ASSESSMENT OF RESIDUAL TIED RIDGES AND FARM YARD MANURE APPLICATION ON SORGHUM YIELD IN SEMI-ARID AREAS OF HOMBOLO DODOMA, TANZANIA

BY

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ABSTRACT

Soil physical management involves better understanding of the dynamics of soil physical properties. The reported field study was conducted in semi-arid central Tanzania on a continuing five years old tillage trial comprising No-till (NT), shallow tied ridges (STR), deep tied ridges (DTR) and annually made tied ridges (ADTR) to study the effect of residual unmanured and manured 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 the residual tied ridges. The test crop was sorghum variety *Tegemeo*. Investigated parameters included average residual organic matter (OM) content of the experimental site at different depths. Soil surface roughness before and after field operations and after every heavy rainstorm. Dry bulk density was determined before planting, at mid season and at harvest. Cumulative infiltration was determined before planting and at harvest. Gravimetric moisture content determinations at different depths were made on weekly basis. There was no significant ($P<0.05$) difference in residual OM content among tillage treatments. The results were that tillage significantly ($P<0.05$) affected soil surface roughness indices (SSRI) among tillage treatments (NT, STR and DTR). It was 185% high in the residual tied ridges compared to the control. Cumulative infiltration was significantly ($P<0.05$) higher in NT treatments than in all other six treatments. It was 285.66 mm/hr before planting and 412.83 mm/hr at harvest. STR, DTR and ADTR had intermediate values. Weekly gravimetric soil profile moisture content (mm) in 0-50 cm soil layer were significantly ($P<0.05$) influenced by treatments throughout the season. It was high in the residual tied ridges compared to the control. Dry bulk density in the surface layer was not significantly ($P<0.05$) different among treatments. A significant difference in bulk density was observed between treatments only at harvest and within 30-50 cm-soil layer. Farmyard manure had no effect on bulk density. Total porosity values were not significantly different among tillage treatments during the study period. Percentage seedlings emergence and the number of plants at harvest were significantly ($P<0.05$) higher in DTR than the other treatments. Sorghum grain yield was significantly ($P<0.05$) affected by tillage methods. The annually made tied ridges had higher grain yield of 2.17 tons/ha than only 0.42 tons/ha in the control. Grain yield of 1.92 tons/ha under residual tied ridges after five seasons was statistically comparable to the yield from annually made tied ridges. Residual tied ridges can thus be utilized for up to five seasons. The reduced tillage and ridging cost as well as the increased sorghum grain yield under the residual tied ridges is likely to now make the system attractive to farmers in semi-arid areas.

DECLARATION

I, ANDREW KAGGWA KABANZA, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and has not been submitted for a higher degree award in any other University.

Signature:......AKabanza.......

Date:.........26/03/2003.......

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DEDICATION

I would like to dedicate this work to all who have spent most of their time in educating people on rainwater harvesting for agriculture in semi-arid areas of Tanzania.

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LIST OF SYMBOLS AND ABBREVIATIONS

CEC	= cation exchange capacity
°C	= degree Celcius
CV	= coefficient of variation
FYM	= farmyard manure
$R_{(k)}$	= roughness index
Θg	= gravimetric water content
Θp	= profile water content
Θv	= 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
DAP	= days after planting
USA	= United States of America
L	= soil layer
R_r	= random roughness
SOM	= soil organic matter

CHAPTER ONE

1.0 INTRODUCTION

On the basis of agricultural potential, it is estimated that more than 50% of the land in Tanzania is semi-arid LRDC (1987). The semi arid zones occupy about one third of the total area of Tanzania, extending between North-East and South-West across the central part of the country. The areas falling under the semi-arid zone in Tanzania include Dodoma, Singida, some parts of Arusha, Kilimanjaro, Shinyanga, Mbeya and Tabora regions. The semi-arid regions in Tanzania are the zones that are prone to unreliable rainfall ranging from 450-750 mm/year. Taking the case of Hombolo Dodoma, the area is characterized by low rainfall with high variability in quantity, duration and onset. Analysis by Ngana (1993) showed that Dodoma has a mono-modal rainfall which falls between October and May, with a mean annual rainfall of 550 mm. Temperature ranges from 19.6°C to 35°C and the average annual temperature is 22.7°C. It has a high evapotranspiration of 650 mm due to the high temperature and wind speed, and fluctuations in relative humidity (84% to 93% early in the morning to 34% in the hot afternoon). There are also runoff losses during rainfall events, which are estimated to be as high as 40% (Hatibu *et al.*, 1995).

Due to climatic conditions explained above there have been attempts to optimize crop yield by planting drought tolerant crops particularly sorghum and millet in semi-arid areas of Tanzania. Planting of drought tolerant crops has however not eliminated crop failure due to water stress (Mahoo *et al.*, 1999). Another intervention that could be used is the application of farmyard manure (FYM). Organic matter of different origin has been observed to improve water holding capacity of soils by up to five times of its own weight (Young, 1976). Other studies conducted in Ghana reported an increase of soil water holding capacity from 37% to 57% with an increase of organic matter from 3% to 5%, respectively. Some benefits accrued from application of FYM were summarised by Kramer and Boyer (1995). They include formation of stable soil aggregates, supply of plant nutrients, creation of pore spaces, increased amounts of available water, increased infiltration rate, and decreased bulk density. All the above factors enhance plant growth. The potential for application of FYM to improve crop yields in semi-arid Central Tanzania exists since the resource is available and it is under-utilised (Mahoo *et al.*, 1996a, b).

Several studies carried out in Dodoma region have shown that ploughing coupled with tie ridging and application of FYM can increase yield through conservation of moisture (Hatibu *et al.*, 1995; Swai and Rwehumbiza, 1998; Reuben *et al.*, 1998). Despite the obvious advantages farmers have not adopted tie-ridging techniques. The main reason is the fact that land preparation is undertaken before the onset of rains when soils are dry and therefore too hard to till with a hand hoe (Rwehumbiza *et al.*, 2000). Construction of tied ridges is also a tedious and time consuming task (Georgis, 2000). As a result, and due to the shortage of draft power and tillage implements, farmers have developed a less-demanding No-Primary-Tillage (NPT) practice or *kuberega* in local language. *Kuberega* involves superficial scratching of the soil surface with a hand hoe to suppress weeds before sowing (Rwehumbiza *et al.*, 2000). The NPT practice suits resource poor farmers since it requires very little draft power. It has however, low performance in terms of crop yields, mainly due to poor soil water conservation. The latter is caused by high run-off losses of rainfall that occurs with high intensity especially at the beginning of the season (Hatibu *et al.*, 1995). Reducing the time and cost spent on constructing tied-ridges by making ridges once every four or five years can make the practice more acceptable to farmers (Anschütz *et al.*, 1997 and Rwehumbiza *et al.*, 2000). In Hombolo, tied ridges were established in 1996/97 season and have been under experiment as residual tied ridges since then.

Work by Hatibu *et al.* (1995) at Hombolo, on sandy clay loam soils, demonstrated that tie ridging produce the highest sorghum grain yield as compared to flat tillage and no till. However, an impact assessment on improvement of the No-Primary (NPT) '*kuberega*' practice of sorghum-livestock-maize (SLIM) farming systems of semi-arid Tanzania by Mahoo *et al.* (1996b) at Hombolo, revealed that most farmers were reluctant to practice tie ridging system despite its known benefits. This was due to the high labour required to construct tied ridges every season. Thus, the reported study was to evaluate the long term performance of the residual tied ridges and FYM application on yield of sorghum and this would compliment previous studies and come up with a suitable package to be applied by farmers in semi-arid area of Dodoma Tanzania.

In semi-arid areas the primary factor limiting crop production is moisture deficiency. The amount of rainfall, its frequency and duration are usually erratic (Swai, 1999; Rwehumbiza *et al.*, 2000). Apart from unfavourable conditions, low crop yield potential is mainly due to poor tillage practices which are inappropriate for soil water conservation. There is ample evidence indicating that application of FYM increases soil available water capacity (Tisdale and Oades, 1982; MacLean and More, 1979; Kramer and Boyer, 1995; Swai, 1999; Rwehumbiza *et al.*, 2000). Studies conducted in Hombolo, have shown that, the use of tied ridges associated with application of FYM increased yields through the conservation of moisture (Hatibu *et al.*, 1995; Swai and Rwehumbiza, 1998; Reuben *et al.*, 1998; Swai, 1999; Rwehumbiza *et al.*, 2000). However, the high labour requirement and exercise of making tied ridges by hand hoe, the lack of means of transport to carry FYM to distant crop fields and limited draft power for land tilling are bottlenecks in the adoption of the practice (Rwehumbiza *et al.*, 2000).

Tie ridging is economically a desirable practice. There is a need to ensure that it is done in such a way that a long-term and productive system is created. The goal should therefore be to develop affordable moisture conservation tillage techniques that will subsequently alleviate labour bottlenecks and increase crop yields above the currently low levels obtained in semi-arid areas.

Assessment of long term effects of residual tied ridges with and without FYM application has not been done at Hombolo. This study will provide information on changes in soil physical and hydrological properties, and crop yields, when residual tied ridges with and without farmyard manure are practised on a long-term basis (more than five seasons).

Based on this study, a suitable package on the use of residual tied ridges will be developed and recommended to farmers.

The main objective of this study was therefore to assess residual tied-ridges and FYM application as soil water harvesting technique on sorghum grain yields in semi-arid areas of Hombolo in Dodoma region, in Tanzania.

The specific objectives included the following:

1. To assess the effect of residual tied-ridges on soil moisture storage status.
2. To evaluate residual organic matter (FYM) content at different depths in the residual tied ridges.
3. To investigate the effects of residual tied-ridges and FYM on establishment and grain yield of sorghum.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Tie ridging

Tie ridging is an engineering practice of constructing ea ridges at right angles to them in intervals of 1-4 m Hulugalle, 1987; Malley, 1997). The practice is synony diking, furrow dumming or blocking by earthened dikes *al*., 1991). Clark and Jones (1981) and Jones and Stewa as basin tillage or furrow damming, furrow diking, b tillage. The diking/tie ridges have a potential for inc (Jones and Stewart, 1990; Unger *et al*., 1991; Hatibu *et al*., 1995; Swai and Rwehumbiza, 1998; Swai, 1999; Rwehumbiza *et al*., 2000 and Mwaliko, 2001).

The tie ridging system is used to trap rainwater and conserves it in the relatively drier areas, which are flat to gently slopping (Dagg and Macartney, 1968; Perrier, 1987; Hulugalle, 1990; Jones and Stewart, 1990). Perrier (1987) observed that tied ridges help to increase yields when surface runoff occurs at a greater rate than infiltration. Dagg and Macartney (1968) reported that tie ridging increased maize yield in a moderate rainfall year, but not in years that had either poor or high rainfall. Some studies have actually indicated yield reduction in years of high rainfall (Dagg and Macartney, 1968; Hulugalle, 1990; Jones and Stewart, 1990 and Rwehumbiza *et al*., 2000).

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On a red soil of northern Tanzania, work by Dagg and Macartney (1968) showed improved water penetration and conservation in the tied ridges compared to either ridges without ties or the flat cultivation. Perrier (1987) has reported similar yield improvements of sorghum and millet varieties by the tie ridging practice in loam and sandy loam soils of Burkina Faso. Hulugalle (1990) has also reviewed the benefits of the ridging on soil water conservation and its ultimate effect on yield of various crops in West African Sudan Savannah, while those in the Texas Northern High Plains on Pullman clay loam by Sow *et al.*, (1996). Jones and Stewart (1990) have reviewed central Great Plains of USA and Southern Great Plains have been reviewed by Unger (1994); Unger and Baumhardt (1999) and Thompson (2001). In the Central Queensland, Australia Radford *et al.*, (1995) and that of Northern Territory and Far North Queensland, Thiagalingam *et al.*, (1996).

Another review is by Selvaraju *et al.*, (1999) on field experiment conducted at Coimbatore, India on Alfisols (Chromic Cambisol). Their results showed that, tie ridging and application of manure (FYM) in combination with inorganic N and P fertilizers increased the soil water storage and yield of crops compared to traditional flat bed cultivation in rainfed Alfisol and related soils of semi arid tropics.

An important effect on soil and water conservation on the tied ridges is the capacity of temporary surface water storage that can reduce runoff and erosion when the precipitation rate exceeds infiltration rate. Tie ridges conserve soil and water by providing more time for runoff infiltration (Monteith, 1974 and Unger *et al.*, 1991). For example, by using the tied ridges on a gently slopping land at Bush land Texas

USA, all water from a 150 mm rain during a 24 hours period was retained on the slowly permeable Pullman clay loam (Jones and Stewart, 1990).

Tie ridging cultivation may increase rain water infiltration and conservation for increased crop growth and yield due to the mechanical loosening of the soil on the ridges (Kayombo, 1992). Dagg and Macartney (1968) reported increased rainfall infiltration and conservation on black, red and ash soils in the tied ridges in Tanzania. Hulugalle (1990) found that in West African Alfisols, tie ridging increased the depth of rooting and subsoil root density for maize, millet and cotton in both dry and wet years, and in cowpea in dry years. All these reviews have shown the importance of tie ridging on conservation of both water and soil.

2.2 No-till tied ridging

In the recent years, interest in conservation tillage system has increased in response to the need to promote water conservation and at the same time to limit soil erosion. No till tied ridging has been developed in Zimbabwe as means of overcoming high labour and draft power required in the making of ridges and ties. In this method, land is ploughed so that the ridges and ties can be built in the first year. 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 the most of the farmers managed trials and it has been widely adopted (Nyamudeza *et al.*, 1993).

2.3 Soil moisture

Conserving soil moisture in the soil profile is very important for crop production (Mwaliko, 2001). Apart from rains, there are other factors, which affect soil moisture storage, and these include evaporation rate, tillage and soil depth. 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. Different tillage systems have been reported to influence soil moisture differently. For example, Lyle and Dixon (1977) found that tie 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.

Goss *et al.*, (1978) made a study on effects of cultivation on soil water retention and water use by cereals in clay soils. They observed that gravimetric field soil moisture results for a comparatively wet growing season and dry season was that ploughed soil could retain more soil moisture during wet season, than during the dry season. Thus soil moisture content in relation to soil depth may increase due to different reasons as reviewed by Aujilla and Cheema (1983).

2.3.1 Soil moisture and rainfall

The primary factor limiting crop production in semi-arid areas is moisture deficiency (Webster and Wilson, 1980). Rainfall is the major factor influencing crop and livestock production but apart from being low in amount, it also falls at high intensity, which causes substantial runoff (Hatibu *et al.*, 1995). Both rainfall frequency and duration are usually erratic (Mahoo *et al.*, 1996a, b).

Crop production in a semi-arid region is dependent on both rainfall and stored water. Among other factors, rainfall is one of the major constraints in agricultural production. The problem of semi-arid areas as regards to rainfall for agriculture is both quantity, distribution and reliability. There is high fluctuation of monthly rainfall from the mean with high variation at the beginning and end of the season (Ngana, 1991). Thus, this results into low availability of soil moisture (Hatibu *et al.*, 1995). Apart from unfavourable conditions, low crop yields potential are mainly due to poor tillage practices that are inappropriate for soil water conservation. Sorghum is the most important crop in smallholder farming systems in the semi-arid region of Dodoma (Hella, *et al.*, 1998). In examining several problems that limit productivity of the crop, Hella, *et al.*, (1998) reported the order of problems with the priority given by the respondents. The weather problems ranked high (40%) as compared to other problems- market unavailability for the produce (18%), lack of capital and equipment (16%), insect pests (9%), unavailability of inputs (6%), disease problems (3%), and labour problems (3%). There is a need therefore for efficient utilization and management of soil water.

2.4 Soil water conservation

Conservation of rain water/rainfall as soil water is one of the most important soil management aspects (Cook, 1962). When rainfall 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). Use of tied ridges is one of the engineering methods with considerable success. The method has been developed from the modification of locally used ridges. The method has been tested in Tanzania (Dagg and Macarteney, 1968; Hatibu, *et al.*, 1995; Swai and Rwehumbiza, 1998; Swai, 1999; Rwehumbiza *et al.*, 2000 and Mwaliko, 2001). West African Sudan Savannah (Hulugalle, 1990), the semi arid tropics of Burkina Faso (Perrier, 1987) and in the Central Great Plains of the USA (Jones and Stewart, 1990 and Unger and Baumhardt, 1999).

2.5 Soil water management aspects 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). Some soil water management aspects include water harvesting with ridge tillage (Lal, 1993). Rainwater harvesting for crop production has been seen as promising and generally appropriate way of upgrading rainfed agriculture in the semi-arid tropics. This is due to the fact that rainwater harvesting is aimed at managing rain water from the moment it falls and ensuring that most of it is used productively before it is returned to the atmosphere by evaporation (Hatibu, 2000). However, tillage techniques differ depending on soil physical properties and antecedent soil condition.

2.6 Organic matter and soil water management

Apart from moisture, organic matter is of beneficial role in tropical agroecological systems than any other soil characteristics (Young, 1976). The amount of soil organic matter (SOM) in most semi-arid dryland soils is relatively low, ranging from 0.5 to 3% and typically less than 1%. The influence of SOM on soil properties is of major significance (Smith and Elliot, 1990). Literature shows that SOM content is usually estimated from analysis of soil organic carbon content because the latter can be determined more precisely (EUROCONSULT, 1989; Landon, 1991; Brady and Weil, 1996; Brady, 2000; and Møberg, 2000). The organic carbon contents of subsurface horizons are generally much lower than those of the surface soils (Brady and Weil, 1996; Brady, 2000). Thus most of the organic matter is found in the upper soil horizons.

There is a body of evidence indicating that manuring increases the available water range (Tisdale and Oades, 1982; MacLean and More, 1979; Kramer and Boyer, 1995; Swai, 1999; and Rwehumbiza *et al.*, 2000). Clay-humus complexes are good protection against wind and water erosion, they promote permeability and improve water storage (Young, 1976; Sanchez, 1976 and Lal, 1979). The continued application of manure modifies, in addition to supply of plant nutrients, soil physical properties (Biswas *et al.*, 1970). There is adequate information that quantifies the beneficial effect of long-term manure application on the physical properties of several soils (Sanchez, 1976). Several studies have shown that long term manuring increased available water range, aggregate stability, infiltration rate, pore space and decreased bulk density (Biswas *et al.*, 1970; Tisdale and Oades, 1982; Kramer and Boyer, 1995).

Biswas and Khosla (1971) reported the increase of water content in soils under different soil conditions in which the increase from 28 to 37%, 29 to 31%, 21 to 23%, were observed in soils which received FYM of 74, 45 and 9 tons/ha respectively. In semi arid areas of Tanzania the recommended rates for FYM have not been established due to the variation in the composition and quality of the FYM from different places. Application rates ranging from 10 to 15 tons FMY/ha have been suggested. Higher rates 25-50 tons/ha have also been applied without any injurious effects to crops (Scaife, 1971). Intensive tillage systems, fallowing and low crop productivity combined with physical soil loss by erosion decrease the organic matter content over time (Tisdale *et al.*, 1993; Ayanaba *et al.*, 1976). This shows that SOM transformations are very dynamic. An understanding of organic matter dynamics is a subject of considerable and continuing interest (Greenland *et al.*, 1992). The information on the residual effect of FYM on residual tie ridges in semi-arid areas therefore needs investigation.

2.7 Effect of tillage on physical and hydrological soil parameters

Tillage is defined as the mechanical manipulation of the soil aimed at improving soil conditions affecting crop production (Hillel, 1980). In all tillage operations, a mechanical force that is applied to the soil tends to modify the state and behavioral properties of the soil. Tillage operations affect physical as well as hydrological properties of the soil. This is through loosening the soil, compaction, crushing shattering and inverting the soil (Lal, 1979; 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, particle size distribution, surface roughness, water content, infiltration and soil porosity have been used to describe the different tillage induced soil conditions (Larson, 1964; Malik, *et al.*, 1985).

2.7.1 Effect of tillage on bulk density

A number of scientists have investigated on the effect of tillage on bulk density (Adeoye, 1982; Cassel and Nelson, 1985; Kayombo, 1986; Agenbag and Marce, 1991 and Cresswell *et al.*, 1991). It was observed in all these studies that bulk density of the soil increased with depth depending on the degree of pressure exerted by different tillage systems. Most tillage operations when performed decrease soil bulk density within the disturbed zone. However bulk density varies temporarily and spatially (Allmaras *et al.*, 1966; Landon, 1991). This may be due to organic matter level, root penetration and soil structure (Landon, 1991). Other causes of variation in bulk density include the undisturbed zone within the soil, compaction and reconsolidation due to subsequent tillage operations. Also break down of unstable soil aggregates due to rain drops impact (Macartney *et al.*, 1971; Willcocks, 1981; Swai and Rwehumbiza, 1998; Swai, 1999; Rwehumbiza *et al.*, 2000 and Mwaliko, 2001).

2.7.2 Effect of tillage on soil structure and aggregation

The term structure relates to the grouping or arrangement of soil particles (Hillel, 1980; Brady and Weil, 1996; Brady, 2000). It describes the gross, overall combination or arrangement of the primary soil separates into secondary groupings called aggregates or peds (Brady and Weil, 1996; Brady, 2000). Soil structure is strongly affected by changes in climate, biological activity and soil management practices, and it is vulnerable to destructive forces of a mechanical and physical chemical nature (Hillel, 1980). Soil structure determines the total porosity as well as the shape of individual pores and their size distribution. Hence soil structure affects the retention and transmission of fluids in the soil, including infiltration and aeration (Hillel, 1980). Moreover, as soil structure influences the mechanical properties of the soil it may affect germination, root growth, tillage, overland traffic and aeration. 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. Since soil structure is among the primary aims of tillage; its management is crucial and therefore all advantages accrued from soil structure improvement are of benefit to crop growth and development.

2.7.3 Effect of tillage on soil strength

Soil strength is a measure of the capacity of a soil to withstand stresses without giving way to those stresses by collapsing or becoming deformed (Brady and Weil, 1996; Brady, 2000). 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). Increase in soil strength in compacted soils has been associated with bulk density (Mwaliko, 2001). According to Williams and Shaykewich (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/cm^3 and a 70% decrease in root penetration in a soil with a bulk density of 1.75 g/cm^3.

2.7.4 The effect of tillage on pore size distribution

Pore size distribution as defined by Brady (1996) is the volume of the various sizes of pores in a soil. It is expressed as percentages of the bulk volume (soil plus pore space). Brady (1996) also defines soil porosity, as the volume percentage of the total soil bulk not occupied by solid particles.

Tillage systems modify the size of the soil pore system and its continuity (Adeoye, 1982; Datiri and Lowery, 1981; 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 raindrop impact (Adeoye, 1982). Unger and Cassel (1991) reported variations in pore sizes 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 moldboard plough and disc plough created rough surfaces with large surface macropores which increased infiltration significantly at the beginning of the rain season.

2.7.5 Effect of tillage on moisture conservation

Tillage is usually defined as the mechanical manipulation of the soil aimed at improving soil conditions affecting crop production (Hillel, 1980). Ploughing has effects on the dynamic of surface water, depending on experimental conditions, period of investigation and topographical features (slope, soil depth) the effect may be either to increase the rate of soil degradation (runoff and erosion) or, in contrast, to improve crop production by improving the utilization of rainfall. Storage of water in the surface layer is increased by ploughing and this has particular benefits in areas with erratic rainfall patterns (Blevins *et al.*, 1971).

2.7.6 The effect of tillage on soil water availability and retention

Besides soil physical properties such as pore size distribution, soil texture and compaction, tillage methods too, affects soil water retention (Swai, 1991). Lal (1985) observed that water retention at -0.01 MPa matric potential increased from 14.7 to 17.5% in the no tillage water shed after six years of continued mechanized farming, whereas it decreased from 17.7 to 13.8% in the ploughed watershed, at 0-10 cm depth. The same study also showed that available water capacity (AWC) expressed as the difference between moisture retention at -0.01 MPa and at -1.5 MPa increased from 9.3 to 17.3% under no till and 9.6 to 16.2% under ploughing. The increase in available water capacity with cultivation was due to change of transmission to retention size pores. Soil water retention and available water capacity may also be affected by naturally compacted soils (Swai, 1999). For instance, in semi-arid areas of West Africa, water content in the soil surface ranged from 8 to 15% at -0.03 MPa and from 2 to 7% at -1.5 MPa (Perrier, 1987). Tollner *et al.*, (1984) work on influence of conventional and no till practice on soil physical properties in the southern Piedmont of USA showed that, the surface soil (at 30 cm) in the conventional tillage plots held more water than no till at the suction of 80 kPa or less. At suction of 300 kPa and more, there were no differences between treatments.

2.7.7 Effect of tillage on total porosity

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 (Mwaliko, 2001). 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 that influence moisture retention. Some tropical soils are naturally compact and have low total porosity (Honisch, 1974 and Parthasarthy *et al.*, 1976). Low total porosity is aggravated by among other factors, poor soil management (Casagrande *et al.*, 1975). Studies by Van Wambeke, (1974) observed that alterations of structure cause a change in pore size distribution. Khan and Datta (1984) observed higher porosity values in recently tilled plots. Where porosity is limiting, tillage also decreases mechanical resistance to root penetration and roots develop more quickly and more deeply (Swai, 1999).

2.7.8 Effect of tillage on infiltration rate

Infiltration rate is a soil characteristic describing the maximum rate at which water can enter the soil under specified conditions, including the presence of an excess of water (Brady and Weil, 1996; Brady, 2000). Measurement of infiltration rate is essential in studies related to hydrology, water conservation, runoff and erosion and irrigation (Ghildyal and Tripathi, 1987). 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 in a field study. They reported that ridging and tied ridging tillage methods maintained high infiltration rate, which in turn ensured high moisture supply throughout the growing season. In contrast Hulugalle, (1988) observed that cumulative infiltration determined for two hours was greater with flat cultivation than tied ridging. He attributed this to the relatively high clay content in the soil surface (0.05 m) with tie ridging than flat cultivation.

Therefore planning for water and conservation activities require accurate information on the rate at which water enters the soil under different soil conditions. The main factor governing infiltration is the time available for infiltration to occur (Ghildyal and Tripathi, 1987). Soil management that modifies physical properties and practices, which slow down the movement of water significantly affect infiltration rate (Swai, 1999). Management practices that affect the time water can be retained on the land surface will also inevitably affect infiltration rate. A study by Meickle (1972) revealed that tied ridging technique is very effective in improving infiltration and moisture storage in the soil. Tied ridging is also known to significantly reduce soil loss and runoff (Prestt, 1986).

2.7.9 Surface roughness

Allmaras *et al.*, (1967) defined surface roughness as the surface configuration of the soil caused by the randomly oriented arrangement of soil clods in the field. Linden and Van Doren, (1986) further defined surface roughness as the surface configuration of the soil as a result of equipment traffic and the orientation of the soil clods that are broken, lifted, shattered and resettled during tillage. Soil surface roughness is closely related to surface depression storage capacity (Monteith, 1974 and Onstad, 1984). Rough soil surface has proved to store more water in surface depression than smooth soil surface (Zobeck and Onstad, 1987).

Soil surface roughness undergoes small-scale changes during the growing season after primary cultivation. The type of implement used and the soil conditions at the time of tillage have a large influence on the resulting configuration.

2.7.9.1 Influence of tillage on depression storage

Gayle and Skaggs (1978) defined depression storage as a means by which ponded water from rainfall is kept on the surface and allowed to infiltrate when the rainfall rate falls. There are two types of surface storage, micro storage and macro storage (Gayle and Skaggs, 1978). Micro storage is defined, as storage in very small pockets while macro storage is storage in large depression basins caused by surface roughness or topographic undulating of the land surface such as that created by tillage. Depression storage is closely related to surface roughness (Monteith, 1974; Onstad, 1984).

Romkens and Wang (1986) reported that soil surface roughness control runoff and soil erosion, improves infiltration (Zobeck and Onstad, 1987) and decreases evaporation rate (Linden, 1982). Monteith, (1974) found that large surface depressions retain water in excess of infiltration from short duration storms. This was seen to reduce runoff that could have led to high losses of soil moisture. Tillage action increases micro relief or minor undulations and irregularities with differences in height between crest and trough on the land surface and these may affect depression storage (Mwaliko, 2001). These rough soil surfaces have proved to store more water in surface depression than smooth soils surface (Zobeck and Onstad, 1987). Usually depression storage decreases with decreasing surface roughness and increasing slope of the land (Swai, 1999).

The effect of tillage system and row direction on depression storage was investigated by Mahamoud *et al.*, (1990) and their findings indicated that mean depression storage of contoured plots was significantly greater than depression storage of up and down slope plots. Other factors that influence depression storage include variation in residue cover on the soil surface, initial moisture content and slope of the land (Swai, 1999).

2.7.9.2 Depression storage measurement from soil micro relief data

Several researchers (Seginer, 1971; Monteith, 1974; Michell and Jones, 1976, 1978, Gayle and Skaggs, 1978; Huggins and Monke, 1978; Linden, 1986; Moore *at al.*, 1980; Onstad, 1984) have used microrelief data measured using microrelief meters in estimating depression storage on flat cultivated land. Swai and Rwehumbiza (1998), Swai (1999) and Mwaliko (2001) through the models developed estimated depression storage on tied ridges. These models use complex computer algorithms to stimulate the rate at which water accumulates at the surface during rainfall event. Kuipers (1957) was the first person to develop the index concept to quantify soil roughness, he defined the roughness by the Index $R_{(k)}$ as:

$R_{(k)} = 100 \times \log_{10}S$.

Where, S = Standard deviation of the elevations in centimetres.

Mitchell and Jones (1978) and Onstad (1984) further used regression analysis to develop simpler relationships for estimating depressional storage from easily measured parameters. They used microrelief meter data to obtain depth storage value on the assumption that each point measurement was centre of a 2.5 cm square level surface as presented by Mitchell and Jones model below;

$$Sr = \sum_{i=1}^{n}\sum_{j=1}^{m}(Hr - Ha)$$

Where, Sr = Surface depressional storage (cm)

i, j = row and columns of point measurement respectively

Hr = reference height (cm) and

Ha = point measurement (cm)

Onstad model is presented as:

$D_s = 1.112R_r + 0.031R_{r2} - 0.012R_rS$

Where, D_s = maximum depression storage (cm)

R_r = random roughness (cm)

S = slope steepness (%)

It can be observed from the literature reviewed above that tillage cause changes in physical and hydrological properties. The changes can lead to significant variations in soil water that consequently affect crop yields.

This study assessed the performance and therefore the possibilities of continued use of the residual tied ridges with and without FYM applied at the establishment of the experiment five years ago.

2.8 Effect of tillage and physical factors influencing plant growth

In dryland areas there are long intervals between rain events and these affect germination and emergency of sown seeds (Mwaliko, 2001). This reduces plant population and restricts early growth as observed by Aujilla and Cheema (1983). Decrease in depression storage and roughness encourage moisture stress (Swai, 1999). 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 and Boyer, 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 moisture conservation measure (Mwaliko, 2001).

Therefore information on changes in physical and hydrological soil factors of the residual tied ridges with time is required before full scale promotion is undertaken in semi-arid areas of Dodoma, Tanzania.

2.9 Effect of tillage on soil moisture and crop yield

Spomer and Hjelmfelt (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. This is due to the fact that 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 (Blevins *et al.*, 1971). Conservation tillage system increases soil moisture by improving soil hydrological properties such as profile water recharge by increasing water infiltration and transmission. The use of tied ridges established before sowing or later in the season, has resulted in large yield increase on the semi-arid tropics of Africa (Perrier, 1987). Yield increases has been attributed due to decrease in runoff and consequently increase in soil water storage (Perriera *et al.*, 1967). Other findings, indicate that seasonal furrow has effect on soil water storage such that it resulted in higher wheat and sorghum yields (Allen *et al.*, 1980). Clark and Jones (1981) observed that water conserved by tied ridging system increased sorghum grain yield by 14% from 1420 to 1650 kg/ha. Increased soil water content and crop yields due to tied ridging 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 from 550 to 800 kg/ha.

Water stress and low soil fertility are the bottlenecks to successful crop production in the dryland areas (Georgis, 2000 and Georgis and Tekele, 2000). In their research activities in semi arid areas of Ethiopia, Georgis and Tekele (2000) observed tied ridges to be efficient in storing the rain water, leading to substantial increase in grain yield of major dryland crops like sorghum, maize, wheat, and mung bean. Grain yield under tie ridges was 50% higher than that of flat planting and other tillage methods. Georgis and Tekele, (2000) concluded that tie ridging is the most effective tillage method recommended for conserving soil and moisture and for maintaining good crop yields in drought prone areas.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location, Soil, Weather and Vegetation

3.1.1 Location

The research work was conducted at Hombolo Agricultural Research Institute (ARI) of the Ministry of Agriculture and Food Security, in Dodoma. Hombolo is located about 58 km North-East of Dodoma Municipality at 05°45'S latitude, 35°57'E longitude and 1020 m above sea level (Fig. 1a and 1b).

3.1.2 Soil of Hombolo Experimental Site

The soils 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 1. 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.

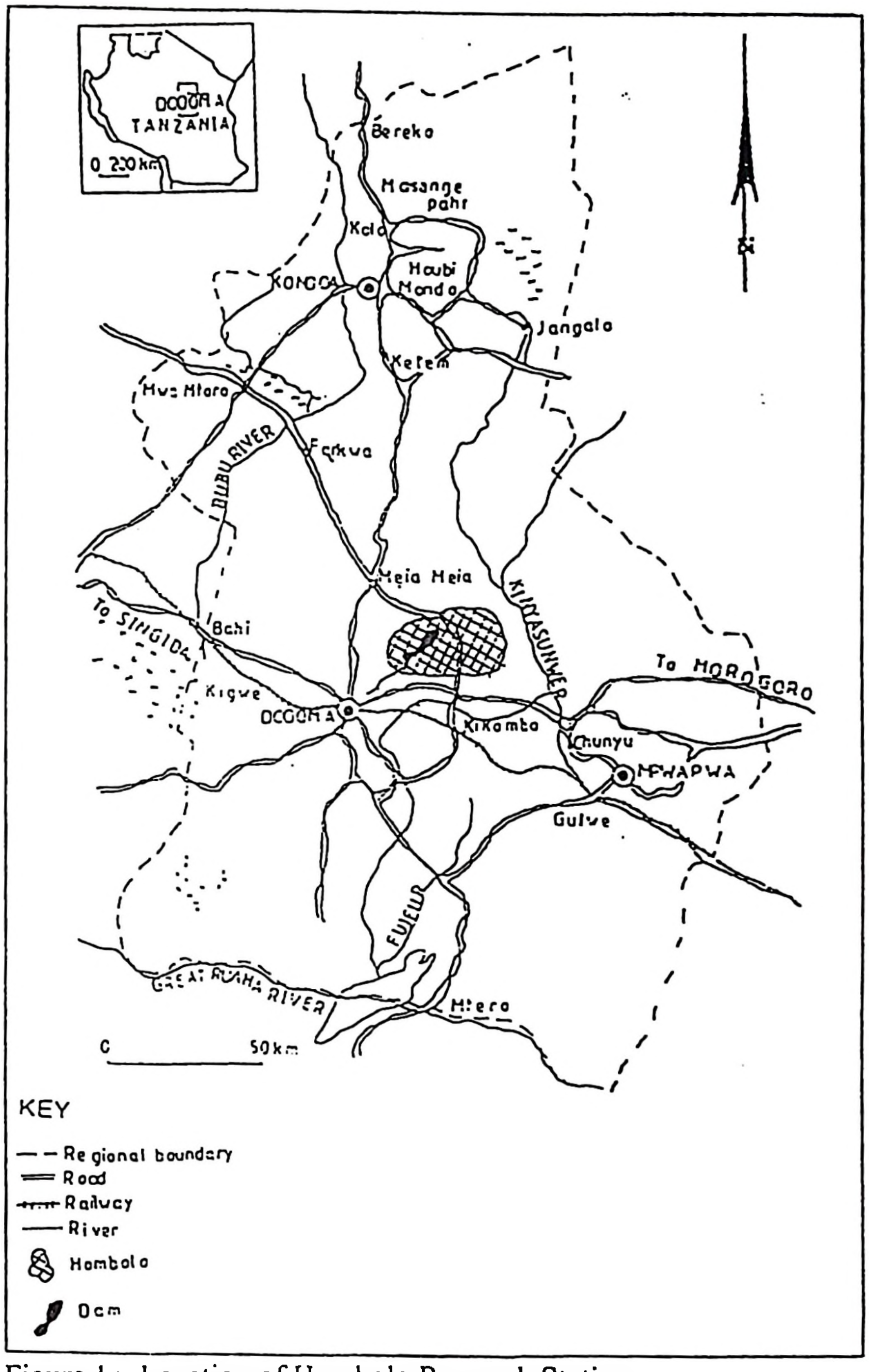


Figure 1a: Location of Hombolo Research Station

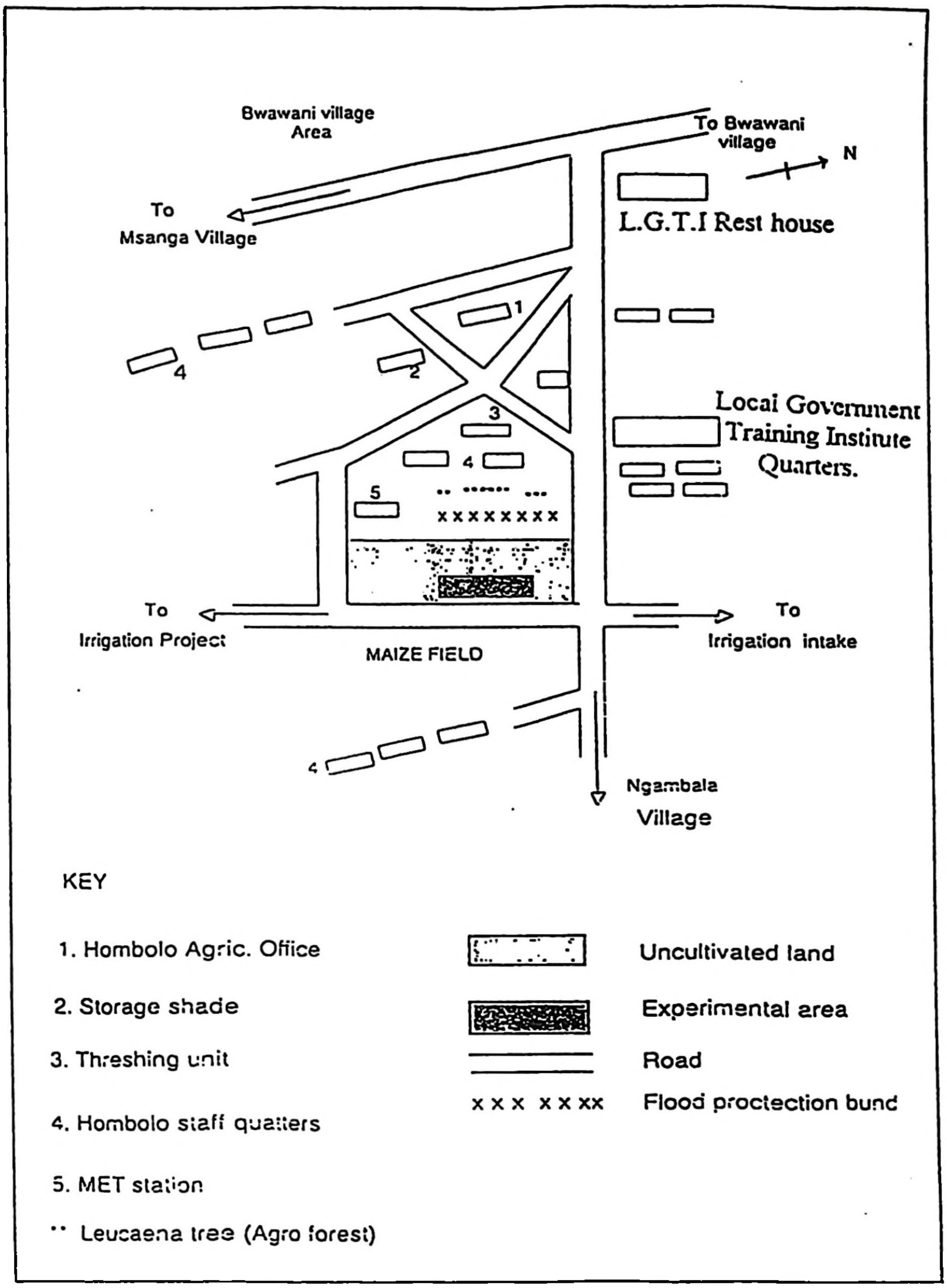


Figure 1b: Location of experimental site in Hombolo Bwawani

3.1.3 Weather and Climate

Meteorological parameters are based on the data from the Hombolo Agrometeorological Station located at Hombolo Research Station (Figure 1b).

3.1.3.1 Rainfall

The average annual precipitation in Hombolo is 589 mm. The movement of the Inter Tropical Convergence Zone (ITCZ) between the northern and the southern hemispheres influences the general rainfall pattern in the study area. 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.

Analysis of rainfall characteristics and their relevance to agricultural planning in semi arid central Tanzania by Ngana (1993) showed that Dodoma has a mono-modal rainfall which falls between October and May, it has a mean annual rainfall of 550 mm. Mean monthly rainfall distribution at Hombolo from 1982-2000 is shown in Table 1. Overall annual average rainfall for 18 years (1982-2000) was 637 mm and rainfall at Hombolo meteorological station for the season 2001/02 is shown in Table 2.

3.1.3.2 Temperature

Temperature ranges from 19.6°C to 35°C and the average annual temperature is 22.7°C. It has a high annual evapotranspiration of 650 mm due to the high temperature and wind speed and fluctuations in relative humidity (84% to 93% early in the morning) but in the hot afternoon, average relative humidity is 34%.

3.1.4 Vegetation

The experimental plots were located on a piece of land that has been under intensive cultivation for the past five years before 2001/02 cropping season. The native vegetation in the surrounding area consists of scattered *Adansonia digitata* (baobab trees) and *Hyperrhenia acacia* bush with grassland. Other indigenous grass types which colonise the surrounding land are such as *Tricodesma zeylanicum* (late weed), *Borhavia diffusa* (Tar vine), *Chrolis gayana* (Rhodes grass) and *Cynodon dactylon* (Star grass).

Table 1: Average monthly Rainfall at Hombolo Meteorological Station for the period 1982-2000.

Month	Rainfall (mm)
July	0
August	0
September	0
October	4
November	44
December	129
January	155
February	125
March	127
April	65
May	9
June	0

Source: Hombolo Agrometerological Station. (2002).

Table 2: Rainfall at Hombolo Meteorological Station for the season 2001/02.

Month	Rainfall (mm)
July	0
August	0
September	0
October	0
November	0
December	53.3
January	143.1
February	39.4
March	160.9
April	27.2
May	0
June	0

Source: Hombolo Agrometerological Station (2002).

3.2 Experimental design and tillage treatments

3.2.1 Experimental design

The study was conducted on the on-going experiment. The experimental design applied was Randomized Complete Block Design (CRBD). The field experiment was designed (i) to assess the effects of tillage regime, tillage depth, tie-ridging, and farmyard manure application on sorghum growth and yields during the 2001/02 cropping season, and (ii) to assess the residual effects of tie-ridging and FYM application on sorghum yields.

3.2.2 Tillage treatments

Seven treatments comprising different water conservation techniques (tillage practices) and FYM were arranged in CRBD with three replications. These were:-

Treatment 1: NPT: No Primary Tillage with no FYM.

It is a current practice by many farmers and this served as a control.

Treatment 2: NPT+F: No Primary Tillage with 30 t/ha of FYM.

Is an improvement of treatment 1. It is practised by many farmers on small plots located near livestock *bomas* because of the ease of transporting FYM. The manure is just spread on the field before planting and no attempt is made to incorporate it into the soil.

Treatment 3: STR: Shallow depth of tillage with tie ridging without FYM.

Is the first step towards high soil-surface management. It involves the making of tie-ridges at the beginning of the experiment after shallow tillage with hand hoe. Initially (1996/97) the field was dug to a depth of 10 cm using a traditional hand hoe, the ridges were made at 0.75 m apart and tied at 1.5 m intervals which produced a series of basins.

Treatment 4: DTR: Deep depth of tillage with tie ridging without FYM.

Is similar to treatment 3 except that the ridges were made following deep tillage with a tractor-drawn plough. Initially (1996/97) the field was dug to a depth of 20 cm using a tractor. The ridges were made at 1m apart and tied at 1.5 m intervals.

Treatment 5: STR+F; Shallow depth of tillage with tie ridging and 30 t/ha FYM.

Is similar to treatment 3 except that 30 t/ha of FYM was applied before making the ridges.

Treatment 6: DTR+F: Deep depth of tillage with tie-ridging and 30t/ha FYM.

Is the best of what can be achieved by farmers. It involves one deep tillage at the beginning of the experiment, application of FYM at 30 t/ha followed by formation of ridges.

Treatment 7: ADTR+F: Same as in (4) above except that it is ploughed annually.

Is similar to treatment 6 except that it is ploughed annually.

During the second, third, fourth, and fifth seasons, land preparation was limited to the removal of weeds without ploughing except in treatment 7 which was ploughed annually. The size of each plot was 20 m by 10 m (200 m^2) (as was measured during experiment establishment). The test crop was sorghum variety *Tegemeo*. Five seeds were planted per hill by dibbling at a spacing of 0.75 m by 0.4 m for no till (local practice) and in shallow tied ridges. Deep tied ridges both with and without FYM were planted at a spacing of 1m by 0.3 m.

3.3 Land preparation, planting and thinning

This involved the collection, rem[illegible] op residues, grasses and weeds from the field which previou[illegible] grown with sorghum variety *Tegemeo* since 1996/97 season a[illegible] in between plots. The previous tied ridges (residual tied ridges) both shallow and deep ones were maintained to their original shape without altering their dimensions. The absolute control plots (no-till) which are 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 hand hoe and it was done on 26 November, 2001.

Planting was done on 6 December, 2001. Five seeds were planted per hill by dibbling at a spacing of 0.75 m by 0.4 m for no till (local practice) and in shallow tied ridges while the deep tied ridges were planted at a spacing of 1m by 0.3 m. Thinning to two seedlings per hill was done five weeks after emergence giving a plant population of 66,667 plants/ha. The delay in thinning was due to the dry spell, which persisted for almost two weeks after emergence.

3.4 Management of the Experimental plots

The crop was weeded three times, 17 DAP, (for replanting due to seeds germination failure at the first planting), 50 DAP and 85 DAP. As in the previous years, weeding was done using a hand hoe. The study was on residual tied ridges, so no inorganic fertilizer or manure was applied during the 2001/02 cropping season. This was done purposely to reflect farmers practice in the study area as most of them do not apply inorganic fertilizer or manure.

Peasant farmers in this area have too low purchasing power to afford the high cost of inorganic fertilizer. Incase of manure, its supply is limited. The large amount of manure needed and the lack of means of transport to the farms are bottlenecks in the use of FYM. When the crop was 60 cm in height, it was infested by stalk borer (*Bussuela fusca*). The insecticide thionex (1.5 litre/ha) was applied using knapsack sprayer as a control measure.

3.5 Determination of hydrological properties of soil

3.5.1 Determination of Soil Moisture

Determinations of soil moisture were carried out at weekly intervals after planting at three depths: 0-10 cm, 20-30 cm, and 30-50 cm until to harvesting. Samples for soil moisture determination were taken from each 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 the dessicator and reweighed. 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) as shown in equation 3.1 below,

$$\Theta g = (Ww - Wo)/Wo \quad \text{...(3.1)}$$

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

Ww = the weight of wet soils, g.

Wo = the weight of 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 as expressed in equation 3.2 below,

$$\Theta v = \Theta g \times Bd/dw \quad \text{...(3.2)}$$

Where: Θv = Volumetric moisture content, cm^3/cm^3.

Θg = Gravimetric moisture content, g/g.

Bd = Soil bulk density, g/cm^3.

dw = Density of water assumed to be 1.00 g/cm^3.

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 in equation 3.3 below,

$$\Theta p = \Sigma(\Theta v \times L) \quad \text{..........(3.3)}$$

Where: Θp = profile water content.

Θv = volumetric water content, cm^3/cm^3.

L = thickness of soil layer, cm.

3.5.2 Soil Infiltration Measurement

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

3.5.3 Measurement of Surface Roughness

Measurement of surface roughness was done using a micro relief meter (Plate 1). The micro relief meter used in this study was similar to the one used by Kuipers (1957). The main features of the instrument are as illustrated in Plate 1. It consists of a 130 cm by 90 cm 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 slides 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 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 measurements were done before and after weeding and after every big rainstorm. The surface roughness was determined as the standard deviation of the pin height measurements. The data was then fitted to the Kuiper's (1957) equation and there after analysis of variance was used to compare the differences in random roughness caused by different tillage treatment.

Plate 1: Microrelief meter

3.6 Determination of some physical and chemical properties of soil

3.6.1 Bulk density and total porosity determination

The bulk density determination was done in three occasions using metallic cores (Blake and Hartage, 1986). Samples were taken before land preparation, at mid-season and at harvest. These undisturbed soil samples were taken in each plot at depth of 0-10 cm, 20-30 cm and 30-50 cm 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 of 2.65 g/cm^3 using the equation 3.4 below,

$TP = (1 - Bd/Pd) \times 100$ ....(3.4)

Where: TP = Total porosity, %.

Bd = Bulk density, Mg m^{-3}.

Pd = Particle density, Mg m^{-3}.

3.6.2 Organic matter determination

Composite soil samples for organic matter determination as described by Nelson and Sommers (1982) were collected at harvesting time (June 2002). Samples for laboratory analysis were taken at 0-10 cm, 20-30 cm and 30-50 cm depth from each plot. Soil organic matter was obtained by multiplying the percentage organic carbon by a factor of 100/58 as described by Nelson and Sommers, (1982).

3.6.3 Soil sampling for routine analysis

Soil composite samples were collected from each treatment before land preparation to a depth of 20 cm from the soil surface. The soil was air dried, ground and sieved through a 2 mm sieve (Day, 1965). Soil chemical analyses were done in the Department of Soil Science at Sokoine University of Agriculture. Soil pH was measured potentialmetrically 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) and organic matter content of the soil at different depth was obtained by multiplying the organic carbon content of the respective depths by 1.72 (Møberg, 2000). Total Nitrogen was determined by the semi-microkjedahl (Bremner and Mulveney, 1982). Cation exchange capacity and exchangeable bases were determined by Neutral Ammonium Acetate extract and then Atomic absorption spectrophotometry (AAS) (Thomas, 1982). Bray and Kurtz (1945) method determined available phosphorus.

3.7 Crop growth and yield components

Germination percentage from all treatments was determined after emergence had occurred by counting the total number of hills with emerged seedling seven days after emergence was first observed. Plant height was measured at 45 and 90 days after emergence (DAE) in all treatments. Heights of 10 randomly selected plants were measured using a tape measure. The measurements were respectively taken from soil surface to the top most leaf and from the soil surface to the top of sorghum heads.

At maturity, sorghum heads were cut using a sharp knife from a net area of 72 m^2 per plot in each treatment. Heads were sun dried for five consecutive days to attain a constant moisture content. To ensure uniform drying regular turning of the produce was done.

Threshing was done using a tradition mortar and pestle. Immediately after winnowing sorghum grain yields and 1000 kernel from each plot were weighed using a common field and sensitive balance respectively. Yield and seed weights were recorded accordingly.

3.8 Statistical analysis

Analysis of variance was run using MSTATC. Version 4.0/EM for the analysis of the observed parameters namely: Bulk density, Profile soil moisture, Organic matter content, Plant growth variables (seed germination percentage, and plant height) and grain yield. Means were separated using New Duncan's Multiple Range Test.

The statistical model used is according to Snedecor and Cochran (1989) as shown below:

$Xijk = \mu + Ti + Pj + Hk + (TPH)ijk + eijk$

Where Xijk = Response measurement

μ = general mean common to all observations

Ti = effect of i^{th} treatment T (Tillage methods)

Pj = effect of j^{th} treatment P (Physical factors)

(Hk) = effect of k^{th} treatment H (Hydrological factors)

(TPH)ij = Tillage methods, physical and hydrological factors interaction effects

eijk = random errors and non systematic variation of the measured variables

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

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

The physico-chemical properties of surface soil (0-20 cm) are given in Table 3 .The soil is sand clay loam. The pH was 5.6 in 1:2.5 H_2O and 4 0 in 1:2.5 KCl. The mean organic carbon and nitrogen percentages were 0.53 and 0.05 respectively. Phosphorus content was 2.4 mg/kg. The exchangeable sodium, potassium, calcium and magnesium were 0.4, 0.6, 0.3, and 0.1 cmol(+)/kg respectively. The cation exchange capacity was 14 cmol(+)/kg. The bulk density was 1.60 Mg m^{-3}.

Table 3: Physico-chemical status of the top (0-20 cm) of the experimental site

Soil property	Mean ± S.E	Interpretation
Particle size		
Sand (%) (2000µm-20µm)	67.15 ± 1.98	
Silt (%) (20µm-2µm)	1.86 ± 0.37	
Clay (%) (<2µm)	30.99 ± 1.63	
Texture class	SCL	Sand clay loam
pH		
In 1:2.5 water	5.55 ± 0.01	Medium
In 1:2.5 KCl	4.03 ± 0.01	
Organic carbon (%)	0.53 ± 0.01	Very low
Total N (%)	0.05 ± 0.01	Very low
Extractable P (mg/kg)	2.38 ± 0.19	Low
Exchangeable bases		
Na (me/100g)	0.40 ± 0.01	Medium
K (me/100g)	0.63 ± 0.01	Medium
Ca (me/100g)	0.25 ± 0.01	Very low
Mg (me/100g)	0.13 ± 0.01	Very low
Cation Exch. Capacity (CEC)	13.97 ± 1.07	Medium

S.E = Standard error

These results are similar to those obtained by Mahoo and Kaaya (1993) in the same location. The soils are sand clay loam and therefore coarse textured, this property can 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.

Furthermore, deterioration of soil fertility is likely to have occurred due to continuous sorghum monocropping cultivation. Thus considering the above observations, the fertility status of the experimental site was very low.

4.2 Rainfall pattern during 2001/02 cropping season

The rainfall pattern during the 2001/02 season is shown in Figure 2. In 2001/02, rain started in December and ceased in April. The seasonal total rainfall was 423.9 mm which was below the ten-year average of 678 mm (Fig.3). All the same, the amount of rainfall received in January and March was higher than in the previous ten years (1991/92-2000/01).

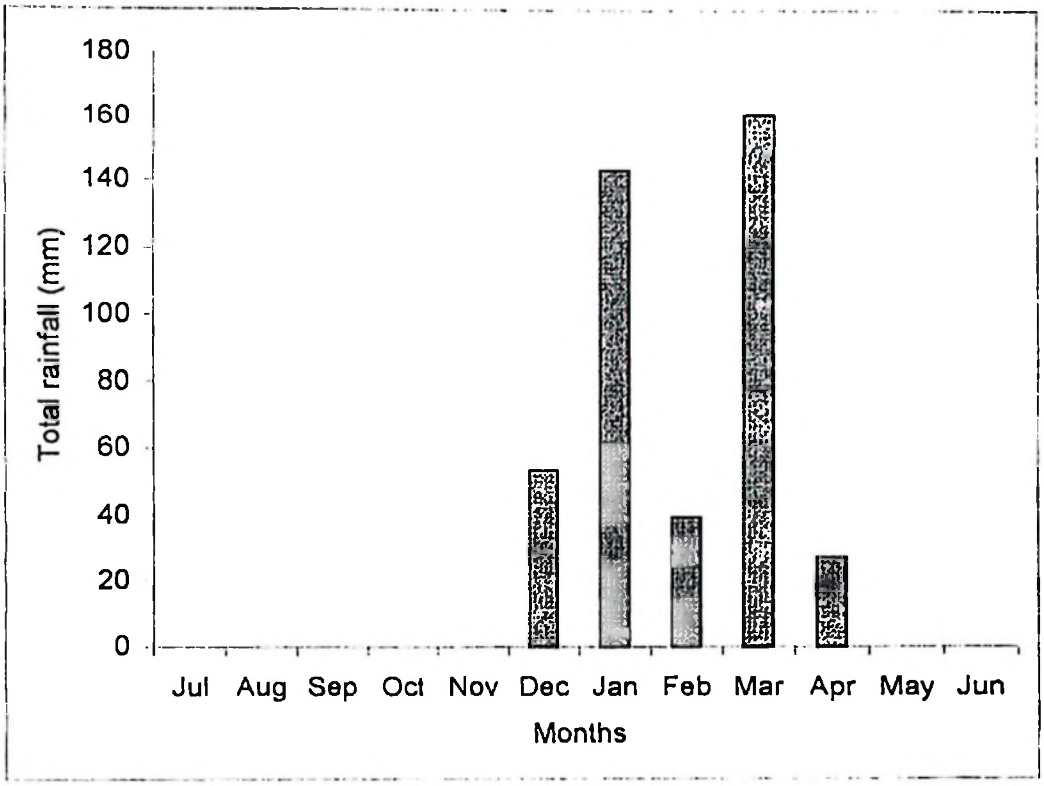


Figure 2: Monthly rainfall distribution at Hombolo during 2001/02 cropping season

In 1991/92-2000/01 rainfall started in October and ceased in June. January had generally higher rainfall than other months in the ten years monthly average rainfall. The rainfall received at the experimental site in 2001/02 season was not well distributed throughout the season and it was below the average value in Hombolo by 28 %. It was exceeded by 38 % and 34 % by ten and eighteen year average rainfall respectively. The above was also observed by Ngana, (1991, 1993), Mahoo *et al.*, (1996a, b) and Hella *et al.*, (1996) in their various research work in the semi-arid areas of Dodoma. They suggested that inadequate rainfall among other factors could be the cause of low sorghum grain yield. This shows that average rainfall data does not tell much about the nature of rains in the area.

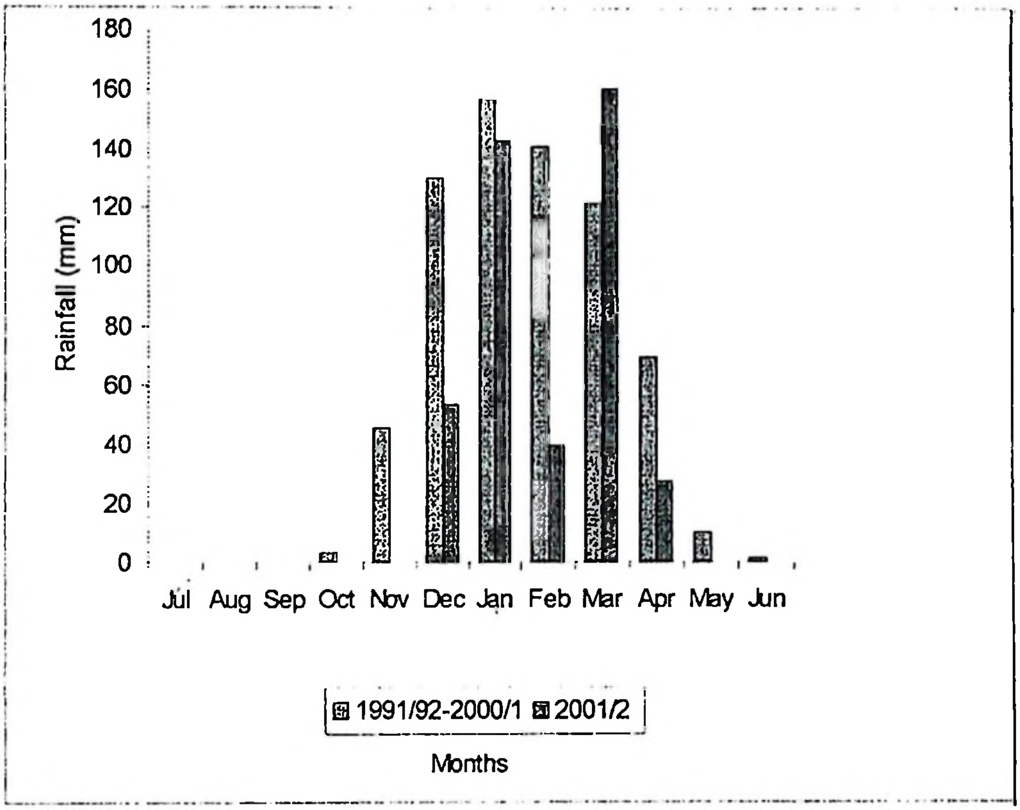


Figure 3: Comparison of ten years rainfall (1991/92-2000/01) with that of 2001/02

4.3 Effect of residual tied ridges on soil physical and hydrological properties

4.3 1 Effect of tillage methods on soil organic matter content

The results for residual soil organic matter (OM) percentage are shown in Table 4a. Tillage alone had no significant (P<0.05) effect on residual soil organic matter content. The NT, residual and annually ploughed tied ridges had no significant effect on residual soil organic matter content.

Table 4a: Mean residual organic matter content in g/100g as affected by different tillage methods

Tillage methods	Farm yard manure (tons/ha)		TM. Means
	0	30	
NT	0.52c	0.84a	0.68
STR	0.69ab	0.70ab	0.69
DTR	0.69ab	0.63ab	0.66
ADTR		0.82a	0.82
FYM Means	0.63	0.74	
S.E ±	0.08		
CV (%)	19.94		

NT = No-till, STR = Shallow depth of tillage with tie ridges, DTR = Deep depth of tillage with tie ridges, ADTR = Annual Deep depth of tillage with tie ridges. Means followed by the same letter along the same column are not significantly different at 5% probability level by Duncan New Multiple Range Test.

At various depth the organic matter content at harvest was not significant (P < 0.05) different among treatments (Table 4b). The residual organic matter content decreased with depth 0-10 cm > 20-30 cm > 30-50 cm. The 0-10 cm depth had relatively higher organic matter content than 20-30 and 30-50 cm depths. However, according to EUROCONSULT, (1989) categorization of soil organic matter, the mean residual organic matter content of the experimental site was very low (<1.0). It has decreased compared to that reported by Swai (1999) which ranged from 1.73 to 2.14%. And it is similar to that observed by Mwaliko (2001). Similar trend of SOM content decrease was reported by Ayanaba *et al.*, (1976) and Tisdall *et al.*, (1993). This may be due to continuous sorghum cultivation and soil loss by erosion that has resulted into decreased SOM content in the study area over time.

Table 4b: Mean organic matter content (g/100g) at different depths as affected by different tillage methods at harvest

Tillage methods	Soil layer (cm)						Treatment means over depth (0-50 cm)
	0-10		20-30		30-50		
	0	30	0	30	0	30	
NT	0.52b	1.02ab	0.58a	0.62a	0.46a	0.90a	0.68
STR	0.75bc	0.94ab	0.68a	0.58a	0.65a	0.59a	0.69
DTR	0.93ab	0.75bc	0.65a	0.60a	0.51a	0.54a	0.66
ADTR		1.22a		0.73a		0.51a	0.82
Depth means	0.73	0.98	0.63	0.63	0.54	0.63	
S.E ±	0.10		0.05		0.13		
CV (%)	21.59		15.74		20.21		

NT = No-till, STR = Shallow depth of tillage with tie ridges, DTR = Deep depth of tillage with tie ridges, ADTR = Annual Deep depth of tillage with tie ridges. Means followed by the same letter along the same column are not significantly different at 5% probability level by Duncan New Multiple Range Test.

4.3.2 Effect of tillage on soil surface roughness indices

The effect of tillage methods on mean Soil Surface Roughness indices (SSRI) is shown in Table 5. Tillage had significant (P<0.05) effect in SSRI just after land preparation (26 November, 2001), a heavy rainfall and after weedings. No-till treatments had lower SSRI values which were significantly different from the deep tillage tied ridges ones. STR and DTR did not differ significantly (P<0.05) with respect to SSRI. Higher surface roughness was observed in residual DTR (Table 5). Throughout the growing season, the control (NT) had significantly (P < 0.05) lower SSRI values than in residual tied ridges treatments (STR and DTR). The values tended to change due to the physical action of the soil brought about by field operations (land tilling and weeding) and heavy rainfall events.

There was low SSRI values in NT and this did not vary much (P<0.05) throughout the season. On the other hand there were higher SSRI values in STR and DTR which although changed due to cultivation and rainfall events, remained high throughout the season. Reid (1989), Swai (1999) and Mwaliko (2001) reported similar observations. Mwaliko, (2001) attributed this to resettling of soil particles after some time, sloughing and breakdown of aggregates as a result of wetting and rainfall impact due to dissipation of rainfall energy on the surface of the soil and deposition into the depressions (in STR and DTR).

Table 5: The effect of tillage treatments on soil surface roughness (Kuipers, 1957)

Date of measurement	Tillage treatments			Mean	LSD (0.05)	C.V (%)
	NT	STR	DTR			
8 Dec 2001	76.38c	140.8b	174.5a	130.56	5.79	7.69
28 Dec 2001	75.13b	138.7a	140.5a	118.11	14.30	20.96
17 Jan 2002	87.39b	150.1a	174.1a	137.19	6.81	8.61
7 Feb 2002	75.89c	147.5b	173.5a	132.29	6.11	8.00
2 March 2002	88.11b	146.6a	169.7a	134.80	8.36	10.75
20 March 2002	78.52b	118.3a	164.9a	120.57	12.40	17.81
27 March 2002	80.57b	143.0a	167.1a	130.22	7.14	9.50
4 April 2002	71.36b	141.5a	166.6a	126.48	6.72	9.21

NT = No-till, STR = Shallow depth of tillage with tie ridges, DTR = Deep depth of tillage with tie ridges, LSD = Least Significant Difference. Means followed by the same letter along the same column are not significantly different at 5% probability level by Duncan New Multiple Range Test.

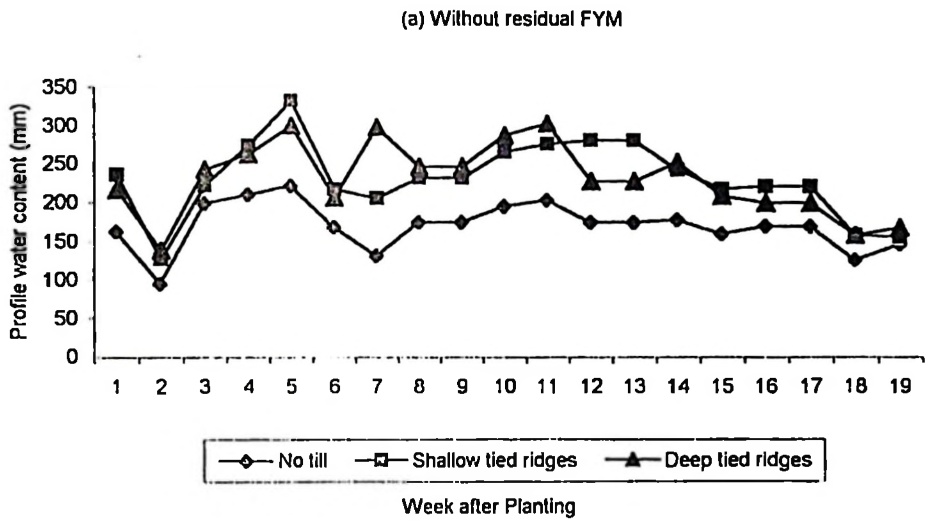
4.3.3 Effect of tillage and FYM interaction on seasonal soil profile water content (mm) of 0-50 cm soil layer during the study period.

Seasonal soil profile moisture content (mm) as affected by different tillage methods and FYM are shown in Fig 4 and Appendix 2 respectively. Monitoring of soil profile water content during the 2001/02 cropping season showed that tillage in combination with residual unmanured and manured treatments varied considerably during the 19 weeks of the growing season. The analysis of variance revealed that tillage in combination with residual FYM did not increase soil profile moisture content. Tillage alone had a significant ($P < 0.05$) effect on soil profile water content averaged over the measurement period and had the following trend T5>T3=T4>T6>T7>T2>T1.

Residual manured STR maintained significantly ($P < 0.05$) higher soil profile water content than either of the six treatments. On the other hand, NT plots always had lower profile water content. This may be due to low depression storage and higher runoff generated from the plots due to the fact that the soil of the experimental site at Hombolo are fairly sandy in texture and there was evidence of runoff (rills) in the NT treatments.

Residual tied ridges (STR, DTR and ADTR) conserved more soil water than NT. This may be probably due to the depression storage effect which allowed more time for more water to infiltrate into the soil in residual tied ridges than in NT where the soil surface was flat (refer plates 2, 3, 4, 5, 6 and 7).

The results showed that treatments that had high depression storage were associated with high profile moisture content. Similar findings were reported by Lawes, (1966), Dagg and Marcatney, (1968), Hulugalle, (1987), Day, (1988), Swai and Rwehumbiza, (1998), Swai, (1999) and Mwaliko, (2001).



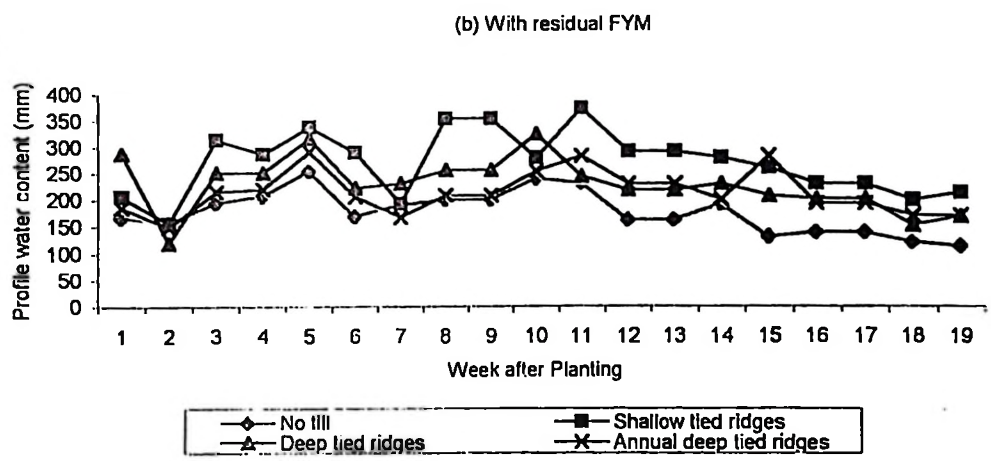


Figure 4: Profile water content in the 0-50 cm soil layer during the 2001/02 cropping season

4.3.4 Effect of tillage on Cumulative Infiltration

Table 6 shows cumulative infiltration measurement taken before planting and at harvest. Tillage methods alone had significant ($P<0.05$) effect in cumulative infiltration both before planting and at harvest. Cumulative infiltration before planting had the following trend NT > ADTR > STR > DTR. In NT and DTR cumulative infiltration significantly ($P<0.05$) differed from STR and ADTR. Compared to before planting, mean cumulative infiltration at harvest had decreased in the order NT>STR>ADTR>DTR. The NT treatment had significantly ($P<0.05$) higher cumulative infiltration than other residual tied ridges (STR, DTR, and ADTR).

The current findings may be due to the fact that tillage reduced infiltration by creating discontinuous pore spaces in the plough layer and by weakening the structure due to microfractures. Freebrain *et al.*, (1989), Hulugalle, (1988), Swai, (1999) and Mwaliko, (2001) reported similar findings. The significant reduction in infiltration in STR, DTR and ADTR compared to the control (NT) were possibly due to the increase in siltation in basins.

On the other hand, the cumulative infiltration in residual unmanured and manured plots at harvest did not differ significantly ($P<0.05$). However, cumulative infiltration at harvest had increased may be due to tillage that temporarily removed sediments on the basins that had created surface seals at before planting. Similar findings were reported by McFarland *et al.*, (1991) in their studies on cumulative infiltration and attributed this to the greater earthworm activities and greater continuity of soil pores under NT tillage system.

Table 6: The effect of tillage methods on cumulative infiltration (mm) per hour.

Time of measurement	Tillage methods	Farm yard manure (tons/ha) 0	30	Treatment means
Before planting	NT	243.76ab	327.56a	285.66
	STR	168.56ab	158.00ab	163.28
	DTR	141.33ab	91.23b	116.28
	ADTR		209.60ab	209.60
	FYM. Means	184.55	196.59	
	S.E ±	17.76		
	CV (%)	26.78		
At harvest	NT	380.33a	445.33a	412.83
	STR	328.33a	367.66a	347.99
	DTR	186.56a	178.66a	182.61
	ADTR		259.23a	259.23
	FYM. Means	298.40	312.72	
	S.E ±	27.16		
	CV (%)	26		

NT = No-till, STR = Shallow depth of tillage with tie ridges, DTR = Deep depth of tillage with tie ridges, ADTR = Annual Deep depth of tillage with tie ridges. Means followed by the same letter along the same column are not significantly different at 5% probability level by Duncan New Multiple Range Test.

4.3.5 Effect of tillage methods on soil bulk density

Bulk density measurement before planting, at mid season and at harvest were as reported in Table 7a. Bulk density values throughout the growing season were not significantly different ($P < 0.05$) between treatments. On the other hand bulk density values were significantly different ($P < 0.05$) between treatments and depth (Table 7b). It varied temporarily and spatially. This could be due to the undisturbed zone within the soil, compaction and reconsolidation due to subsequent tillage operations and break down of unstable soil aggregates due to raindrops impact. These results are comparable to those reported by Allmaras *et al.*, (1966), Macartney *et al.*, (1971), Willcocks, (1981), Swai, (1999) and Mwaliko, (2001).

Considering tillage methods and residual FYM at different depths at planting, mid season and at harvest, there was a significant difference ($p < 0.05$) in bulk density between depths 0-10 cm, 30-50 cm and 20-30 cm. Overall mean bulk density in the 0-50 cm was higher in STR than in NT, DTR and ADTR throughout the cropping season (2001/02). This is similar to the explanations by Landon, (1991) that in horizons of similar texture lying at similar depth there are usually great differences in bulk density values depending on organic matter levels, root penetration, soil structure and there is very often a tendency for bulk density values to rise with depth as effects of cultivation and organic matter content decrease.

Still these results conform to those obtained by Swai, (1999) and Mwaliko, (2001). This also can be explained in the sense that fine soil particles washed by rainwater into the pore spaces (especially at mid season) might have decreased the macropores in the soil and hence increased the bulk density. Tillage usually loosens the soil and thus lowers bulk density. The effect seems to be short lived since by mid season tilled and untilled plots had similar values of bulk densities.

Table 7a: Effect of tillage methods on soil bulk densities (Mg/m^3)

Time of planting	Tillage methods	Farm yard manure (tons/ha)		TM
		0	30	
Before planting	NT	1.57a	1.60a	1.58
	STR	1.57a	1.88a	1.72
	DTR	1.53a	1.50a	1.51
	ADTR		1.54a	1.54
	FYM. Means	1.55	1.63	
	S.E ±	0.13		
	CV (%)	14.67		
Mid season	NT	1.58a	1.55a	1.56
	STR	1.57a	1.93a	1.75
	DTR	1.58a	1.53a	1.55
	ADTR		1.56a	1.56
	FYM. Means	1.57	1.64	
	S.E ±	0.13		
	CV (%)	14.69		
At harvest	NT	1.59a	1.51a	1.55
	STR	1.59a	1.86a	1.72
	DTR	1.52a	1.50a	1.51
	ADTR		1.53a	1.53
	FYM. Means	1.56	1.60	
	S.E ±	0.13		
	CV (%)	14.47		

NT = No-till, STR = Shallow depth of tillage with tie ridges, DTR = Deep depth of tillage with tie ridges, ADTR = Annual Deep depth of tillage with tie ridges, TM = Treatment means. Means followed by the same letter along the same column are not significantly different at 5% probability level by Duncan New Multiple Range Test.

Table 7b: Effect of tillage methods on soil bulk densities (Mg/m^3) at different soil depths

Time of measurement	Tillage methods	Soil layer (cm)						TM over depth (0-50 cm)
		0-10		20-30		30-50		
		0	30	0	30	0	30	
At planting	NT	1.55a	1.65a	1.57b	1.63b	1.58a	1.53a	1.58
	STR	1.55a	1.56a	1.61b	1.63a	1.55a	1.46a	1.56
	DTR	1.52a	1.54a	1.57b	1.53b	1.53a	1.44a	1.52
	ADTR		1.51a		1.63b		1.49a	1.54
	Depth means	1.54	1.56	1.58	1.60	1.55	1.48	
	CV (%)	6.31		4.40		5.79		
	S.E ±	0.05		0.04		0.05		
Mid season	NT	1.61a	1.63a	1.58b	1.52b	1.57a	1.50a	1.56
	STR	1.58a	1.63a	1.61b	1.65a	1.54a	1.52a	1.58
	DTR	1.64a	1.54ab	1.57b	1.55b	1.54a	1.51a	1.55
	ADTR		1.45b		1.63b		1.61a	1.56
	Depth means	1.61	1.56	1.58	1.58	1.55	1.53	
	CV (%)	3.22		5.54		5.52		
	S.E ±	0.03		0.05		0.04		
At harvest	NT	1.56a	1.58a	1.56b	1.51b	1.66a	1.46c	1.55
	STR	1.57a	1.58a	1.64b	1.56a	1.58ab	1.47c	1.56
	DTR	1.59a	1.48b	1.51b	1.55b	1.49bc	1.48bc	1.51
	ADTR		1.44b		1.57b		1.58ab	1.53
	Depth means	1.57	1.52	1.57	1.54	1.57	1.49	
	CV (%)	2.81		4.40		3.76		
	S.E ±	0.02		0.04		0.03		

NT = No-till, STR = Shallow depth of tillage with tie ridges, DTR = Deep depth of tillage with tie ridges. ADTR = Annual Deep depth of tillage with tie ridges, TM = Treatment means. Means followed by the same letter along the same column are not significantly different at 5% probability level by Duncan New Multiple Range Test

4.3.6 Effect of tillage methods on soil total porosity

Table 8 shows total porosity for each tillage practice. Like for bulk densities there was no significant difference ($P > 0.05$) in total porosity between treatments. In mid season and at harvest there was a significant difference ($P < 0.05$) among treatments and depths. Total porosity varied temporarily and substantially among treatments in all soil depths.

The treatment mean values obtained over (0-50 cm) soil depth before planting, at mid season and at harvest were higher in DTR than those in NT, STR and ADTR. On the other hand, the treatments mean values obtained over (0-50 cm) soil depth before planting, at mid season and at harvest in STR were lower than those in NT, DTR and ADTR. This has been also observed by Swai, (1999) and Mwaliko, (2001). Possible explanations include crusting and negligible disturbance of the plough layer due to lack of primary tillage as described under bulk density section.

Table 8: Total porosity (volume %) as affected by tillage methods at various soil depths

Time of measurement	Tillage methods	Soil layer (cm)						TM over depth (0-50 cm)
		0-10		20-30		30-50		
		0	30	0	30	0	30	
At planting	NT	41.61a	37.52a	40.14.a	38.33a	40.21a	42.27a	40.01
	STR	41.09a	41.00a	39.09a	30.2b	41.23a	44.89a	35.05
	DTR	42.53a	41.95a	40.82a	42.10a	42.10a	45.45a	42.49
	ADTR		43.15a		38.39a		43.61a	41.71
	Depth means	41.74	40.90	40.01	30.46	41.18	44.05	
	S.E ±	2.13		1.85		1.88		
	CV (%)	8.97		9.29		7.62		
Mid season	NT	39.27b	38.60b	40.23a	42.44a	40.51a	43.15a	40.70
	STR	40.47b	38.56b	39.06a	48.0b	41.74a	42.52a	33.80
	DTR	38.23b	41.97ab	40.84a	41.47a	41.70a	42.84a	41.17
	ADTR		45.27a		38.32a		39.16a	40.91
	Depth means	39.32	41.10	40.04	30.67	41.31	41.91	
	S.E ±	1.12		2.11		1.86		
	CV (%)	4.81		10.56		7.76		
At harvest	NT	41.15b	40.39b	41.06a	42.85a	37.14c	44.9a	41.25
	STR	41.42b	40.48b	38.06a	33.70b	40.20bc	44.45a	34.66
	DTR	40.16b	44.27a	43.11a	41.58a	43.66ab	43.97ab	42.79
	ADTR		45.48a		40.73a		40.28bc	42.16
	Depth means	40.91	42.65	40.74	32.13	40.33	43.40	
	S.E ±	0.90		1.62		1.26		
	CV (%)	3.74		7.87		5.19		

NT = No-till, STR = Shallow depth of tillage with tie ridges. DTR = Deep depth of tillage with tie ridges. ADTR = Annual Deep depth of tillage with tie ridges, TM = Treatment means. Means followed by the same letter along the same column are not significantly different at 5% probability level by Duncan New Multiple Range Test.

4.4 Effect of tillage on sorghum growth and yield

4.4.1 Effect of tillage methods on seedling emergence, plant height and number of plants at harvest

Percentage seedling emergence, plant height and number of plants at harvest as was influenced by tillage practices are shown in Table 9, 10, and Appendix 3 respectively. Mean separation using Duncan's New Multipe Range Test at 5% probability level showed a significant difference (P < 0.05) between treatments on seedling emergence especially those with and without residual FYM. Treatment DTR had high emergence percentage followed by NT, STR and ADTR. The lower percentage seedlings emergency in ADTR was due to seeds germination failure.

Furthermore, there was a significant difference between treatments (P < 0.05) on the number of plants harvested (at harvest) Appendix 3. The higher seedling emergence in DTR could be explained as due to high profile moisture content observed in DTR compared to that in NT, STR and ADTR at planting. Also DTR had moderately rapid cumulative infiltration throughout the cropping season.

Generally, tied ridges had plants which were growing well (Table 10). There was no significant difference in plant height at 45 DAE and 90 DAE between treatments. However plant height at 45 DAE and 90 DAE in the treatments with high profile moisture content in residual tied ridges had taller plants compared to those in the control (NT) (refer to plates 3, 4, 5, 6 and 7).

Determination of the number of hills at harvest showed similar trend to the aforementioned percentage seedlings emergence (DTR>STR>NT>ADTR). Further more due to subsequent moisture stress experienced during the study period some of the seedlings in the control (NT) died.

Plant height and number of plants at harvest results are similar to those observed by Swai (1999) and Mwaliko (2001). However seedlings emergence results are in contrast to those by Swai (1999) and Mwaliko (2001) who observed higher seedlings emergence in residual tied ridges treatments than in the control (NT).

Table 9: Seedling emergence (%) as influenced by tillage methods

Tillage method	Farm yard manure (tons/ha)		Tillage method. Means
	0	30	
NT	91.49ab	91.09ab	91.19
STR	87.44ab	86.39ab	86.54
DTR	93.89a	92.24ab	92.99.
ADTR		72.44b	72.44
FYM. Means	90.89	85.49	
S.E ±	3.92		
CV (%)	11.60		

NT = No-till, STR = Shallow depth of tillage with tie ridges, DTR = Deep depth of tillage with tie ridges, ADTR = Annual Deep depth of tillage with tie ridges. Means followed by the same letter along the same column are not significantly different at 5% probability level by Duncan New Multiple Range Test

Table 10: Plant height at 45 and 90 DAE as affected by tillage methods

Tillage methods	Plant height (cm) at 45 DAE/ Farm yard manure		Treatment means	Plant height (cm) at 90 DAE/ Farm yard manure		TM
	0	30		0	30	
NT	32.99b	56.46a	44.72	128.6a	145.9a	137.25
STR	53.19a	48.65ab	50.92	142.8a	145.5a	144.15
DTR	49.50ab	44.75ab	47.12	145.0a	143.5a	144.25
ADTR		51.62a	51.62		137.6a	137.6
FYM. Means	45.22	50.37		137.13	143.12	
S.E ±	5.30			7.91		
CV (%)	19.08			9.70		

NT = No-till, STR = Shallow depth of tillage with tie ridges, DTR = Deep depth of tillage with tie ridges, ADTR = Annual Deep depth of tillage with tie ridges, TM = Treatment means. Means followed by the same letter along the same column are not significantly different at 5% probability level by Duncan New Multiple Range Test.

4.4.2 Effect of tillage methods on sorghum grain yield

The sorghum grain yield as was affected by tillage methods is presented in Fig 5 and Appendix 5. The absolute control (NT) had significantly lower grain yield compared to other treatments. The annually made ridges (ADTR) had significantly ($P<0.05$) higher sorghum grain yield at 2.17 tons/ha compared to only 0.42 tons/ha in the control.

The effect of tillage and residual FYM on grain yield was significant ($P<0.05$). With and without application of FYM, sorghum grain yield was more than doubled under residual STR or DTR compared to the control (NT). All the treatments with residual FYM had higher sorghum grain yield and this was more than four times compared to the control.

The higher yield observed in STR, DTR and ADTR were attributed primarily due to the increase in soil water storage which became available at critical period of the crop growth. In this regard, land configuration played an important role as it determined the retention time for rainwater to infiltrate into the soil. On the other hand the lower soil profile water content in the ADTR had no effect on crop growth probably because the lower profile water content did not occur in the critical period of growth for sorghum (it occurred after grain filling, 45 DAE).

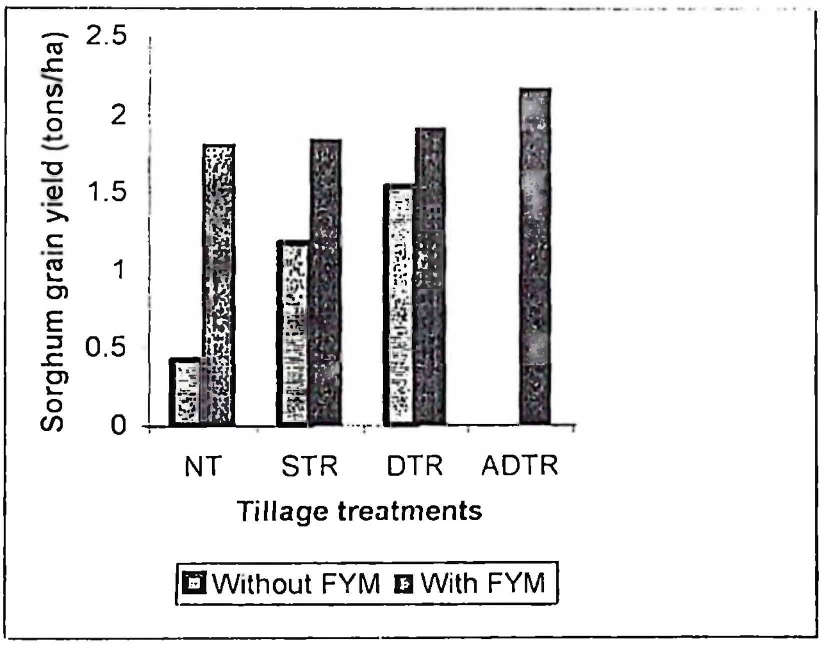


Figure 5: Sorghum grain yield as was affected by tillage treatments during 2001/02 season

Significant increase in yields of cotton, sorghum, and maize were 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. Also these results have similar trend to that observed by Hulugalle, (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.

Swai (1999) also observed high sorghum grain yields in residual and annually made tie ridges compared to the control (NT). This concurred with Clark and Jones (1981), MaCartney *at al.*, (1971) and Vogel (1994) who attributed higher sorghum grain yields under tied ridges primarily to decreased runoff and consequently increased soil water storage. Rwehumbiza *et al.*, (2000) in their research on tied ridging as a water harvesting technique also observed an increase in sorghum grain yields in unmanured and manured tied ridges compared to the control (NT). Sorghum grain yield was more than doubled in the first season, in the second season (1997/98) sorghum grain yield was even lower, they attributed this low yield to *El-nino* rains which were above normal while in the third season sorghum grain yield was far better (Table 11) than the first two seasons.

In the fourth season Mwaliko (2001) obtained higher sorghum grain yield in the residual deep tied ridges as compared to the control (NT) and attributed this to increased soil water storage. The results from the four seasons that had variable rainfall amounts and distribution (Table 11) have shown that: Tillage coupled with tied ridges enhanced the capture of rainwater and increased sorghum grain yield.

Similar findings were reported by Swai and Rwehumbiza, 1998; Reuben *et al*, 1998; Swai, 1999; Mwaliko, 2001).

Swai and Rwehumbiza, (1998); Reuben *et a.l*, (1998); Swai (1999); Mwaliko (2001) attributed the high increase in sorghum grain yield in annually ploughed and residual tied ridges to increased storage of soil water in the field while Reuben *et al.*, (1998) attributed the increased sorghum grain yield in annually ploughed and residual tied ridges to larger panicles which produced more grains than smaller panicle in the control (NT) plots. Application of FYM even when no tillage was undertaken significantly increased sorghum grain yield compared to the control treatment (Swai and Rwehumbiza, 1998). FYM is known to improve soil water retention and supply plant nutrients (Young, 1976; Kramer and Boyer, 1995).

The 2001/02 results indicated that there were still benefits when using residual tied ridges up to five seasons without annual ploughing and reconstruction of tied ridges.

Table 11: Sorghum grain yield as affected by tillage methods and FYM after five seasons

Treatments	Grain yield (kg/ha)				
	*1996/97 (1st season)	*1997/98 Residual tied-ridges (2nd season)	*1998/99 Residual tied-ridges (3rd season)	**1999/2000 Residual tied-ridges (4th season)	2001/2002 Residual tied-ridges (5th season)
NT	509a	310a	1652a	635b	420a
NT+F	1245b	1050b	1718a		1810ab
STR	1150ab	650a	2408ab	1488a	1180ab
DTR	1490b	1050b	3105ab	1698a	1540ab
STR +F	1250b	1200c	3360b		1840ab
DTR + F	1100ab	1400c	3476b		1920a
ADTR+F	1150ab	1485c	2925ab		2170a

* Obtained from Rwehumbiza *et al.*, (2000), and ** Mwaliko, (2001).
NT = No-till, NTF = NT + FYM, STR = Shallow depth of tillage with tie ridges without FYM, DTR = Deep depth of tillage with tie ridges without FYM, STRF = STR + FYM, DTRF = DTR + FYM, ADTRF = Annual Deep depth of tillage with tie ridges with FYM. Treatments sharing the same letter in each season are not significantly different at P= 0.05. (FYM was applied once in the 1st season).

4.4.3 Effect of tillage methods on a 1000 sorghum kernel weight

Table 12 shows 1000 kernel weight as affected by tillage methods. The variation on a 1000 kernel weight was not significant ($P < 0.05$) between treatments. This may be due to the fact that the parameter is stable and genetically determined (Mwaliko, 2001). This can also be explained by the fact that the annually ploughed (ADTR) and residual tied ridges had larger panicles with heavier grains than the control (NT) which had smaller panicles with lighter weights (Reuben *et al.*, 1998) (Appendix 4). And Mwaliko (2001) attributed this to compaction, low depression storage in NT, which was related to low surface roughness that led to loss of water and soil nutrients through runoff.

Table 12: Sorghum 1000 kernel weight (g) as affected by tillage methods

Tillage methods	Farm yard manure (tons/ha)		Tillage methods. Means
	0	30	
NT	25.05ab	24.91ab	24.98
STR	25.72ab	24.19b	24.95
DTR	25.13ab	25.78ab	25.45
ADTR		27.73a	27.73
FYM. Means	25.30	25.65	
S.E ±	0.92		
CV (%)	6.31		

NT No-till. STR = Shallow depth of tillage with tie ridges. DTR Deep depth of tillage with tie ridges. ADTR Annual Deep depth of tillage with tie ridges Means followed by the same letter along the same column are not significantly different at 5% probability level by Duncan New Multiple Range Test.

Plate 2. The tie ridging system with water on basins in annually made deep tied ridges

Plate 3. Sorghum crop under no till system without farm yard manure

Plate 4. Sorghum crop under no till system without farm yard manure

Plate 5. Sorghum crop under shallow tied ridges without farm yard manure
(Note the effect of residual shallow tied ridges on the depression storages)

Plate 6. Sorghum crop under deep tied ridges with farm yard manure

(Note the effect of deep tied ridges on the depression storage)

Plate 7. Sorghum crop under annually made deep tied ridges with farm yard manure

(Note the effect of deep tied ridges on the depression storage)

Note: Plates 2, 3, 4, 5, 6 and 7 were taken on the same date.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

The 2001/02 cropping season had very low rainfall compared to the average rainfall in the study area. The conclusions that can be made from the current work are summarized below.

5.1.1 Effect of tillage methods on soil physical and hydrological properties

These include.

(a) Bulk density did no vary during the 2001/02 cropping season. However temporal and spatial variations of bulk density with depths were observed at harvest especially in 30-50 cm depth. This may be attributed to increase in weight per unit volume as a result of water washing the fine soil particles into the pore spaces and due to compaction caused by overlying soil layer. The residual FYM did not influence bulk density and this did not affect total porosity.

(b) The effect of tillage on profile water content was significant throughout the cropping season. Generally residual tied ridges maintained higher profile water content than the control (NT) that had the lowest profile water content. Annually made tied ridges had lower profile water content but this did not affect sorghum grain yield.

(c) NT had higher cumulative infiltration throughout the season. It was 285.66 mm/hr at planting followed by STR, ADTR and DTR and 412.83 mm/hr at harvest with the same trend. Higher cumulative infiltration rate in NT may be attributed to greater continuity of soil pores under this system. Lower cumulative infiltration rate in the remaining treatments may be associated with tillage effect that created discontinuous pore space in the plough layer and weakening the structure due to microfractures. Further more sedimentation in the basins created surface seals which reduced infiltration.

(d) Soil surface roughness indices had the following trend DTR>STR>NT. This parameter was affected mainly by tillage depth and to some small extent by weeding operations and by rainfall.

5.1.2 Effect of tillage methods on sorghum growth and yield

Residual deep tied ridges had higher seedling emergency percentage than all other treatments. There was no significant statistical difference in plant height among treatments. The use of residual unmanured and manured tied ridges had no significant effect on crop growth. The effect of tillage on sorghum grain yield among treatments was significant ($P < 0.05$). Grain yield was more than doubled in tie-ridged treatments with residual FYM compared to the control. All the treatments with residual FYM had higher sorghum grain yield and this was more than four times compared to the control.

In view of the 2001/02 cropping season results, there are still benefits of using the residual tied ridges five years/seasons since their establishment, in the semi-arid area of Hombolo Dodoma, Tanzania.

5.2 RECOMMENDATIONS

From the results reported above, the following recommendations can be made:

(a) Residual tied ridges may be adopted and used for up to five seasons thereby increasing yield and reducing labour.

(b) There is a need also of using sensitive field methods for moisture determination directly in the field on daily basis, for the weekly determinations sometimes failed to discriminate between treatments.

6.0 REFERENCES

Adeoye, K. B. (1982). Effect of tillage depth on physical properties of a tropical Alfosols and yield of maize, sorghum and cotton. *Soil and Tillage Research* 2: 225-231.

Agenbag, G. A. and Maree, P. C. J. (1991). Effect of tillage on some soil physical properties, plant development and yield of spring wheat (*Trisicum aestivum*) in stone soils. *Soil and Tillage Research* 18: 107-111.

Aina, P. O.; Lal, R. and Roose, E. J. (1991). Tillage methods, soil and water conservation in West Africa. *Soil and Tillage Research* 20: 165-186.

Allen, R. R.; Musick, J. T.; Unger, P. W. and Wiese, A. F. (1980). Soil water and energy conserving tillage in the Southern plains. *Proceedings of the American Society of Agricultural Engineers* Publication 7.81. Conference on crop production with conservation in the 80's. pp 94-101.

Allmaras, R.; Burwell, R. E; Larson, E. W; Holt, R. F and Nelson, W. W. (1966). *Total porosity and random roughness of inter-row zone as affected by tillage.* U.S Department Conservation Research Report, 7. Washington District of Columbia. pp 22.

Allmaras, R. R. (1967). Soil Water Storage as Affected by Infiltration and Evaporation in Relation to Tillage-Induced Soil Structure. In: *Conference Proceeding: Tillage for greater Production. Michigan, December, 11 and 12. ASA Winter Meeting.* American Society of Agricultural Engineers, State Joseph, Michigan. pp 37-43.

Anschütz, J.; Kome A.; Nederlof, M.; de Neef, R.; Van de Ven T. (1997). *Water harvesting and soil moisture retention.* Agrodok series no 13. 92 pp.

Arora, V. K.; Gajri, P. R. and Prihar, S. S. (1990). Tillage effects on corn in sandy soil in relation to water retentivity, nutrient and water management and seasonal evaporativity. *Soil and Tillage Research* 21: 1-21.

Aujilla, T. S. and Cheema, S. S. (1983). Modifying profile water storage, herbicide and straw mulch. *Soil and Tillage Research* 3: 159-170.

Ayanaba, A.; Tuckwell, A. B. and Jenkinson, D. S. (1976). The effect of clearing and cropping on the organic residues and biomass of tropical forest soils. *Soil Biology and Biochemistry* 8: 519-525.

Benjamin, J. G.; Blalock, A. D.; Brown, H. J. and Cruse, R. M. (1990). Ridge tillage effects on simulated water and heat transport. *Soil and Tillage Research* 18: 167-180.

Biswas, T. D. and Khosla, B. K. (1971). Building up of organic matter status of the soil and its relation to the soil physical properties. In: *Proceedings for International symposium on Fertility Evaluation*. New Delhi 1: 831-842.

Biswas, T. D.; Roy, M. R. and Sahu, B. N. (1970). Effect of Different Sources of Organic manures on physical Properties of the soil growing rice. *Journal of the Indian Society of Soil Science* 18 (3): 233-242.

Blake, G. R. and Hartage, K. H. (1986). Bulk density. In: *Methods of soil analysis part I.* Physical and Mineralogy methods 2nd edition. *(Edited by Klute, A.) American Society of Agronomy*, Madison, Wisconsin. pp 363-375.

Blevins, R. L.; Cook, D.; Phillips, S. H. (1971). Influence of no- tillage on moisture. *Agronomy Journal* 60: 17 - 20.

Brady, N. C. (2000). *The Nature and Properties of Soils*. Tenth edition. Prentice-Hall of India Private Limited, New Delhi. 621 pp.

Brady, N. C. and Weil, R. R (1996). *The Nature and Properties of Soils* 11th edition. Prentice Hall Inc. New Jersey USA. 740 pp.

Bray, R. H. and Kurtz, L. T. (1945). Determination of total organic and available forms of phosphorus in the soil. *Soil Journal* 59: 39-45.

Bremner, J. M. and Mulvaney, C. S. (1982). Total nitrogen. In: *Methods of soil analysis Part 2 chemical and microbiological properties. (Edited by Page, A.L.; Miller, R.H. and Keeney, D.R.).* 2nd edition. Agronomy No. 9. American Society of Agronomy, Madison, Wisconsin, USA. pp 595-622.

Casagrande, A. A.; Pereira, G. O. and Corsini, P. C. (1975). Effect on soil of mechanical cultivation and levels of fertilizer applied to a first ratoon of sugarcane crop. *Brasil Acucareiro* 84: 30-49.

Cassel, D. K. and Nelson, L. A. (1985). Spatial and temporal variability of soil physical properties of Norfolk loamy soils as affected by tillage. *Soil and Tillage Research* 55: 5-17.

Clark, R. N. and Jones, O. R. (1981). Furrow dams of conserving rainwater in semi-arid climate. In: *Proc. Am. Soc. Eng. Conf.* On Crop Production with Conservation in the 80's, Chicago, Illinois. pp 12.

Cook, R. L. (1962). *Soil management for conservation and production*. John Willey and Sons, Inc. London. 527 pp.

Cresswell, H. P.; Painter, D. J. and Cameroon, K. C. (1991). Tillage and water content effects on surface soil physical properties. *Soil and Tillage Research* 21: 67-83.

Dagg, M. and Macartney, J. C. (1968). The agronomic efficiency of National Institute of Agricultural Engineers (N.I.A.E) mechanized tie ridge system of cultivation. *Exploring Agriculture* 4: 279-294.

Datiri, B. C. and Lowery, B. (1991). Effect of conservation tillage on the hydraulic properties of Griswold silt loam soil. *Soil and Tillage Research* 21: 257-271.

Day, J. C. (1988). *Water conservation in Arid and Semi-arid Agriculture : A case study analysis for West Africa*. International Congress on Water Resource, Ottawa Canada. pp 23.

Day, P. R. (1965). Particle fractionation and particle size analysis. In: *Methods of soil analysis part I. (Edited by Evans, D.D.; White, J.L; Ensminger, L.E. and Clark, F.E.)* Madison USA. pp 545-568.

Elwell, H. A. and Norton, J. A. (1988). No till tied-ridging. A recommended sustained crop production system. Agritex Handbook. Harare. 40 pp.

EUROCONSULT (1989). Agricultural Compendium For Rural Development in the Tropics and Subtropics. ELSEVIER SCIENCE PUBLISHERS B V. Amsterdam, Netherlands. pp 91.

FAO-UNESCO (1974). Soil Map of the World, 1:5,000,000. Vol. 1 Legend UNESCO Paris. 59 pp.

Food and Agriculture Organization (1977). Guidelines for Soil Profile Description, FAO Rome. 53 pp.

Freebrain, D. M.; Gupta, S. C.; Onstad, C. A. and Rawls, W. J. (1989). Antercedent rainfall and tillage effects upon infiltration. *Soil Science Society of America Proceedings* 53: 1183-1189.

Gayle, G. A. and Skaggs, R. W. (1978). Surface Storage on Bedded Cultivated Lands. *Transactions of the American Society of Agricultural Engineers* 21 (1): 101-104, 109.

Georgis, K. (2000). Conservation tillage research findings: the Ethiopian experience. In: *Conservation Tillage for Dryland Farming. Technological options and experiences in Eastern and Southern Africa. (Edited by Biamah, E.K.; Rockstrom, J and Okwach, G. E.).* Regional Land Management Unit (RELMA), Swedish International Development Cooperation Agency (Sida). Workshop Report No.3. pp 148-151.

Georgis, K. and Tekele, A. (2000). Conservation Farming Technologies for Sustaining Crop Production in semi-arid areas of Ethiopia. In: *Conservation Tillage for Dryland Farming. Technological options and experiences in Eastern and Southern Africa (Edited by Biamah, E. K.; Rockstrom, J and Okwach, G. E.).* Regional Land Management Unit (RELMA), Swedish International Development Cooperation Agency (Sida). Workshop Report No.3. pp 142-147

Ghildyal, B. R. and Tripathi, R. P. (1987). Soil physics. Wiley Easter Limited New Delhi. pp 208-223.

Gill, K. S.; Galaten, S. K.; Prihar, S. S. and Chaudhary, N. T. (1977). Water conservation by soil mulch in relation to soil type, time of tillage, tilth and evaporarity. *Journal of Indian Society Soil Science* 25: 360-366.

Goss, M. J.; Howse, K. R. and Harris, W. (1978). Effect of cultivation on soil water retention and water use by cereals in clay soils. *Journal of Soil Science* 29: 475-488.

Greenland, D. J.; Wild, A. and Adams, D. (1992). Organic Matter Dynamics in Soils of the Tropics-From Myth to Complex Reyality. In: *Myths and Science of Soils of the Tropics. (Edited by Lal, R. and Sanchez, P.A.)*. Soil Science Society of America Special Publication Number 29. pp 17-33.

Griffith, D. R.; Kladivko, E. J. and Mannering, J. W. (1986). Conservation tillage effects on soil properties and yield of corn and Soya beans in Indiana. *Soil and Tillage Research* 4: 277-287.

Hatibu, N. (2000). Importance of semi-arid areas of Tanzania. In: *Rainwater Harvesting for Natural Resources Management: A planning guide for Tanzania. (Edited by Hatibu, N. and Mahoo, H.F.)*. Chapter 1. Regional Land Management Unit (RELMA), Swedish International Development Cooperation Agency (Sida). RELMA Technical Handbook Series No. 22. Nairobi Kenya. pp 1-4.

Hatibu, N.; Mahoo, H. F.; Kayombo, B.; Mbiha, E.; Senkondo, E. M.; Mwaseba, D. and Ussiri, D. A. (1995). Soil and Water Management in Semi-arid Tanzania Research Project. Research News 5 (2): 13-15.

Hella, J. P.; Mbwaga, J.; Mdolwa, S.; Wilson, K.; Kamugisha, R.; Safari, E. and Mtenga, K. T. (1998). Farmers Participation in Formulation of Research Objectives: A case study of Smuts disease in Dodoma region. In: *Proceedings of the Second Faculty of Agriculture Annual Research Conference. (Edited by Dihenga, H. O.; Kimambo, A. E.; Tarimo, A. J. P. and Temu, A. E.)*. 25-27 September 1996, Morogoro Tanzania, pp 251-262.

Hillel, D. (1980). *Fundamentals of Soil Physics*. (Ed). Academic Press .New York. 413 pp.

Honisch, O. (1974). water conservation in three grain crops in the Zambezi Valley. *Experimental Agriculture* 10: 1-8.

Huggins, L. F. and Monke, E. J. (1978). A mathematical model for simulating the hydrologic response of a watershed. *Water Resource Research* 4(3): 529-533.

Hulugalle, N. R. (1987). Effect of tied ridges on soil water content, evapotranspiration, growth and yield of cowpeas in the Sudan Savannah of Burkina Faso. *Field Crops Research* 17: 219-228.

Hulugalle, N. R. (1988). Properties of tied ridges in the Sudan Savannah of the West Africa semi-arid tropics. In: *Land Conservation for Future Generations* (Edited by Rimwanich). Thailand. 52 pp.

Hulugalle, N. R. (1990). Alleviation of soil constraints to crop growth in the upland Alfisols and associated soil groups of the West African Sudan Savannah by tied ridges. *Soil and Tillage Research* 18: 231-247.

Jones, O. R. and Stewart, B.A. (1990). Basin tillage. *Soil and Tillage Research* 18: 249-265.

Kamara, C. S.; Haque, I. and Saka, A. R. (1992). *Soil Physics Manual.* Plant Science Division working Document No B 12 (Revised). International Livestock Centre for Africa. (ILCA), Addis Ababa, Ethiopia. 132 pp.

Kayombo, B. (1986). Influence of traffic-induced compaction on tropical Alfisol soil physical properties. *Journal of Science Food Agriculture* 22: 969-978.

Kayombo, B. (1992). Tillage systems and soil compaction in semi-arid Tanzania. *Proceedings of Tanzania Society of Agricultural Engineers* 4: 80-88.

Khan, A. R. and Datta, B. (1984). Effect of aggregate size on water uptake by peanut seeds. *Soil and Tillage Research* 3: 172-184.

Klute, A. K. (1986). Water retantion. In: *Methods of soil analysis part I. Physical and Mineralogical methods.* 2nd edition. (Edited by Klute, A.K.). American Society of Agronomy, Madison, Wisconsin. pp 635-662.

Kramer, P. J. and Boyer J. S. (1995). Water relations of plants and soils. London, pp 56.

Kuipers, H. (1957). A relief meter for soil Cultivation Studies, Netherlands. *Journal of Agricultural Science* 5: 255-262.

Lal. R. (1979). Physical characteristics of soils of the tropics: Determination and management. In: *Soil physical properties and crop production in tropics. (Edited by Lal, R. and Greenland, D.J.).* Chichester, Willey and Sons. pp 551.

Lal, R. (1985). Mechanized tillage systems effects on properties of a tropical Alfisol in watersheds cropped to maize. *Soil and Tillage Research* 6: 149-161.

Lal, R. (1989). Agroforestry system and soil surface management of tropical Alfisol II. *Soil erosion and nutrient loss Agroforestry systems* 8: 97-111.

Lal, R. (1993). Water management on various crop production systems related to soil tillage. *Soil and Tillage Research* 30: 169-185.

Land Resources Development Centre (LRDC) (1987). *Tanzania: Profile of Agricultural Potential.* NRI, London. 26 pp.

Landon, J. R. (1991). *Booker Tropical Soil Manual.* A Hand Book of Soil Survey and Agricultural Land Evaluation in the Tropics and Sub-tropical. Longman Inc. New York. 450 pp.

Larson, W. E. (1964). Soil parameters for evaluating tillage needs and operations. *Soil Science Society of America Proceedings* 28: 118-122.

Lawes, D. A. (1966). Rainfall Conservation and the Yield of Sorghum and Groundnuts in Northern Nigeria. *Exploring Agriculture* 2: 139-146.

Linden, D. R. (1982). Predicting tillage effects on evaporation from soil. In: *Predicting tillage effect on soil physical properties and processes. (Edited by Unger, P. W. and Van Doren, D. M.)*. American society of Agronomy Special Publication 44. Madison, Wisconsin. pp 117-132.

Linden, D. R. and Van Doren, D.M. Jr. (1986). Parameters for characterizing tillage induced soil surface roughness. *Soil Science Society of America Journal* 50: 1560-1565.

Lyle, W. M. and Dixon, O. R. (1977). Basin tillage for rainfall retention. *Transactions of the American Society of Agricultural Engineers* 20: 1013-1017.

Macartney, J. C.; Northwood, P. J. and Dawson, R. (1971). The effect of different cultivation techniques on soil moisture conservation and the establishment and yield of maize at Kongwa, Central Tanzania. *Tropical Agriculture* 48 (1): 9-24.

MacLean, A. J. and More, F. R. (1979). Manure and Composite. Agriculture. Canada Publication. No 868. Ottawa, Canada. pp 17.

MaClean, E. O. (1982). Soil pH and lime requirement. In: *Methods of soil analysis Part 2 (Edited by Page, A. L.; Miller, R. H. and Keeney, D. R.)*. American Society of Agronomy, Madison, Wisconsin. pp 199-224.

Mahoo, H. F. and Kaaya, A. K. (1993). Characterization and Classification of Soils at Hombolo Experimental Site. Soil Water Management in Semi-arid Tanzania. Project Proceedings of the Planning Workshop. pp 37-43.

Mahoo, H. F.; Hatibu, N.; Kayombo, B. and Ussiri, D. A. N. (1996a). Effects of Tillage and rainfall pattern on crop yield in semi-arid Tanzania. In: *Proceedings of the First Faculty of Agriculture Annual Research Conference. (Edited by. Mattee, A. Z.; Sibuga, K. P.; Semoka, J. M. R. and Tsunoda, M.)*. 28-30 August 1995, Morogoro Tanzania. pp 304-319.

Mahoo, H. F.; Rwehumbiza, F. B. R.; Reuben, S. S.; Kayombo, B.; Hatibu, N.; Makungu, P. and Ashimogo, G. (1996b). Improvement of the No-Primary Tillage (NPT) '*kuberega*' practice of sorghum-livestock-maize (SLIM) farming systems of semi-arid Tanzania: Rapid Rural Appraisal of Mpwapwa District. 21 pp.

Mahoo, H. F.; Young, M.D.B. and Mzirai, O. B. (1999). Rainfall Variability and Its Implications for the Transferability of Experimental Results in the Semi-Arid Areas of Tanzania. *Tanzania Journal of Agricultural Sciences* 2 (2): 127-140.

Makungu, P. S. J. J. (1991). Prediction of tillage parameters for moisture conservation in the semi arid tropics. Unpublished PhD. Thesis. University of New Casttle Upon Tyne, United Kingdom. 429 pp

Malik, R. S.; Jhorar, B. S. and Dahiya, L. S. (1985). Influence of seedbed tilth on emergence, root and shoot growth of seedling of some crops. *Experimental Agriculture* 21: 59-65.

Malley, Z. J. U. (1997). Effect of Pit size in Ngoro cultivation systems on soil water conservation and yield of maize (*Zea mays* L.). Unpublished Dissertation for Award of MSc. Degree at Sokoine University of Agriculture Morogoro, Tanzania. 103 pp.

McFarland, M. C; Hons, F.M and Saladino, V. A. (1991). Effects of furrow Diking and Tillage on Grain yield and Nitrogen accumulation. *Agronomy Journal* 83: 382-386.

Meickle, J. G. (1972). The use of tillage techniques for improving moisture infiltration and storage. In: *Water in Agriculture*. Rhodesia. Agriculture Technical Bulletin No.15. pp 139-146.

Mitchell, J. K. and Jones, B. A. (1976). Microrelief surface depression storage: Analysis of models to describe the depth storage function. *Water Resource Bulletin* 12 (6): 1205-1222.

Mitchell, J. K. and Jones, B. A. (1978). Microrelief surface depression storage: Changes during rainfall events and their application to rainfall runoff models. *Water Resource Bulletin* 14: 777-802.

Moberg, J.P. (2000). *Soil analysis manual*. The Royal Veterinary and Agricultural University. Chemistry department, Copenhagen, Department. 137 pp.

Mohamoud, Y. M.; Ewing, L. K. and Boast, C. W. (1990). Small plot hydrology: I. Rainfall infiltration and depression storage determination. *Transactions of the American Society of Agricultural Engineers* 33 (4): 1121-1131.

Monteith, N. H. (1974). The role of surface roughness in runoff. *Journal of Soil Conservation of New South Wales* 30: 42-45.

Moore, I. D.; Larson, C .D. and Slack, D. C. (1980). Predicting infiltration and microrelief surface storage for cultivated soils. Water Resource Centre University of Minesota Bulletin. 102. pp 122.

Mwaliko, R. B. M. (2001). Effects of Residual Tied ridges on Soil physical factors and sorghum yield in semi arid Central Tanzania. Unpublished Dissertation for Award of MSc. Degree at Sokoine University of Agriculture, Morogoro Tanzania. 87 pp.

Nelson, D. W. and Sommers, L. E. (1982). Total Carbon, Organic carbon and Organic matter. In: *Methods of Soil Analysis Part 2. (Edited by Page. A. L.)* Chemical and microbiological properties. pp 539-579.

Ngana, J. O. (1991). Modeling the periodic features in seasonal rainfall and its implication to water resource and agricultural planning. Institute of Resource Assessment (IRA) University of Dar Es Salaam (UDSM). Research paper No: 24 pp 46.

Ngana, J. O. (1993). Rainfall Characteristics and Their Relevance to Agricultural Planning in semi-arid Tanzania. *Proceedings of the research Planning Workshop, SWMP. (Edited by Hatibu, N. and Simalenga, T. E.).* 13-15 January 1993, Morogoro Tanzania.

Nicou, R. and Chopart, J. L. (1979). Water management methods in sandy soils of Senegal. In: *Soil Tillage and Crop Production. (Edited by Lal, R.)* IITA, Ibadan. Nigeria 2: 248-257.

Nyamudeza, P.; Mazhangara, E.; Busangaranye T. and Jones, E. (1993). Farmers Adoption of Improved Water Management on Vertisols in semi-arid South east Zimbabwe. In: *Working with the farmers for better land husbandry. (Edited by Hudson, N. and Cheatte, R.J.).* Intermediate Technology Publication. London. pp 13.

Onstad, C. A. (1984). Depression storage on tilled soil surfaces. *Transactions of the American Society of Agricultural Engineers* 27 (3): 729-732.

Overseas Development Administration (ODA) (1980). Dry land Farming Research Scheme Botswana. In: *Tillage system for soil water*. Ministry of Agriculture. Botswana. pp 24.

Parthasarthy, S.; Parushothaman, K.; Natarajan, N.; Arunachalem and Rangaswami. G. (1976). Changes in certain physical properties of soil as influenced by Raji (*Eleusine coracana*) plant growth. *Madras Agriculture Journal* 63: 249-252.

Perrier. E. R. (1987). Adaptation of water management practices to rain fed agriculture on Alfisols in the Sahelian. In: *Food Grain Production in Semi-arid Africa*. (Edited by *Menyonga, J;, Benuzeh, T;, and Youdow,.I)*. Organization of African Countries. SAFGRAD. Ouagadougou, Burkina Faso. pp 445-464.

Perriera. H. C ; Hosegood, P.H. and Dagg, M. (1967). Effect of tie ridges, terraces and grass leys on the lateritic soil in Kenya. *Experimental Agriculture* 3: 89-98.

Prestt, A. J. (1986). Basin tillage. *Zimbabwe Agricultural Journal* 83 (1): 11-14.

Radford. B. J.; Key, A. J.; Robertson, L. N. and Thomas, G. A. (1995). Conservation tillage increases in soil water storage, soil animal populations, grain yield, and response to fertilizer in the semi-arid subtropics. *Australian Journal of Experimental Agriculture* 35 (2): 223-232.

Reid. I. (1989). Seasonal changes in microtopography and surface depression storage of arable soils. In: *Man's impact on the hydrological cycle in the UK. (Edited by Hollis, G.E.)*. Norwich, pp 19-30.

Reuben, S. O. W. M.; Rwehumbiza, F. B. R.; Mahoo, H. F.; Hatibu, N.; Ashimogo, G. C. and Makungu, P. (1998). Paths of influence among components of yield in sorghum (*Sorghum bicolor* L.Moench) grown in the semi-arid Dodoma region, Tanzania. *Tanzania Journal of Agricultural Sciences* 1 (2): 16-24.

Romkens, M. J. M. and Wang, J. Y. (1986). Effect of tillage on surface roughness. *Transactions of the American Society of Agricultural Engineers* 29 (2): 429-433.

Rwehumbiza, F. B. R.; Mahoo, H. F.; Hatibu, N; Reuben, S. O. W. M.; Makungu, J. J. and Ashimogo, G. C. (2000). Tie-ridging as a Rainwater Harvesting Technique. Experience from Hombolo, Dodoma, Tanzania. In: *Proceedings of the first University-wide Scientific Conference. (Edited by Matovelo, J. A.; Luzi-Kihupi, A. Monela, G. C. and Mgasa, M. N.)*. 5-7 April 2000. Morogoro Tanzania. pp 172-178.

Saka, A. R. and Haque, I. (1993). Method of analysis of selected physical properties. *Soil Science Fact Sheet No. 2*. Department of Agricultural Research. Chitedze Agricultural Research Station. Lilongwe, Malawi. pp 74.

Sanchez, P. A. (1976). *Properties and Management of Soils in the Tropics*. John Willey and Sons, New York. pp 162-181.

Scaife, M. A. (1971). The long-term effects of fertilizers, farmyard manure and leys at Mwanhala, western Tanzania. *East African Agricultural Forestry Journal* 37: 8-14.

Seginer, I. (1971). A model for surface drainage of cultivated fields. *Journal of hydrology* 13: 139-152.

Selvaraju, R.; Subbian, P.; Balasubramanian, A. and Lal, R. (1999). Land configuration and soil nutrient management options for sustainable crop production on Alfisols and Vertisols of southern peninsular India. *Soil and Tillage Research* 9 52 (3/4): 203-216.

Smith, J. L. and Elliott, L. F. (1990). Tillage and Residue Management Effects on Soil Organic Matter Dynamics in Semi-arid Regions. In: *Dryland Agriculture Strategies for sustainability. (Edited by Singh, R. P.; Parr, J. F. and Stewart, B. A.).* Advances in Soil Science. Volume 13. Springer-Verlag, London. pp 69.

Snedecor. W. G. and Cochran. G. W. (1989). *Statistical Methods.* Eighth Edition. Iowa State University Press. Ames. 503 pp.

Sow, A. A.; Hossner, L. R.; Unger, P. W. and Stewart, B. A. (1996). Effects of Furrow Diking and Tillage on Water Storage, Plant Water Use Efficiency and Yield of Sorghum. *African Crop Science Journal* 4: 433-440.

Spomer. R. G. and Hjelmfelt. A. T. (1984). Soil moisture response to cropping and tillage on Western Iowa Loess soils. *Transactions of the American Society of Agricultural Engineers* 83: 822-826.

Stewart. B. A. and Musisck. J. T. (1982). Conjecture use of rainfall and irrigation in semi-arid regions. *Advances in irrigation* 1: 1-24.

Swai, E. Y. (1999). Effect of Residual Tie-ridging and Farm yard manure Application on Soil Water Status and yield of Sorghum in Semi arid areas. A case study in Hombolo, Dodoma-Tanzania. Unpublished Dissertation for Award of MSc. Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 135 pp.

Swai, E. Y. and Rwehumbiza, F. B. R. (1998). Effects of residual tie-ridging and farm yard manure on soil water storage in Central semi-arid areas of Tanzania. In: *Proceedings of the Tanzania Society of Agricultural engineers* 8: 7-19.

Taylor, H. M and Gardner, H. R. (1963). Penetration of cotton seedling tap roots as influenced by density, moisture content and strength of the soil. *Journal of Soil Science 96: 153-156.*

Thiagalingam, K.; Dalgliesh, N. P.; Gould, N. S.; McCown, R. L.; Cogle, A. L. and Chapman, A. L. (1996). Comparison of no-tillage and conventional tillage in the development of sustainable farming systems in the semi-arid tropics. *Australian Journal of Experimental Agriculture* 36 (8): 995-1002.

Thomas, G. W. (1982). Exchangeable cations. In: *Methods of soil analysis Part 2. 2nd edition. (Edited by Page, A. L; Miller, R. H. and Keeney, D. R.).* American Society of Agronomy, Soil Science Society of America Monograph No. 9. Madison, Wisconsin, USA. pp 155-165.

Thompson, C. A. (2001). Winter Wheat and Grain Sorghum Production as Influenced by Depth of Soil Water, Tillage and Cropping System. *Journal of Soil and Water Conservation* 56: 56-63.

Tisdale, J. M. and Oades, J. M. (1982). Organic matter and water stable aggregates in soil. *Journal of Soil Science* 33: 141-163.

Tisdale, S. L.; Nelson, L. N.; Beaton, J. D. and Havlin, J. L. (1993). *Soil fertility and fertilizers.* 5th edition. Prentice-Hall, Simon & Schuster/A Viacom Company. Upper Saddle River, New Jersey. 634pp.

Tollner, E. W.; Hargrove, W. L. and Langdale, G. W. (1984). Influence of no-till practices on soil physical properties in the southern Piedmont. *Journal of Soil and Water Conservation* 39: 73-76.

Unger, P. W. (1994). Tillage Effects On Dryland and Wheat Production in the Southern great Plains. *Agronomy Journal* 86 (2): 310-314.

Unger, P. W. and Baumhardt, R. L. (1999). Factors Related to Dryland Grain Sorghum Yield Increases: 1939 through 1997. *Agronomy Journal* 91: 870-875.

Unger, P. W. and Cassel, D. K. (1991). Tillage implement disturbance effects on soil properties related to soil water conservation. *Soil and Tillage Research* 19: 363-382.

Unger, P. W.; Stewart, B. A.; Parr, J. F. and Sing, R. P. (1991). Crop residue management and tillage methods for conserving soil and water in semi-arid regions. *Soil and Tillage Research* 20: 219-240.

Van Ouwerkerk, C. and Boone, F. R. (1970). Soil physical properties of zero tillage experiments. *Netherlands Journal of Agricultural Science* 18: 247-261.

Van Wambeke, A. (1974). Management Properties of Ferrasols. Food and Agriculture Organization (FAO) Soil Bulletin 23. 129 pp.

Vogel, H. (1994). *Conservation Tillage in Zimbabwe.* Evaluation of Several Techniques for the Development of Sustainable Crop Production systems in Smallholder Farming. Geographical Bernensia and Geographical Society Berne. University of Berne Switzerland. pp 150.

Webster, C. C. and Wilson, P. N. (1980). *Agriculture in the Tropics.* 2nd edition. Longman Group Limited. 640 pp.

Willcocks, T. J. (1981). Tillage of clod forming sandy loam soils in the semi arid climate of Botswana. *Soil and Tillage Research* 1: 323-350.

Williams, J. and Shaykewich, C. F. (1971). Influence of Soil Water Matric Potential and Hydraulic Conductivity on the Germination of Rape (*Brassica napus* L.). *Journal of Experimental Botany* 22 (72): 586-597.

Young, A. (1976). *Tropical Soils and Soil Survey*. Cambridge University Press. Cambridge. 467 pp.

Zobeck, T. M. and Ostad, C. A. (1987). Tillage and rainfall effect on random roughness: A review. *Soil and Tillage Research* 9: 1-20.

7.0 APPENDICES

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

Profile No. Hombolo Agricultural Research Station

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

Elevation: 1037 m 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 *Andosonia digitata* (baobab) and *Hyperrhenia-acacia* 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 (7.5YR 6/4) dry , sandy loam; moderately weak medium crumb; slightly sticky, slightly plastic (wet), very friable (moist) and slightly hard (dry; many very fine random pores; porosity 42.7%; common very fine roots; abrupt, smooth boundary.

AB 12-28cm Brown to brown (7.5YR 4/4) moist and brown (7.5YR 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%; very few fine roots; clear; smooth boundary.

Bu1 28-46cm Strong brown (7.5YR 5/8) moist and reddish yellow (7.5YR 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.

Bu2 46-102cm 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.

Bu3 102-158cm 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 (7.5YR 6/4) moist and pink (7.5YR 7/4) dry, common fine faint clear strong brown (7.5YR 5/6 and 7.5YR 5/8) mottles; slightly gravel sandy clay loam; moderately coarse sub-angular blocky 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 (7.5YR 6/2) moist and pinkish grey (7.5YR 7/2) dry; common medium distinct clear strong brown mottles, slightly gravel sandy clay loam; massive; sticky and plastic (wet), firm (moist) and extremely hard (dry); few fine pores; porosity 30.7%; very few large (1.0-1.5cm) slightly soft irregular dark red ironstone nodules.

Appendix 1b: Analytical data of the profile

Horizon	Depth (cm)	Clay (µm)	Silt (µm)	Sand (µm)	Textural class	pH H_2O (1:2.5)	pH KCl (1:2.5)	Organic Carbon (%)	Total Nitrogen (%)
Ap	1-12	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
Bgcs	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 Al	CEC (cmol(+)/kg)	%Base 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

nd=not determined

Source: Mahoo and Kaaya (1993)

Appendix 2: Effect of tillage on profile water content (mm) in the 0-50 cm soil layer

Week after planting	Tillage treatments							Means	S.E ±	CV(%)
	NT	NTF	STR	DTR	STRF	DTRF	ADTRF			
1	163.2b	167.2b	236.4ab	216.4ab	205.0b	286.4a	184.0b	208.38	22.64	18.82
2	95.3b	156.4a	126.7ab	138.2ab	154.2a	118.1ab	147.3a	133.73	13.63	17.66
3	200.1bc	194.7c	222.5bc	243.0bc	312.5a	250.2b	213.9b	233.83	15.58	11.54
4	211.8a	208.6a	273.7a	262.9a	284.8a	250.3a	219.5a	244.49	23.69	16.78
5	223.5b	254.7ab	333.1a	300.2ab	336.6a	314.4ab	289.5ab	293.1	29.51	17.44
6	170.0b	169.9b	217.5ab	206.6ab	288.4a	221.7ab	204.3a	210.46	25.83	21.26
7	132.2a	191.9a	206.3a	298.3a	191.1a	230.4a	166.8a	202.4	26.21	15.68
8	176.4b	201.3b	232.2b	246.9b	351.5a	255.6b	207.2b	238.74	29.34	21.29
9	176.4b	201.3b	232.2b	246.9b	351.5a	255.6b	207.2b	238.74	29.34	21.29
10	197.2c	240.7bc	265.6ab	288.2ab	277.6ab	322.8a	252.9bc	263.56	20.45	13.44
11	205.5c	231.8bc	276.1bc	303.0ab	371.4a	243.6bc	281.2b	273.24	24.16	15.32
12	176.8b	162.3b	281.0a	228.1ab	290.3a	216.5ab	228.6a	226.23	26.73	20.46
13	176.8b	162.3b	281.0a	228.1ab	290.3a	216.5ab	228.6a	226.23	26.73	20.46
14	180.3d	191.2cd	242.6abc	253.0ab	277.7a	228.3abcd	198.4bcd	224.49	17.92	13.83
15	161.7bc	131.4c	218.5abc	209.5abc	258.3ab	206.2abc	281.1a	209.51	34.85	28.81
16	171.9ab	139.6b	221.7a	200.6a	228.9a	200.5a	191.9ab	193.59	17.15	15.34
17	171.9ab	139.6b	221.7a	200.6a	228.9a	200.5a	191.9ab	193.59	17.15	15.34
18	127.5bc	122.2c	158.9abc	158.3abc	197.6a	150.8bc	168.5ab	154.83	13.37	14.95
19	147.8b	114.5b	155.8ab	168.7ab.	211.7a	167.1ab	169.4ab	162.14	16.88	18.03
Treatment means	171.91	177.97	231.76	231.44	268.84	228.18	212.22			

NT = No-till, NTF = NT + FYM, STR = Shallow depth of tillage with tie ridges without FYM, DTR = Deep depth of tillage with tie ridges without FYM, STRF = STR + FYM, DTRF = DTR + FYM, ADTRF = Annual Deep depth of tillage with tie ridges with FYM. Means followed by the same letter along the same column are not significantly different at 5% probability level by Duncan New Multiple Range Test.

Appendix 3: Number of plants harvested

Tillage methods	Farm yard manure (tons/ha)		Treatment means
	0	30	
NT	149b	277a	213
STR	206ab	247ab	226
DTR	200ab	271ab	235
ADTR		178ab	178
FYM. Means	185	243	
S.E ±	3.69		
C.V (%)	28.85		

NT = No-till, STR = Shallow depth of tillage with tie ridges, DTR = Deep depth of tillage with tie ridges, ADTR = Annual Deep depth of tillage with tie ridges. Means followed by the same letter along the same column are not significantly different at 5% probability level by Duncan New Multiple Range Test.

Appendix 4: Heads/Panicle weight (kg)

Tillage methods	Farm yard manure (tons/ha)		Treatment means
	0	30	
NT	4.07b	16.03a	10.05
STR	10.77ab	16.31a	13.54
DTR	13.51ab	16.21a	14.86
ADTR		18.61a	18.61
FYM. Means	9.45	16.79	
S.E ±	3.54		
C.V (%)	22.50		

NT = No-till, STR = Shallow depth of tillage with tie ridges, DTR = Deep depth of tillage with tie ridges, ADTR = Annual Deep depth of tillage with tie ridges. Means followed by the same letter along the same column are not significantly different at 5% probability level by Duncan New Multiple Range Test.

Appendix 5: Sorghum grains yield (tons/ha) as affected by tillage methods

Tillage methods	Farm yard manure (tons/ha)		Tillage methods. Means
	0	30	
NT	0.42a	1.81ab	1.11
STR	1.18ab	1.84ab	1.85
DTR	1.54ab	1.92a	1.73
ADTR		2.17a	2.17
FYM. Means	1.05	1.93	
S.E ±	3.08		
CV (%)	23.78		

NT = No-till. STR = Shallow depth of tillage with tie ridges. DTR = Deep depth of tillage with tie ridges, ADTR = Annual Deep depth of tillage with tie ridges. Means followed by the same letter along the same column are not significantly different at 5% probability level by Duncan New Multiple Range Test.