is tine tillage, ploughing, tied ridging and ridging on soil water balance and crop yield. Ridging and tied ridging tillage methods maintained high infiltration rate which in turn ensured high

moisture supply throughout the growing season. In contrast Hulugale (1988) observed that cumulative infiltration determined for two hours rose significantly in flat cultivation than tied ridging.

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 (Freebrain *et al.*, 1989). The effect of tillage on infiltration, therefore, depends on the type and stability of the surface micro structure produced. This is the reason why infiltration on flat tilled fields is highly dynamic with time depending upon the previous and most recent tillage operations.

2.6.6 Effect of Tillage on Soil Hydraulic Conductivity.

Tillage operations change the soil conditions and hydraulic conductivity (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 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 (Cassel and Nelson, 1985). 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) also reported

similar effects on saturated hydraulic conductivity for conventional, chisel plough, and subsoil bed tillage on a loamy sand that had a plough pan.

2. 6.7 The Effect of Tillage on Soil Structure

Griffith *et al.*, (1986) studied the effect of different tillage operations on soil structure in India and USA, and found that after 5 years of maize cropping, the soil aggregate stability was increased in reduced tillage with the highest increase in the no-till system. Chisel and disc tillage system produced aggregates with an intermediate level of stability. In the mould board tillage operation, most of the aggregates were pulverised.

The above studies observed that, yields of maize and soyabeans improved significantly with time in no-till plots and eventually exceeded those from the conventionally tilled soil.

2. 6.8 The Effect of Tillage on Pore Size Distribution.

Tillage system modify the size of the soil pore system and its continuity (Adeoye, 1982; Datiri and Lowery, 1991; Unger and Cassel, 1991). Pore size distribution is dynamic and depends on the ability of the soil aggregate to withstand pressure exerted by different tillage systems and rain drop impact (Adeoye, 1982). Unger and Cassel (1991) reported variations in pore size and pore size distribution between no-till and conventional tillage. The no till plots had a smooth surface with small pores while fields cultivated with the mouldboard plough and disc plough created rough surfaces with large surface

macropores which increased infiltration significantly at the beginning of the rainy season.

2. 6.9 The Effect of Tillage on Mechanical Impedance of the Soil

Mechanical impedance is the capacity of the soil to withstand force without experiencing failure whether by rupture, fragmentation or flow (Cassel, 1980; Adeoye, 1982; Kayombo, 1986 and Cresswell *et al.*, 1980). Research carried out by Cresswell *et al.* (1991) and Agenbag and Maree (1991) showed that cone resistance was lower for the tilled plots than untilled plots but rose significantly after the first rains when the pores were sealed with fine soil particles.

2. 6.10 The Effect of Tillage on Soil Temperature

Research conducted by Benjamin *et al.*, (1990) on water and heat transport on flat, furrows or ridge treatments showed higher maximum temperature and lower minimum temperature on ridge than on flat surface or on furrows. Hence, the ridge peak dried more quickly than the furrow. Similarly, Gupta *et al.*, (1991) found a sinusoidal temperature pattern between a ridge and furrow system. Whilst on a similar study, Hulugalle (1987) found no significant difference in soil temperature between flat cultivation and open ridging.

2. 6.11 Effect of Tillage on Crop Growth

Tillage system that increase depression storage and rainfall infiltration and thus reduce runoff and soil erosion are favourable (Mohamoud *et al.*, 1990). Different tillage methods result in different surface conditions with respect to porespace and roughness and therefore affect runoff (Larson, 1964). Decrease in depression storage and roughness encourage moisture stress. It has also been observed that as moisture stress increases in the soil, cell enlargement virtually cease and the rate of cell division is markedly reduced causing slow down in the expansion of the leaf area and growth rate (Kramer, 1995).

Many studies have reported several soil moisture conservation techniques in semi-arid areas (Makungu, 1991). Residual tied ridges are an example of an effective and low cost soil moisture conservation measure. However, more information on changes in physical and hydrological soil factors under this practice is required before full scale promotion and adoption is undertaken in semi-arid areas of Tanzania.

2.7 Surface Roughness

Surface roughness is the surface configuration of the soil caused by the randomly oriented arrangement of soil clods (Allmaras *et al.*, 1967). The resulting surface configuration of the soil is caused by equipment traffic and the orientation of soil clods that are broken, lifted, shattered and resettled during tillage (Linden and Van Doren, 1986). The type of implement used and the soil conditions at the time of tillage have a large influence on the resulting configuration. Subsidence of surface roughness is caused

by both physical and chemical action of rainfall and other physical actions on the soil during the growing season Dexter, (1977).

Soil surface roughness undergoes small scale changes during the growing season after primary cultivation. These changes arise from the breakdown of clods into aggregates and individual particles (Reid, 1989). The breakdown of clods is mainly caused by rainfall impact due to the dissipation of rainfall energy on the surface of the tilled soil, which reduces roughness.

2. 7.1 Influence of Tillage on Depression Storage

Depression storage is a means by which ponded water from rainfall is kept on the surface and allowed to infiltrate when the rainfall rate falls (Gayle and Skaggs, 1978). Two types of surface storage are recognised, macro-storage and micro-storage (Gayle and Skaggs, 1978). Macro-storage can be defined as the storage in the larger depressional basin caused by topographic undulations of the land surface. Micro-storage is defined as the storage in small depression caused by surface roughness such as that created by tillage. Depression storage is closely related to soil surface roughness (Monteith, 1974, Onstad, 1984). Romkens and Wang (1986) reported that soil surface roughness controls runoff and soil erosion, improves infiltration (Larson, 1962; Zobeck and Onstad, 1987) and decrease evaporation rate (Linden, 1982). Monteith, (1974) found that large surface depression retain water in excess of infiltration from short duration storms. This, in turn reduces runoff which could have led to high losses of soil moisture.

Tillage may influence the depression storage through production of soil micro-relief. Soil micro-relief are minor undulations and irregularities of the land surface, with differences in height between crest and trough. Soils with high microrelief will often maintain higher infiltration rates than smooth soils because dense crusts tend to form mainly in the depression of uneven soils and over the entire surface of smooth soils (Larson, 1962). This in turn enhance high depression storage. Rough surface store more water on the surface than smooth ones, and as a result soils with high microrelief have high depression storage (Onstad, 1984).

Soil microrelief can be affected by tillage tools as well as the tillage system. Tillage tools which produce rough soil surface, for example primary tillage tools used in ploughing and cultivation, increase the depression storage of the soil (Gayle and Skaggs, 1978). Secondary tillage tools like those used in seedbed preparation decreases the depression storage that developed by primary tillage tools. Mohamoud *et al*, (1990) observed less depression storage on no till system than on conventional, disc and chisel tillage systems. Also depression storage on plot with contoured rows was significantly greater than that on plots with rows running up and down slopes for each tillage system (Onstad, 1984; Mohamoud, 1990). This is because there is higher depression storage on tillage performed on contours than on rows running up and down slope. The amount of runoff reduction caused by depression storage over a rainfall event depends on the characteristics of a particular rainfall, the soil microrelief (roughness of the surface)

which also differ depending on the tillage tool used and on the tillage system employed (Mitchell and Jones, 1978).

2.7.2 The Role of Depressional Storage in the Hydrological Processes

Tillage induced soil surface roughness comprises micro-depressions and elevations. During rainfall event some of the water is stored temporarily in the micro depressions (Burwell *et al.*, 1968). This volume of water stored in the micro depressions is referred to as depressional storage.

Depressional storage can be enhanced by various tillage methods for water and soil conservation including the ridging system, however the process is dynamic due to changes in surface roughness, bulk density and hydraulic conductivity (Burwell and Larson, 1969 and Onstad, 1984). This is particularly so on freshly tilled soil surface that change rapidly during rainfall events.

Some studies (Burwell *et al.*, 1969) have investigated the role of depressional storage in moisture conservation in relation to infiltration, evaporation and runoff retardation. Burwell *et al.*, (1969) recorded highly significant correlations of infiltration capacities prior to the start of runoff with a roughness index. Falayi and Bauma (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. Moreover, the amount of soil water controlled through tillage induced surface conditions is based on the

interrelationship between the supply of rainwater, surface depressional storage, infiltration and the dynamic water movement in the root zone (Makungu, 1991).

2. 7. 3 Depression Storage Measurement from Soil Microrelief Data

Several researchers (Montieth, 1974; Mitchell and Jones, 1976; Gayle and Skaggs, 1978), Huggins and Monke (1978), Linden (1979), Onstad (1984) Moore *et al*, (1980) have used microrelief data measured using microrelief metres in estimating depression storage on flat cultivated land through models developed for estimating depression storage.

These models use complex computer algorithms to stimulate the rate at which water accumulates at the surface during rainfall event.

Kuiper (1957) was the first person to develop the index concept to quantify soil roughness, he defined roughness by the index $R_{(k)}$ as:

$$R_{(k)} = 100 \times \text{Log}_{10}S.$$

Where: S = is the standard deviation of the elevations, in centimetres.

Mitchell and Jones (1978) further used regression analysis to develop simpler relationships for estimating depressional storage from easily measured parameters. Mitchell and Jones (1978) processed microrelief meter data to obtain depth storage value on the assumption that each point measurement was the centre of a 2.5cm square level surface was presented below.

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

Where, S_r = Surface depressional storage (cm)

i, j = row and columns of point measurement respectively

H_r = reference height (cm)

H_a = point measurement (cm)

The preceding literature review shows that tillage cause changes in physical and hydrological properties. Such changes can lead to significant changes in the soil water which in turn affects crop yields. Nevertheless, there is relatively little information available on the effect of using no- till tied ridges and crop yields in semi-arid tropics. Hence this necessitated a need to undertake basic research in these semi-arid regions in order to narrow down the knowledge gap.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location, Soil and Weather

3.1.1 Location

The research work was conducted at Hombolo Agricultural Research Institute (ARI) of the Ministry of Agriculture, in Dodoma. It is located about 58 km North-East of Dodoma Municipality at 5°53'S latitude, 35°55'E longitude and 1097 m above sea level (Fig. 1a and 1b). The Dodoma region is generally flat but there are two mountain chains and numerous rocky inselbergs standing several hundreds meters above the surrounding countryside.

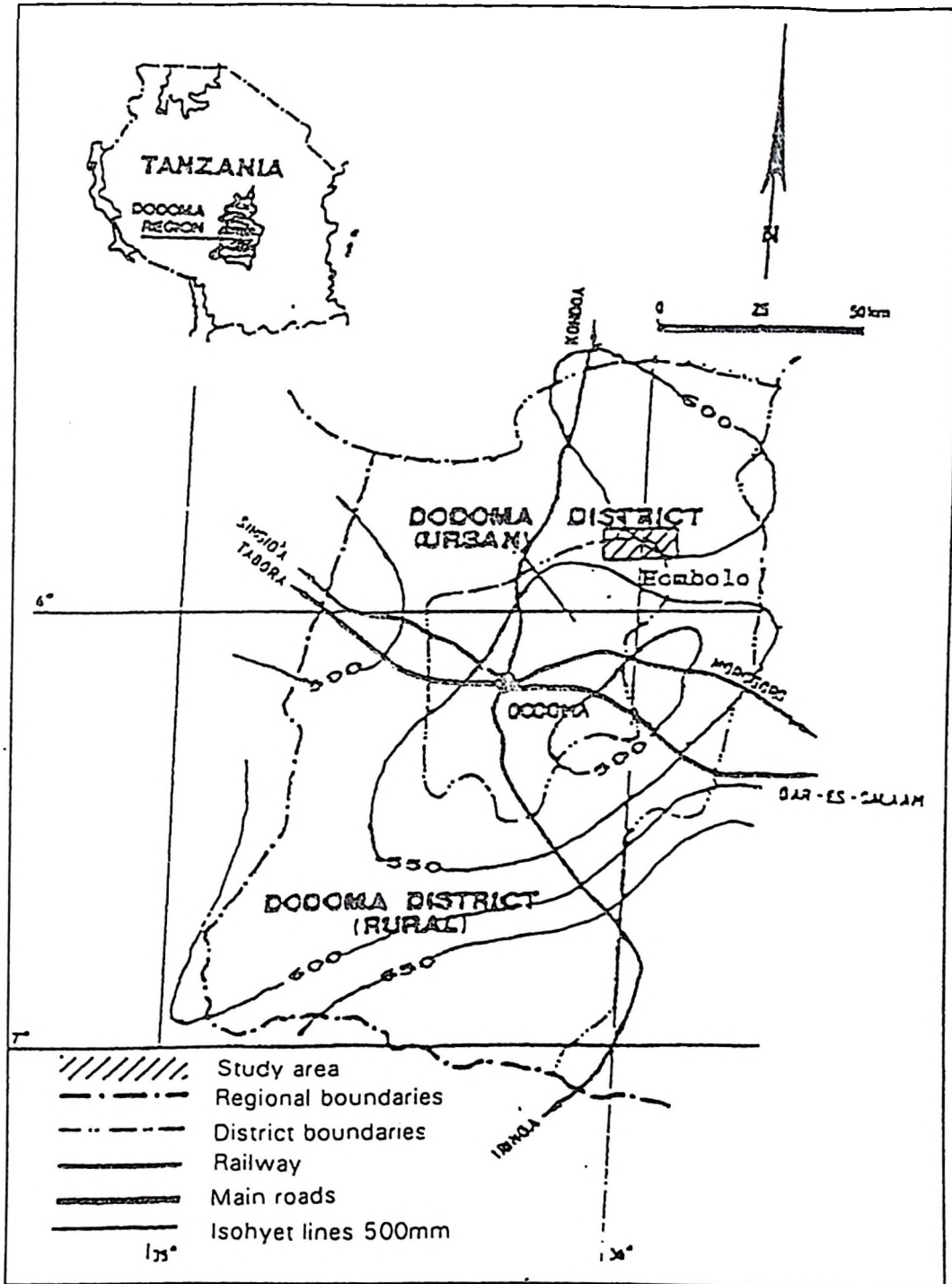


Figure.1.a: Location of Hombolo Research station.

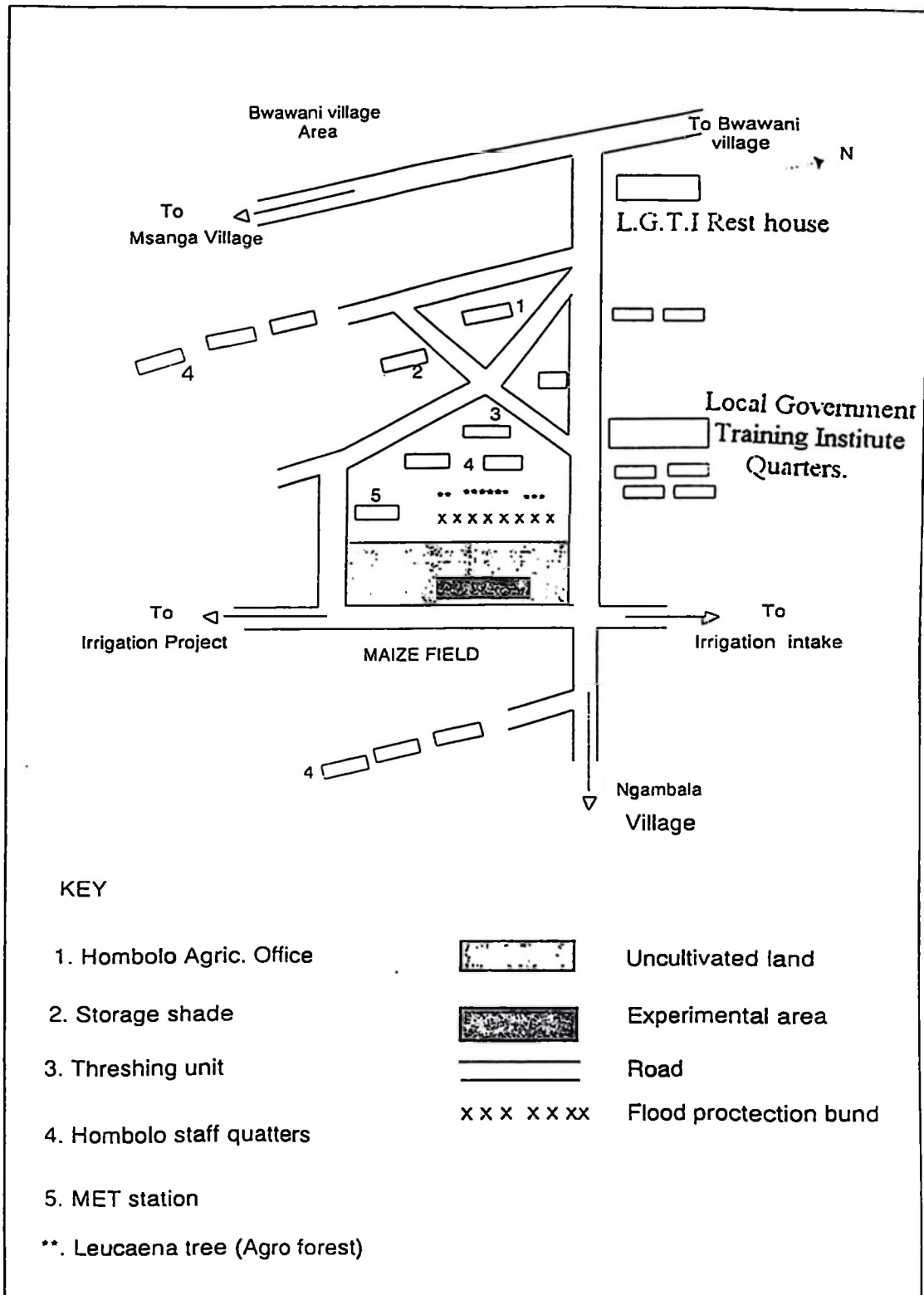


Figure .1b: Location of experimental site in Hombolo Bwawani village

3.1.2 Soil of Hombolo Experimental Site

The soil of experimental site, are fairly uniform based on colour and texture (Hatibu et al., 1995). A description of a representative soil profile is given in Appendix I. The soil has been classified by Mahoo and Kaaya (1993) as typic ustorthent in the US Soil Taxonomy and as Dystric Regosol in the FAO (1977) and FAO-UNESCO (1974) system.

3.1.3 Rainfall

The average annual precipitation in Hombolo is 589mm. The general rainfall pattern in the study area is influenced by the movement of the inter tropical convergence zone (ITCZ) between the northern and the southern hemispheres. The year may be divided into two distinct seasons. A dry season lasts between May and November and a rainy season from December to March.

**Table 2. Average monthly Rainfall at Hombolo Meteorological Station for the
Period 1974 - 1999**

Month	Rainfall (mm)
August	0
September	0
October	6
November	34
December	69
January	155
February	128
March	91
April	79
May	11
June	1
July	0

Source: Hombolo Agrometerological station. (1999).

Table 3. Monthly rainfall (mm) variability in Dodoma (after Ngana, 1993)

Month	Mean	S.D	C.V
September	0.0	-	-
October	0.0	-	-
November	23.1	41.1	180.0
December	108.5	65.2	60.0
January	132.4	79.7	60.0
February	109.1	65.1	60.0
March	117.7	62.5	56.0
April	52.1	51.4	99.0
May	3.8	7.2	189.0
June	0.0	-	-
July	0.0	-	-
August	0.0	-	-

S.D = Standard deviation, C.V = Coefficient of variation.

3.1.4 Vegetation

The experimental plots were located on a piece of land which had been under intensive cultivation for the past three years before 1999 cropping season. The native vegetation in the surrounding area consisted of scattered *Adansonia digitata* (baobab tree) and *Hyperrhenia acacia* bush with grass land. Other indigenous grass types which colonise the surroundings land are such as *Tricodesma Zeylanicum* (late weed), *Borhavia diffusa* (Tar vine), *Chrolis gayana* (Rhodes grass) and *Cynodon dactylon* (Star grass).

3.1.5 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.

3.1.6 Evaporation

As in most semi arid regions, potential evaporation is normally high and it reaches its peak in November due to the high temperature and high wind speeds. Average annual potential evaporation is 2123mm (Christianson, 1981). The actual evaporation is 650 mm and only on very few occasions the rainfall meets the evapotranspiration demand.

3.1.7 Relative Humidity

The high day time 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 midday relative humidity is 34%.

3.2 Experimental Design and Tillage Treatments

The study was conducted to evaluate the effect of residual tied ridges on some physical soil factors, sorghum growth and grain yields. The experimental plots consisted of no-till, shallow and deep tillage residual tied ridges which were constructed in 1996/97. A randomized complete block design (RCBD) was used in the investigation.

Tillage treatments.

There were three tillage treatments replicated four times, thus giving a total of twelve field plots, each plot with an area of 20 by 10m (200m²). These treatments were as detailed below.

Treatment 1. No-till (NT):

No-till is locally called 'kuberega', a traditional tillage method which is commonly practiced by local farmers in the area. It involve manual slashing of standing vegetation or removal of previous crop residues from the field followed by burning.

Treatment 2. Residual Shallow Tied Ridges (RST):

This involved the use of the previous shallow tied ridges (residual shallow tied ridges) which formerly was grown with sorghum variety Tegemeo since 1996/97 season. Initially (in 1996/97) the field was dug to a depth of 10cm using a traditional handhoe. Ridges were made at 0.75m apart and tied at 1.5m intervals which produced a series of basins.

Treatment 3. Residual Deep Tied Ridges (RDT):

This involved the use of previous deep tied ridges (residual deep tied ridges) which were grown with sorghum variety Tegemeo since 1996/97. Initially (in 1996/97) the field was ploughed to a depth of 20cm. The ridges were made at 1m apart and tied at 1.5m intervals which also produce a series of basins.

These three treatments in subsequent seasons were used without any alteration except the removal of previous crop residues and slight maintenance of ridges and ties. Sorghum (sorghum bicolor cultivar tegemeo) was used as a test crop.

3. 3 Land preparation, planting and thinning

This involved the removal and burning of previous crop residues. Grasses from the field which previously had tied ridges grown with sorghum var Tegemeo since 1996/97 season. The previous tied ridges (residual tied ridges) both shallow and deep ones, were maintained to their original shape without altering their dimensions. The control plots

(no-till) which is an analogy of the local practice (kuberega) were prepared in the same way as what farmers normally do every year. The experimental field was prepared using a traditional hand hoe and it was done on 24 of November, 1999.

Planting of sorghum seeds was done on 17 of December, 1999. Five seeds were planted per hill by dibbling at a spacing of 0.75m by 0.4m for no-till (local practice) and in shallow tied ridges while the deep tied ridges were planted at a spacing of 1m by 0.3m. Thinning to two seedlings per hill was done five weeks after emergence giving a plant population of 66,667 plant/ha. The delay in thinning was due to a dry spell which persisted for almost two weeks after emergence.

3. 4 Management of the Experimental Plots

The crop was weeded two times. As in the previous years, weeding was done using a traditional hand hoe. No inorganic fertilizers or manure were applied. This was done purposely so as to reflect farmers practice in the study area since most of them do not apply inorganic fertilizers or manure.

The peasant farmers in this area have too low purchasing power to afford the high cost of inorganic fertilizers while in case of manure, its limited supply, the large amount of manure needed and lack of means of transportation to the farms are bottlenecks. When the crop was 60cm in height, it was infested by stalk borer (*Bussuela fusca*).

An insecticide endosulfan (1.5 litre/ha) was applied using knapsack sprayer as a control measure.

3.5 Determination of Soil Moisture

Determination of soil moisture in four replicates were carried out at weekly intervals after planting and at three depths: 0-10, 10-30 and 30-50cm until to harvesting. One sample for soil moisture determination was taken from the ridges at the above mentioned depths from each replicate plot using a soil auger, then placed in aluminium cans and immediately sealed before being taken to the laboratory. Soil samples were weighed, oven dried at 105°C for 24 hours, then cooled in a dessicator and re-weighed. Gravimetric moisture content was calculated as the ratio of the water loss on drying to the oven dry mass (Kamara *et al*, 1992; Saka and Haque, 1993).

$$\text{i.e. } \Theta_g = (W_w - W_o)/W_o$$

where: Θ_g = the gravimetric water content on dry weight basis, g/g.

W_w = the weight of wet soils, g.

W_o = the weight of oven dry soils, g.

The Gravimetric moisture content was converted to volumetric moisture content by multiplying respective values with appropriate bulk density of the respective soil layer.

$$\Theta_v = \Theta_g * B_d/d_w$$

where: Θ_v = volumetric moisture content, cm³/cm³

Θ_g = Gravimetric moisture content, g/g

Bd = soil bulk density, g/cm³

dw = Density of water, assumed to be 1.00 g/cm³

The profile water content for each treatment was calculated by the summation of the product between volumetric water content for each layer and respective depth as follows:

$$\Theta_p = \sum \Theta_v \times L$$

where: Θ_p = profile water content

Θ_v = volumetric water content, cm³/cm³

L = thickness of soil layer, cm

3. 6 Soil Infiltration Measurement

Measurements of cumulative infiltration in all treatments was conducted prior to the rains, at mid season and after harvest. The double ring infiltrometer method (Klute, 1986; Saka and Haque, 1993) was used. This consists of an inner ring, with 27.8cm diameter surrounded by an outer ring with 54.5cm diameter. Both rings were 35cm high and were driven into the soil to a depth of 15cm by using a sledge hammer. This operation was done with utmost care to prevent disturbance of the soil.

3. 7 Bulk Density Determination

The bulk density determination in the four replicates was done on three occasions using metallic core procedure (Blake and Hartge, 1986). Samples were taken before land preparation, at mid-season during the growing season and at harvest. One undisturbed

soil sample was taken from each replicate plot at depths of 0-10cm, 10-30cm and 30-50cm using sampling cores. The samples were oven dried at 105°C for 48 hours and cooled in a dessicator then weighed. Bulk density was then calculated as the ratio of the dry mass of the soil to the core volume. Total porosity was calculated from the relationship between bulk density and particle density assumed to be 2.65 g cm⁻³ using the equation below.

$$TP = (1 - Bd/Pd) *100$$

Where:

TP = Total porosity %

Bd = Bulk density, Mg m⁻³

Pd = Particle density, Mg m⁻³

3. 8 Soil sampling for routine analysis

Composite soil samples were collected from each treatment before land preparation to a depth of 20cm from the soil surface. The soil was air dried, ground and sieved through a 2mm sieve (Day, 1965). Soil chemical analysis were done in the department of soil science at Sokoine University of Agriculture. Soil pH was measured potentiometrically in 1:2.5 soil water suspension following the procedure outlined by MaClean (1982). Organic carbon was determined by the wet oxidation method of Wakley-Black (Nelson and Sommer, 1982). Total Nitrogen was determined by the semi-microkjedahl (Bremner and Mulvaney, 1982), Cation exchange capacity and exchangeable bases were

determined by Neutral Ammonium Acetate extract and then Atomic absorption spectrophotometry (AAS)(Thomas, 1982). Available phosphorous was determined by the Bray and Kurtz (1945) method.

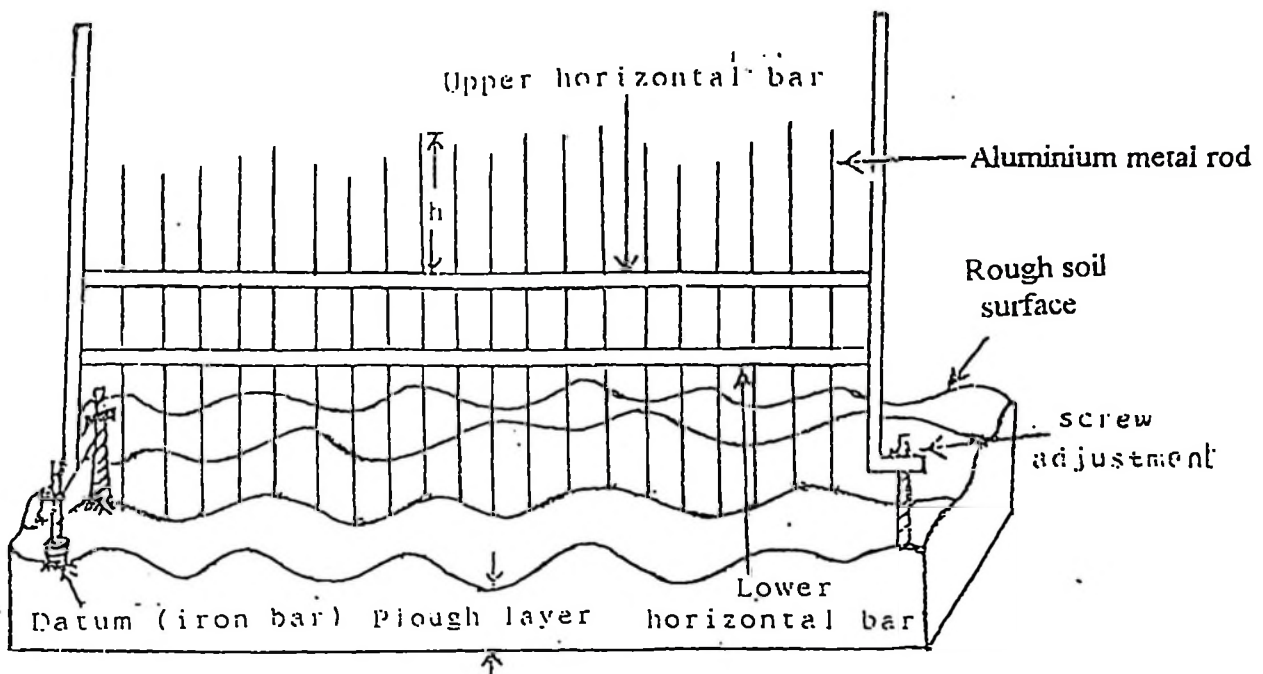
3. 9 Measurement of Surface Roughness

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 features of the instruments are as illustrated in Figure 3. It consists of a 130cm by 90cm main frame of aluminium bars. Across the middle of the frame is a rods locking string. The string is designed to hold 23 rods which slide up and down. Each is fitted with a small foot to prevent it from penetration in the soil.

In measuring micro-relief, the whole device was placed horizontally perpendicular to the crop rows with the rods locked up. The instrument was leveled by means of a spirit level and adjusting the support pins. The rods were then allowed to slide down until their feet touched the soil surface. Once all rods had touched the ground, the rods were then locked in that position. The height of each rod above the top of the frame was measured with a ruler. Then the rods were pulled up again, locked and the meter moved to the next measuring position.

The measurement was done immediately after land preparation and subsequent measurement were done before and after weeding and after every big rains. The surface roughness was determined as the standard deviation of the pin height measurements. The

data was then calculated using the Kuiper's (1957) equation (section 2.7.3) and there after analysis of variance was used to compare the differences in random roughness caused by different tillage treatment.



Key

h = elevation relative to the datum

Fig. 2: Microrelief meter set on a transect

3. 10 Crop Growth and Yield Components.

During the growing season, emergence percentage from all treatments was determined after germination had occurred by counting the total number of hills with emerged seedling five days after emergence was first observed.

Plant height was measured twice during the growing season from randomly selected plants and measurements were taken from the soil surface to the topmost leaf using a tape measure. The measurements were taken at 45 and 98 days after emergence. This was done in order to compare the differences in the crop growth due to differences in soil moisture storage under the different tillage treatments.

At maturity stage, sorghum heads were harvested by an aid of sharp knives from a net area of 24m² per plot in each treatment. After being harvested, the materials were sun dried, threshed (using traditional mortar and pestle), winnowed and at the end, final grain yield for each treatment was determined.

3.11 Statistical Analysis

Analysis variance was run using MSTAT version 4.00/EM for the observed parameters and means were separated by using Duncan's Multiple range Test. The statistical model used was:

$$X_{ijk} = \mu + T_i + H_k + (TPH)_{ijk} + e_{ijk}.$$

where X_{ijk} = response measurement

μ = Overall mean

T_i = Effect of i^{th} treatment T (Tillage methods).

P_j = Effect of j^{th} treatment P (physical factors).

H_k = Effect of k^{th} treatment H (hydrological factors)

TPH = Tillage methods, physical factors and hydrological factors
interaction effect.

e_{ijk} = Random errors and non systematic variation of the measured
variables.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Physio-chemical status of the top soil (0-20cm) of the experimental site

The average soil physio-chemical characteristics of the experimental site are presented in Table 4. The rating of the soil properties which are soil fertility indicators showed that, the content of organic carbon, total N and available P in these soils to be generally very low. Calcium and Magnesium contents were very low while the level of Potassium and Sodium were medium. Soil pH at 5.8 is within the suitable range for most annual crops, for it favours availability of most plant nutrients. These results conform to those obtained by Mahoo and Kaaya (1993) in the same location. The soils are sand clay loam and therefore coarse textured, a property which may reduce their capacity to retain nutrients against leaching. Because the experimental site was on a gentle slope (1-2%), soil erosion for the past many years might have contributed to the low fertility status of these soils. Further deterioration of soil fertility is likely to have occurred due to continuous cultivation system. In view of the above observations, the fertility status of the experimental site is generally very low.

Table 4. Physio-chemical properties of the top soil (0-20cm) of the experimental area.

Soil property	Mean \pm S.E	Interpretation
Particle size		
Sand (%) (2000 μ m-20 μ m)	71.3 \pm 2.03	
Silt (%) (20 μ m-2 μ m)	4.7 \pm 0.67	
Clay (%) (<2 μ m)	23.9 \pm 1.62	
Texture class	SCL	Sand clay loam
PH		
In 1:2.5 water	5.8 \pm 0.43	Medium
In 1:2.5 Kcl	4.3 \pm 0.45	
Organic carbon (%)	0.4 \pm 0.05	Very low
Total N (%)	0.6 \pm 0.01	Very low
Available P (mg/kg)	4.9 \pm 0.41	Very low
Exchangeable bases		
Na (me/100g)	0.99 \pm 0.01	Medium
K (me/100g)	0.62 \pm 0.16	Medium
Ca (me/100g)	0.25 \pm 0.09	Very low
Mg (me/100g)	0.13 \pm 0.03	Very low
Cation Exch. Capacity (C.E.C)	4.20 \pm 0.67	Very low
S.E = Standard error		

4.2 Bulk density as affected by residual tillage methods

Bulk density measurement prior to planting operation, at mid-season and after harvest were as reported in Table 5. Bulk density values before planting were not significantly different ($p=0.05$) between treatments and depths. It also varied temporarily and spatially. This could be due to the undisturbed zone within the soil, compaction and reconsolidation due to subsequent tillage operations and breakdown of unstable soil aggregates due to raindrops impacts. These results are comparable to those reported by Allmaras *et al* (1966), Macartney *et al*, (1971), and Willcocks, (1981).

At mid-season there were significant differences ($p=0.05$) between T1 and other treatments only within the 0-10cm soil layer. Overall, mean bulk density in the 0-50 cm was slightly higher in T1 than in T2 and T3 at mid season and after harvest. However, there were no significant difference between treatments. Fine soil particles washed by rain water into the pore spaces might have decreased the macropores in the soil and hence increased the bulk density. Generally surface crusting and/or slumping/hard setting and negligible disturbance of the plough layer due to lack of primary tillage are the major causes of such observations.

Table 5. Effect of tillage on soil bulk density (g/cm³) at various soil depths during the study period

Time-of measurement	Tillage treatment	Soil depth (cm)			TM Mean over depth (0 - 50)
		0 - 10	10 - 30	30 - 50	
Before planting	T1	1.41a	1.61a	1.65a	1.55 ± 0.05
	T2	1.59a	1.57a	1.53a	1.56 ± 0.05
	T3	1.56a	1.60a	1.55a	1.57 ± 0.05
	Means	1.52	1.59	1.57	
	S.E ±	0.09	0.09	0.09	
	C.V (%)	11.75	11.75	11.75	
Mid-season	T1	1.71a	1.64ab	1.64ab	1.66 ± 0.02
	T2	1.57b	1.56b	1.56b	1.57 ± 0.02
	T3	1.58b	1.66ab	1.55b	1.60 ± 0.02
	Means	1.62	1.62	1.59	
	S.E ±	0.04	0.04	0.04	
	C.V (%)	4.80	4.80	4.80	
After harvest	T1	1.61a	1.60a	1.57a	1.59 ± 0.02
	T2	1.53a	1.56a	1.56a	1.55 ± 0.02
	T3	1.50a	1.62a	1.59a	1.57 ± 0.02
	Means	1.55	1.59	1.58	
	S.E ±	0.04	0.04	0.04	
	C.V (%)	4.74	4.73	4.73	

T1 = No-till, T2 = Residual shallow tied ridges, T3 = Residual deep tied ridges, S.E± = Standard error, C.V = Coefficient of variation. Means followed by the same letter within column are not significantly different at 5% using DNMRT.

4.3. Total Porosity as Affected by the Residual Tillage Methods

Total porosity for each tillage practice are as shown in Table 6. Like for bulk densities, there was no significant difference ($p=0.05$) in total porosity among the treatments. Total porosity varied temporarily and substantially among treatments in all soil depths. The treatment mean values obtained over (0-50cm) soil depth before planting and after harvest in T1 were slightly lower than those in T2 and T3. Possible explanations include crusting and negligible disturbance of the plough layer due to lack of primary tillage as described under bulk density section while the residual effect of the tied ridges justifies the slight higher value of total porosity in T2 and T3.

Table 6. Total porosity as affected by tillage methods at various soil depths during 1999/2000 cropping season

Time-of measurement	Tillage treatment	Soil depth (cm)			TM - Mean over depth (0 - 50)
		0 - 10	10 - 30	30 - 50	
Before planting	T1	37.45b	39.35ab	37.92b	38.24 ± 0.75
	T2	39.97ab	40.70ab	42.30a	40.99 ± 0.75
	T3	41.15ab	39.77ab	41.38ab	40.77 ± 0.75
	Means	39.53	39.94	40.53	
	S.E ±	1.30	1.30	1.30	
	C.V. (%)	6.49	6.49	6.49	
After harvest	T1	39.45a	39.60a	40.73a	39.93 ± 0.81
	T2	42.13a	41.25a	41.08a	41.48 ± 0.81
	T3	43.33a	38.90a	39.93a	40.72 ± 0.81
	Means	41.63	39.92	40.58	
	S.E ±	0.81	0.81	0.81	
	C.V. (%)	6.88	6.88	6.88	

T1 = No-till, T2 = Residual shallow tied ridges, T3 = Residual deep tied ridges, S.E± = Standard error, C.V. = Coefficient of variation. Means followed by the same letter within column are not significantly different at 5% using DNMRT.

4.4 Effect of tillage on seasonal soil profile water content (mm) of 0-50 cm soil layer, during the study period.

Seasonal soil profile moisture content (mm) and seasonal soil water as affected by tillage methods are shown in table 7 and appendix 2 respectively. The profile moisture content as shown in table 7 varied considerably during the 19 weeks of the growing season. It was mainly influenced by tillage and it had the following trend $T3 > T2 > T1$.

The results show that the treatments had significantly ($p=0.05$) different moisture content on the 4, 8, and 17 week after planting. Furthermore, T2 and T3 differed significantly on the 3, 9, 15, and 16 week after planting while on the remaining weeks, only T1 differed significantly from T2 and T3.

T2 and T3 conserved more soil water than T1 probably due to the depression storage effect which allowed more time for the water to infiltrate into the soil in residual tied ridges than in T1 where the soil surface was flat (refer plate 1- 4). Generally, treatments which have higher depression storage are associated with higher profile moisture content. Similar findings were reported by Lawes, (1966), Dagg and Marcatney, (1968), Hulugalle, (1987) and Day, (1988).

Table 7. Effect of tillage on mean profile water content (mm) in the 0- 50 cm soil layer during the study period

Week after Planting.	Tillage treatment			Mean	S.E \pm	C.V.(%)
	T1	T2	T3			
1	44.95b	54.42a	61.52a	52.63	3.21	12.18
2	55.10b	64.60a	68.72a	62.81	2.09	6.67
3	44.95b	53.85b	66.33a	55.04	2.73	9.91
4	59.35c	73.10b	80.13a	70.86	1.74	4.91
5	54.30b	65.40a	71.80a	63.83	2.53	7.92
6	53.20b	62.45ab	66.38a	60.67	3.05	10.06
7	49.15b	63.53a	75.50a	62.73	3.63	11.58
8	54.67c	65.13b	77.22a	65.68	2.45	7.45
9	56.33b	60.63b	71.47a	62.81	2.15	6.85
10	48.88b	56.90a	61.47a	55.75	2.13	7.64
11	46.83b	53.85ab	60.55a	53.74	3.39	12.61
12	57.75b	66.88a	73.90a	66.18	2.33	7.05
13	43.10b	57.22a	68.40a	56.24	3.44	12.23
14	58.90b	77.68a	85.53a	74.03	3.31	8.94
15	53.50b	62.28b	81.72a	65.83	5.39	16.37
16	46.97b	55.13b	68.70a	56.93	2.37	8.31
17	41.95c	54.05b	66.72a	54.24	3.18	11.73
18	40.40b	48.40ab	57.72a	48.84	2.99	12.27
19	41.65b	51.35ab	57.47a	50.16	3.95	15.75

T1 = No-till, T2 = Residual shallow tied ridges, T3 = Residual deep tied ridges,

S.E \pm = Standard error, C.V. = coefficient of variation. Means followed by the letter along the same row are not significantly different at 5% using DMRT.

4.5 Effect of Tillage on Soil Surface Roughness

Table 8, shows the effect of tillage on mean soil surface roughness indices (SSRI). Throughout the growing season, the control (T1) had significantly ($P= 0.05$) lower SSRI values than in residual tied ridges (T2 and T3). The values tended to change due to the physical action on the soil brought about by field operations and heavy rainfall events.

There was an increase of SSRI values in T1 from 20 November, 1999 to 29 December, 1999, this could be accounted as due to orientation of soil clods and lifting of the soil during site clearance and sowing operations undertaken before 20 November, 1999. Moreover, there was a general gradual decline in SSRI values in T1 from 03 January, 2000 (after the first weeding), onward and T2, T3 after a rain storm (39.4mm) on 17 December, 1999. Resettling of soil particles after some time, sloughing and breakdown of aggregates as a result of wetting and rainfall impact due to the dissipation of rainfall energy on the surface of the soil are possible explanations. Changes in SSRI were also observed on 8 and 18 February, 2000 before and after the second weeding respectively. Similar findings were reported by Reid, (1989). Further more, the subsequent rate of reduction in SSRI in T2 and T3 was encouraged by deposition into the depressions.

Microrelief measurement at harvest (on 13 June, 2000) also showed significant ($p=0.05$) difference between treatments. These were due to the residual effect of an heavy rainstorm event (52.1 mm) which occurred on 21 March, 2000.

The reduction in SSRI values among treatments was not uniform. This is because soil surface roughness subsidence is dependent on the intensity of tillage operations, amount and intensity of rainfall and stability of the soil surface. High intensity rainfall readily disperses less stable surface aggregates. The dispersed soil particles tend to fill surface depressions thereby reducing the surface roughness.

From these results it would appear that the decline in random soil surface roughness indices and its residual values depends to a greater extent on the initial soil surface conditions brought about by tillage.

Table 8. The effect of tillage on soil surface roughness during 1999/2000 cropping season

Date of Measurement	Tillage treatments			Mean	LSD (0.05)	C.V. (%)
	T1	T2	T3			
20 Nov, 1999.	85.65b	169.20a	176.67a	143.84	40.58	6.56
17 Dec, 1999.	87.75b	166.28a	173.20a	142.41	51.71	7.51
29 Dec, 1999.	90.84b	167.29a	173.86a	144.00	55.44	8.95
03 Jan, 2000.	106.31b	160.47a	176.70a	150.83	11.11	1.71
08 Feb, 2000.	89.25b	162.41a	180.01a	143.89	34.95	5.64
18 Feb, 2000.	98.76b	163.57a	174.82a	145.72	52.57	8.38
21 March, 2000.	68.65b	154.87a	175.11a	132.88	85.71	14.99
13 June, 2000.	72.07b	152.81a	174.62a	133.17	79.33	13.84

T1 = No-till, T2 = Residual tied ridges, T3 = Residual deep tied ridges. Means along the same row followed with the same letter are not significantly different at 5% using DNMR.

4.6 Effect of Tillage on Cumulative Infiltration

Table 9 shows cumulative infiltration measurement taken between the rows before planting, at mid-season and at harvest. Cumulative infiltration was significantly ($p=0.05$) higher in T1 than in both residual tie ridges treatments (T2 and T3) during the whole growing season.

The trend for cumulative infiltration values was always $T1 > T2 > T3$. Soil transmissivity was therefore highest in T1 than on the residual tied ridges treatments. This was probably due to the effect of tillage on pore size distribution. Similar findings were reported by Freebrain *et al* (1989) and Hulugale (1988). Explanation to the current findings are, that tillage reduced infiltration by creating discontinuous pore space in the plough layer and by weakening the structure due to microfractures. The significant reduction in infiltration in T2 and T3 were possibly also due to the increase in siltation in basins. The effect of tillage on infiltration therefore depends partially on the type of the surface microstructure produced.

Table 9. The effect of tillage on cumulative infiltration (mm) per 3 hours during the study period

Tillage treatment	Time of measurement		
	Before planting	At mid-season	At harvest
T1	321.8a	1160a	608.8a
T2	187.0b	396.0b	253.8b
T3	149.0b	314.5b	171.8b
Mean	219.25	623.42	344.75
S.E± (0.05)	27.10	218.4	86.73
C.V. (%)	24.72	70.07	50.32

T1 = No-till, T2 = Residual shallow tied ridges, T3 = Residual deep tied ridges, S.E± (0.05) = Standard error, C.V. = Coefficient of variation. Means followed by the same letter along the same column are not significantly different at 5% using DMRT.

4.7 Sorghum Growth and Yield

4.7.1 Seedling Emergence, Plant Height and number of plants at harvest

Percentage seedling emergence, mean plant height and the number of plants at harvest as was influenced by tillage practices are as shown in Table 10, 11 and 12 respectively. Mean separation using Duncan's New Multiple Range Test at 5% probability level showed significant ($p=0.05$) differences between treatments on seedling emergence, plant height at 98 DAE and on the number of plants at harvest.

The higher seedling emergence in T1 could be explained as due to the high cumulative infiltration observed in T1 compared to that in T2 and T3 during the cropping season. Also, the flat surface in T1 could have encourage a uniform distribution of moisture in the soil even after little rainfall events compared to the wave like drying and wetting front exhibited in tied ridges after such little rainfall. The ridges tended to be relatively drier than in the basins. Percentage seedling emergence had the following trend: $T1 > T2 > T3$.

Generally tied ridges had plants which were growing well. T1 plots had plants whose height was on the average lagging behind by 17.1 and 15.3cm to those in T2 and T3 respectively. However, there was no significant ($p=0.05$) difference between the plant heights in T2 and T3 at 45 days after emergence. The significant ($p=0.05$) difference in plant heights at 98 DAE between T1 and other treatments can be linked to profile

moisture content and high depression storage observed in treatments with tied ridges (refer to plates 2, 3 and 4) during the study period.

Determination of the number of hills at harvest showed an opposite trend to the aforementioned percentage seedling emergence, ($T3 > T2 > T1$). These were due to subsequent moisture stress experienced in T1 during the study period which resulted in the death of some of the seedlings.

Table 10. Percentage seedling emergence (%) as influenced by tillage methods during 1999/2000 cropping season

Tillage treatments	Emergence (%)
T1	95.31a
T2	89.64ab
T3	81.11b
Mean	88.69
S.E (0.05)	2.67
C.V. (%)	6.01

T1 = No-till, T2 = Residual shallow tied ridges, T3 = Residual deep tied ridges, S.E± (0.05) = Standard error, C.V. = Coefficient of variation. Means followed by the same letter along the same column are not significantly different at 5% using DMRT.

Table 11. Plant height at 45 and 98 DAE as affected by tillage methods during 1999/2000 cropping season

Tillage treatments	Plant height (cm)	Plant height (cm)
	at 45 DAE	at 98 DAE
T1	25.04a	113.4b
T2	31.70a	130.5a
T3	31.50a	128.7a
Mean	29.42	124.16
S.E (0.05)	2.74	4.09
C.V. (%)	18.65	6.60

T1 = No-till, T2 = Residual shallow tied ridges, T3 = Residual deep tied ridges, S.E = Standard error, C.V. Coefficient of Variation.± Means followed by the same letter along the same column are not significantly deferent at 5% by Duncan New Multiple Range Test.

**Table 12. Effect of treatments on the number of hills at harvest during
1999/2000 cropping season**

Tillage treatment	Percentage of expected plant population (%)
T1	64.92b
T2	75.97a
T3	80.02a
Mean	73.638
S.E	1.959
C.V. (%)	5.32

T1 = No-till, T2 = Residual shallow tied ridges, T3 = Residual deep tied ridges, S.E = Standard error, C.V. Coefficient of Variation. ± Means followed by the same letter along the same column are not significantly different at 5% by Duncan New Multiple Range Test.

4.7.2 Effect of Tillage on a 1000 Kernel Weight and Grain Yield

A 1000 kernel weight and sorghum grain yield as affected by tillage methods are presented in Table 13 and 14. The variation on a 1000 kernel weight was not significantly ($p=0.05$) different between treatments presumably because this is a stable parameter and it is genetically determined.

Grain yield was significantly ($p=0.05$) affected by tillage methods and the yield trend varied between treatments as follows: $T3>T2>T1$. T1 had significantly lower grain yield compared to T2 and T3 treatments. Sorghum grain yield from tied ridges treatments was more than doubled compared to the control. The higher yield observed in T2 and T3 were attributed primarily to the increase in soil water storage. In this regard, land configuration played an important role since it determined the detention time for rain water to infiltrate into the soil.

These results have a similar trend to that observed by Hulugale, (1987) when conducting a field trial on the effect of tied ridges on soil water content, evaporation, root growth and yield of cowpeas in the Savannah of Burkina Faso. Basehart (1973) had similar observations when conducting a field trial on the settlement pattern on homestead farms among the Matengo of Tanzania. Significant increase in yields of cotton, sorghum and maize were also reported by Dagg and Macartney, (1968) on the aforementioned crops

planted in tied ridges compared to those grown on flat surface in Sukumaland in Tanzania.

The low grain yield obtained from T1 could also be attributed to soil compaction as manifested by higher bulk density values observed at mid-season when it was a critical period for grain filling which restricted the ability of plant roots to explore more soil volume in search of water and nutrients. Further to that, the low depression storage in T1 which has been related to low roughness indices lead to loss of water and soil nutrients through run off.

Table 13. Grain weight per hill and a 1000 kernel weight as was affected by tillage methods during 1999/2000 cropping season

Tillage	1000 kernel	Panicle	Grain weight/hill	Shelling percent-
Treatmen	weight (gm)	(gm)	(gm)	age (%)
ts				
T1	22.67a	69.0c	48.0c	74.07a
T2	22.55a	90.0b	72.5b	80.38a
T3	23.30a	110a	91.0a	83.07a
Mean	22.84	89.67	70.50	79.18
S.E	1.62	4.26	4.68	4.96
C.V.(%)	4.11	9.49	13.28	12.52

T1 No-till, T2 = Residual shallow tied ridges, T3 = Residual deep tied ridges, S.E = Standard error, C.V. Coefficient of Variation. Means followed by the same letter along the same column are not significantly deferent at 5% by Duncan New Multiple Range Test.

Table 14. Sorghum grain yield (tons/ha) as affected by tillage methods during 1999/2000 season

Tillage treatments	Yield (tons/ha)
T1	0.635b
T2	1.488a
T3	1.698a
Mean	1.273
S.E (0.05)	1.488
C.V. (%)	39.55

T1 =No-till, T2 = Residual shallow tied ridges, T3 = Residual deep tied ridges, S.E = Standard error, C.V. Coefficient of Variation. Means followed by the same letter along the same column are not significantly deferent at 5% probability level by Duncan New Multiple Range Test.



Plate 1: The tie-ridging system.



Plate 2: Sorghum crop under No-till system.

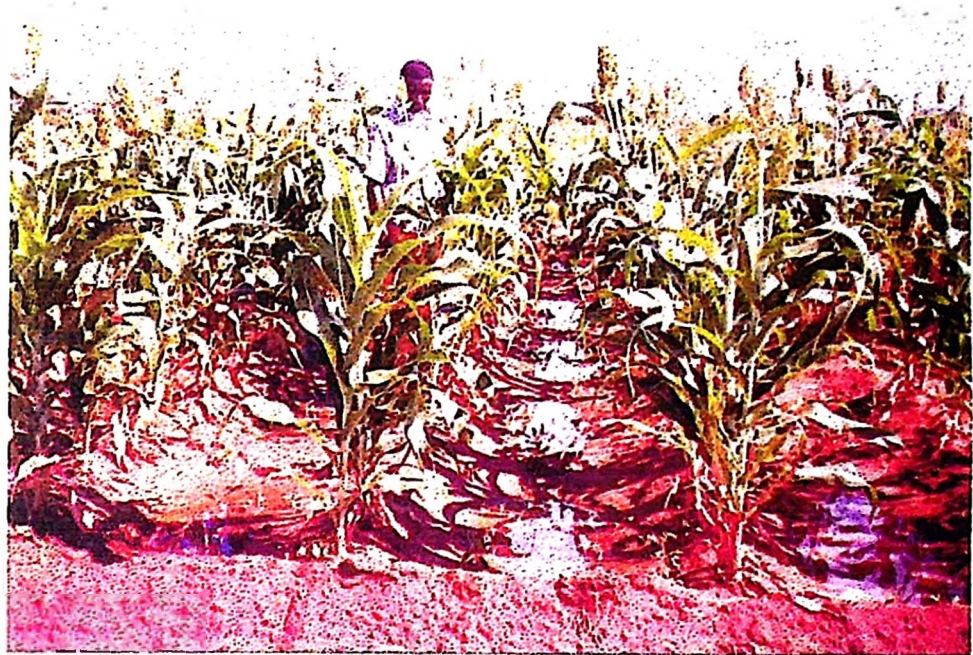


Plate 3: Sorghum crop under residual shallow tie ridges.
(Note the effect of residual shallow tie ridges
on the depression storage).



Plate 4: Sorghum crop under residual deep tie ridges.
(Note the effect of residual deep tied ridges
on the depression storage).

Note: Plate 2, 3 and 4 were taken on the same date.

CHAPTER FIVE

5.0. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Although the study was not conducted on long-term basis, the following tentative conclusions can be drawn from it:

4. Bulk density varied temporarily and spatially, but only during mid-season when significant differences were observed within the 0-10 cm depth between no-till (T1) with both shallow (T2) and deep tied ridges (T3). Presumably it was due to the increased weight per unit volume of the soil as the result of water washing the fine soil particles into the porespaces.
5. The no-till (T1) treatments had the highest cumulative infiltration values while the residual shallow (T2) and deep tied ridges (T3) treatments had comparatively low values. Tillage possibly reduced infiltration by creating discontinuous pore spaces in the plough layer and by weakening the structure due to microfractures. Sedimentation in the basins created a surface seal.
3. Soil surface roughness indices (SSRI) had the following trend: Residual deep tied ridges (T3)> Residual shallow tied ridges (T2)> No-till(T1). This parameter was affected mainly by tillage depth and to some small extent by weeding operations and by rainfall.

4. Soil moisture varied considerably during the growing season and had the following general trend, $T_3 > T_2 > T_1$. This was due to the influence of depression storage induced by the tillage methods.
5. No till (T1) had significantly better seedling emergence than tied ridges. However, most of the seedling died due to subsequent moisture stress. At harvests T1 had significantly lower plant population than in treatments with residual tied ridges.
6. Sorghum grain yield from treatments with tied ridges was more than doubled compared to the control.

5.2. Recommendations

From the results reported herein the following recommendations can be made.

- (a) Residual tied ridges should be adopted by small scale farmers for soil moisture conservation. However tied ridges should be regularly maintained during the growing season because with time they get flattened especially by rain.
- (b) There is a need to determine soil moisture on daily basis, and by using a more sensitive method since the weekly moisture monitoring failed to adequately discriminate between treatments.

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APPENDICES

Appendix 1a: Soil characterization and classification of Hombolo Research Station

Profile No: Hombolo Agricultural Research Station.

Location: Hombolo Agricultural Research Station Farm, about 400m East of the Agricultural Station offices.

Elevation: 1037m above mean sea level

Landform: On middle of a long uniform slope of about 2%

Vegetation/Land use: The area has been under fallow for the past 5 years. However, the native vegetation in the surrounding areas consisted of scattered *Adansonia digitate* (baobab) and *Hyperrhenia-accia* bush with grassland. Exotic species have also been introduced by the Agricultural Research Institute Hombolo. These include *Leucaena spp.*

Parent material: Silicon rich gneiss with granite.

Profile description:

Ap 0-12cm Brown (7.5YR 5/4) moist and light brown (7.5 YR 6/4) dry, sandy loam; moderately weak medium crumb; slightly stick, slightly plastic (wet), very friable (moist) and hard (dry); many very fine random pores; porosity 42.7%; common very fine roots; abrupt, smooth boundary.

AB 12-28cm: Brown to brown (7.5 YR 5/4) dry, sandy loam; strong coarse granular; slightly stick, slightly plastic (wet), very friable (moist) and hard (dry); very few medium and common fine and very fine random pores; porosity 36.5%, few very fine roots; clear; smooth boundary.

Bul 28-46cm: Strong brown (7.5YR 5/8) moist and reddish yellow (7.5 YR 6/6) 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; porosity 38.5%; gradual smooth boundary.

Bu 46- 102 cm: Reddish yellow (5YR 6/8) moist and reddish yellow (5YR 7/8) dry, sandy clay loam; moderately weak medium sub-angular blocky; non stick non plastic (wet); very friable (moist) and hard (dry); common fine and very fine random pores; porosity 42.3%; gradual smooth boundary.

Bu 102 - 158 cm: Reddish yellow (5YR 6/8) moist and reddish yellow (5YR 7/8) dry, sandy clay loam; moderately weak fine and medium sub-angular blocky; slightly stick, slightly plastic (wet), very friable (moist) and hard (dry) common fine and very fine random pores; porosity 40.4% ; clear smooth boundary.

Bgcs 158-178cm: 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 and 7.5 YR 5/8) mottles; slightly gravely

sandy clay loam; moderate coarse sub-angular block sticky and plastic (Wet), firm (moist) and very hard (dry); few fine to medium pores; porosity 35% very few angular quartz gravel (2-4mm) very few large (1.0-1.5cm) slightly soft irregular dark red ironstone nodules; abrupt smooth boundary.

Ccs 178-184cm: Pinkish grey (7.5 YR 6/2) moist and pinkish grey (7.5 YR 7/2) dry; common medium distinct clear strong brown mottles, slightly gravely sandy clay loam; massive; sticky and plastic (wet), firm (moist) and extremely hard (dry); few fine pores; porosity 30.7%; very few large (1.0-1.5) slight soft irregular dark red ironstone nodules.

Appendix 1b: Analytical data of the profile

Horizon	Depth (cm)	Clay	Silt	Sandy %	Textural class	pH	Organic		Total Nitrogen (%)
							carbon (%)	carbon (%)	
							H2O (1:25)	Kcl (1:2.5)	
Ap	0-12	16.0	5.0	79.0	SL	5.4	4.2	1.03	0.05
AB	12-28	17.0	5.0	78.0	SL	5.1	4.0	0.62	0.03
BU1	28-46	22.0	4.0	74.0	SCL	5.2	3.8	0.57	0.04
BU2	46-102	23.0	5.0	72.0	SCL	6.0	3.8	0.28	0.02
BU3	102-158	32.0	2.0	66.0	SCL	5.5	3.8	0.28	0.03
Bgs	158-178	27.0	4.0	69.0	SCL	5.4	3.7	0.34	0.03
Ccs	178-184+	24.0	2.0	74.0	SCL	5.3	5.8	0.19	0.02

Appendix 1b:continued

Available P (mg/kg)	Exchangeable bases (cmol (+)/kg)	Total exchangeable bases	Exchangeable AI	C.E.C. (cmol(+)/kg)	% bases saturation			
	CA ²⁺	Mg ²⁺	Na ⁺	K ⁺				
11.6	2.0	0.6	1.4	0.9	6.8	0.8	12.6	38.9
5.6	5.2	0.4	0.9	0.3	4.9	1.4	9.6	70.8
2.8	2.8	0.3	1.5	0.3	3.6	2.4	11.6	42.2
2.8	2.0	0.2	1.1	0.3	7.2	3.0	14.0	25.7
2.8	2.4	0.6	4.0	0.2	7.2	2.9	13.6	52.9
2.5	4.2	1.1	1.6	0.3	8.8	2.0	15.6	46.2
2.8	4.4	2.3	1.5	0.6	nd	1.0	9.0	97.8

Appendix 2

Average soil water ($\text{cm}^3\text{cm}^{-3}$) distribution as affected by tillage methods at various growth stages on 0-10 cm, 10-30 cm and 30-50cm.

Growth stages	Tillage Treatment	Soil Depth (cm)			Treatment me mean(0-50)
		0 - 10	10 - 30	30 - 50	
Seeding Stage	T1	0.089 ^c	0.116 ^b	0.124 ^b	0.110 ^a
	T2	0.091 ^c	0.135 ^{ab}	0.151 ^a	0.126 ^a
	T3	0.083 ^c	0.112 ^b	0.129 ^b	0.108 ^a
	Mean	0.088 ^b	0.121	0.135	
	L.S.D	0.086	0.086	0.086	
	C.V(%)	17.55	17.55	17.55	
Tasselling Stage	T1	0.112 ^{ab}	0.116 ^{ab}	0.135 ^{ab}	0.121 ^a
	T2	0.105 ^b	0.120 ^{ab}	0.144 ^a	0.123 ^a
	T3	0.104 ^b	0.104 ^b	0.114 ^{ab}	0.107 ^a
	Mean	0.107 ^b	0.113 ^{ab}	0.131 ^a	
	L.S.D	0.02	0.02	0.02	
	C.V(%)	15.99	15.09	15.09	
Grain filling stage	T1	0.096 ^a	0.107 ^{def}	0.145 ^{bc}	0.116 ^a
	T2	0.095 ^f	0.136 ^{cd}	0.173 ^b	0.135 ^a
	T3	0.101 ^{ef}	0.133 ^{de}	0.143 ^{bc}	0.126 ^a
	Mean	0.097 ^e	0.125 ^b	0.153 ^a	
	L.S.D	0.019	0.019	0.019	
	C.V(%)	14.62	14.62	14.62	
Maturity stage	T1	0.064 ^{de}	0.094 ^{cd}	0.128 ^{ab}	0.095 ^a
	T2	0.050 ^f	0.100 ^{bc}	0.142 ^a	0.097 ^a
	T3	0.059 ^f	0.109 ^{bc}	0.127 ^{ab}	0.098 ^a
	Mean	0.058 ^e	0.101 ^b	0.132 ^a	
	L.S.D	0.019	0.019	0.019	
	C.V(%)	9.11	9.11	9.11	

T1 = No-till, T2 = Residual shallow tied ridges, T3 = Residual deep tied ridges
 C.V = coefficient of variation, L.S.D = Least significant difference, Means followed with the same superscripts in the same column are not significantly different at 5% using DMRT.