ASSESSMENT OF *IN-SITU* RAINWATER HARVESTING TECHNIQUES FOR IMPROVING SMALLHOLDER MAIZE PRODUCTION IN SEMI ARID AREAS OF MOROGORO, TANZANIA

BY

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ABSTRACT

A study was conducted at Morogoro, Tanzania during long rains ('Masika') to evaluate the effect of *in-situ* rainwater harvesting (RWH) techniques in improving maize yield. Three commonly used techniques, ridging after planting (RA), ridging before planting (RB), and tied ridging (TR) were tested against a no tillage practice locally known as "kuberega" (K) on an Oxic Paleustalf soil with maize (*Zea maize L.*) variety TMV1 as the test crop. Daily rainfall was recorded and the total rainfall received during the 2001/02 growing season was 562 mm with a series of dry spells. Moisture content at 0-15 and 15-30 cm depth was measured twice weekly. Significantly ($p<0.05$) higher soil moisture variation and lower moisture content were noted in treatment K than in the other treatments. Treatments RB and TR had lower moisture variations and higher moisture content throughout the season. Grain yield, biomass, plant height, bulk density, infiltration rates (on the ridge and in the furrow), runoff and soil loss were also measured. Significant differences were observed among the treatments ($p<0.05$) in runoff, soil loss, on ridge infiltration, grain yield, and biomass. The maize yield ranged between 2.97 Mg/ha and 3.89 Mg/ha for treatments K and RB, respectively. The runoff loss was highest for K and least for TR. Treatments K and RA did not differ significantly from each other but differed significantly from RB and TR ($p<0.05$). Soil loss had a similar trend as that of runoff. More runoff loss was recorded early than late in the season. On ridge infiltration was not significantly different for treatments TR, RA, and RB but was significantly higher than the control (K) at ($p<0.05$). On furrow infiltration, however, had a reverse order with K having higher rates. Bulk density in both depths (0-15 and 15-30 cm) was not statistically different ($p<0.05$), however treatment K had slightly higher bulk density. The results show that ridges are effective *in-situ* rainwater harvesting technique that conserves water and soil and improves productivity. However, ridging after planting is inferior to both ridging before planting and tied ridging.

DECLARATION

I, Thomas Nestory Bwana, 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:..

Date: 21/07/2003

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DEDICATION

To my parents and to all who spend their time and resources in supporting the resource poor farmer in semi arid areas of Tanzania to overcome food shortage due to drought.

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LIST OF ABBREVIATIONS

ANOVA:	Analysis of Variance
ARI:	Agricultural Research Institute
AAS:	Atomic Absorption Spectrophotometer
BC:	Before Christ
C:N	Carbon /Nitrogen Ratio
CA:	Catchment Area
CB:	Cropped Basin
CEC:	Cation Exchange Capacity
CV:	Coefficient of Variation
DANIDA:	Danish International Development Agency
DAP:	Days After Planting
DRPGS:	Directorate of Research and Postgraduate Studies
FAO:	Food and Agriculture Organization of the United Nations
ICE:	Institute of Continuing Education
IITA:	International Institute for Tropical Agriculture
L&WMRP:	Land and Water Management Research Project
LRDC:	Land Resource Development Centre
LSD:	Least Significant Difference
RDD:	Region Development Director
RWH:	Rainwater Harvesting
SAFGRAD:	Semi-Arid Food Grain Research and Development
s.e:	Standard error
SSSA:	Soil Science Society of America

SUA:	Sokoine University of Agriculture
UNCEL:	University of Newcastle Environmental Laboratory
UNESCO:	United Nations Educational, Scientific and Cultural Organization
USA:	United States of America
USDA:	United States Department of Agriculture
WMO:	World Meteorological Organization

CHAPTER ONE

INTRODUCTION

1.1 General

The semi arid zone of Tanzania occupies about one third (295,000 km^2) of the total land area of the country. It extends from the northeast towards the southwest across the central part of the country (DANIDA, 1988). Among other factors, rainfall is one of the major constraints in agricultural production in the zone. The problem relates to the quantity, distribution and reliability of rainfall. There is high fluctuation of monthly rainfall, with high variations at the beginning and at the end of the season (Ngana, 1990; Rwehumbiza, 2000). The semi arid area experiences some periods of short heavy rains that are associated with water loss by run-off. These periods are then followed by long dry periods. Although the total annual rainfall is high, there is an overall moisture deficit to plants and hence poor yield. Due to the poor crop yield people in these areas suffer from food shortage almost every year.

The major occupation of the people in the semi arid areas of Tanzania is agriculture (pastoralism and agripastoralism). This is the principal source of well being for eight out of ten persons in the country (Mascarenhans, 1982). For these people, farming is principally a way of life and not a commercial activity (Kronen, 1994). Despite large investments in the agricultural sector in terms of human manpower, yield is extremely low: sometimes below subsistence level. The shortage of soil moisture to crops is also attributed to unsuitable land preparation and management practices. Land preparation for most of the resource poor farmer in Morogoro and many parts of Tanzania is undertaken before the onset of rains when soils are very dry and too hard to till with a hand hoe. Due to the shortage of draft power and tillage implements, farmers have developed a no primary tillage practice known as 'kuberega' in the local language (Rwehumbiza, *et al.*, 2000). 'Kuberega' involves superficial scratching of the soil surface by a hand hoe to remove vegetation /weeds before sowing. This practice leads to poor crop yield due to poor soil water conservation. The poor soil and water conservation causes high runoff losses that occur with high rainfall intensity, especially at the beginning of the season (Hatibu *et al.*, 1995).

The increasing incidences of food shortage in the country can be attributed to changes in the characteristics of the rural economy. Farmers have moved from traditional food crops such as bulrush millet and sorghum, that are drought tolerant, to maize, a non-drought tolerant crop. Maize has now become the preferred cereal in the country despite repeated crop failure resulting from unreliable rainfall (Rwehumbiza *et al.*, 2000). The unreliable rainfall coupled with sandy soils of low water holding capacity increase the possibility of water stress during the growing season (Hathout, 1983). Most recent studies by Mahoo *et al.* (1999) and Venalainen and Mhita (1998) have revealed that rainfall is very variable both within and between seasons. Runoff losses during rainfall events can be as high as 40% (Hatibu *et al.*, 1995).

In order to stabilize crop production under the variable and unpredictable rainfall in the semi arid areas appropriate technology is urgently needed. The intervention techniques should in general aim at maximizing soil water availability to crops from each rainfall event and optimize crop yield per unit of this available soil water. In the semi arid areas of Tanzania the main intervention so far has been the planting of drought tolerant crops like sorghum and millet. However, planting of drought tolerant crops has not eliminated crop failure due to water stress (Mahoo *et al.*, 1999). The alternative solution to drought in semi arid areas could be irrigation, but irrigation has proved costly and can only benefit a fortunate few. Irrigation is also associated with such problems as diversion of water from other users down stream, clearing of valuable riverine forest, neglect of the rain-fed areas, need to resettle farmers from reserved areas upstream and exclusion of nomads and pastoralist from the areas to be irrigated. Now there is increasing interest in an alternative generally referred to as 'Rainwater harvesting' (FAO, 1994). Rainwater harvesting (RWH) in its broadest sense is the collection of rainwater for its productive use. *In-situ* rainwater harvesting is one of the systems that comprise a group of techniques for preventing runoff and promoting infiltration. Rainwater harvesting insures that rainwater is conserved where it falls as such preventing excessive runoff (Gowing *et al.*, 1999). The use of rainwater harvesting techniques for crop production has not received much attention from research and extension. However, rainwater harvesting for livestock has had high attention (Gowing *et al.*, 1999). Many farmers are interested in rainwater harvesting especially through use of external catchment, but the main constraint to farmers is the limited extent of knowledge. The source of innovation in rainwater harvesting for a long time now has been farmers' own initiatives or indigenous knowledge (Senkondo *et al.*, 1999).

1.2 Objectives of the Study

1.2.1 General objective

The broad objective of this work was to study the potential of different *in-situ* rainwater harvesting methods for improving crop production in semi-arid areas of Tanzania.

1.2.2 Specific objectives

i. To investigate the potential of ridging before planting, ridging after planting, and tie ridging in increasing yield of maize as compared to no tillage practice

ii. To study soil moisture variations during the growing season in each treatment

iii. To determine run off loss from each treatment

iv. To assess the effect of the *in-situ* rainwater harvesting techniques on bulk density and infiltration rate

v. To determine the amount of soil loss from each treatment

vi. To assess the effects of the treatments on some growth components of maize

CHAPTER TWO

LITERATURE REVIEW

2.1 The history of Rainwater Harvesting.

Various forms of rainwater harvesting (RWH) have been used traditionally throughout the centuries. Some of the earliest agriculture, in the Middle East, was based on techniques of rainwater harvesting such as diversion of "Wadi" flow (spate flow from normally dry watercourses) onto agricultural fields. Other examples include the desert areas of Arizona, Northwest Mexico and Southern Tunisia (Pacey and Cullis, 1986).

The first water harvesting facility was in all likelihood nothing more than a depression in a rock surface that trapped rainwater. The collected water served as a drinking water supply for man and animals. These depressions storage are still found in many parts of the world and serve as source of drinking water for many forms of wildlife (Gray, 1994). It is highly probable that the first constructed water harvesting facility was simply an excavated pit. The first evolutionary step might have been to construct a rock diversion or gutter to provide a longer collection area. Researchers have found signs of early water harvesting structures believed to have been constructed some 9000 years ago in the Edom mountains in southern Jordan (Bruins *et al.*, 1986). There is evidence in Iraq that simple forms of water harvesting were practised in the Ur area in 4,500 BC. Along desert roads, from the Arabian Gulf to Mecca there still exist water-harvesting systems that were constructed to supply water for caravans. Evidence of other ancient water harvesting systems has been uncovered in Northern Africa (FAO, 1994).

Traditional, small-scale systems of rainwater harvesting in sub-Saharan Africa have recently been recognised. Simple stone lines are used in Burkina Faso and Mali, earth bunding systems in eastern Sudan, Kenya and the central rangelands of Somalia (Critchley and Reij, 1989).

2.2 Recent Developments in RWH

The potential of water harvesting for improved crop production received great attention in the 1970s and 1980s. This was due to the widespread droughts in Africa that left a trail of crop failures and a serious threat to human and livestock life. Consequently a number of water harvesting projects were set up in sub-Saharan Africa. The main objectives of the projects were to combat the effects of drought by improving plant production and in some areas rehabilitating abandoned and degraded land (Critchley and Reij, 1989).

Ironically, only a few of the projects succeeded in combining technical efficiency with low cost and acceptability to the local farmers or agro-pastoralists. This was partly due to the lack of technical "know how" but also often due to the selection of an inappropriate approach with regard to the prevailing socio-economic conditions (Hatibu and Mahoo, 2000a). In the region there is growing awareness of the efficiency of traditional systems that have been developed by local farmers by trial and error over many generations (Kronen, 1994). Experiments have shown that the 'Ngoro' system, a cultural practice used on hillsides in the Southern Tanzania, produces higher maize yields in wet years than cultivation of maize on ridges or on the flat (Ley, 1990). The system also is most effective for preventing erosion as overflow from one pit is trapped in the next. The system also maintains soil fertility because weeds and crop residues are thrown in the pits. In Zimbabwe the Badza holing out technique is practised by farmers to conserve soil water (Government of Zimbabwe, 1984). The system requires hardly any implement input and the yields are comparable to those achieved with ploughing (Vogel, 1992). However, the disadvantage of this system is the high overall labour cost (Kronen, 1994). Recent investigations in semi arid areas of Tanzania (Shinyanga District) show that the traditional system of rainwater harvesting by collecting and concentrating runoff from large untreated catchments has considerable potential (Mwakila and Hatibu, 1992).

2.3 Concept of Rainwater Harvesting

Water harvesting in its broadest sense can be defined as 'the collection of runoff for its productive use' (Anschutz *et al.*, 1997). Runoff may be collected from roofs and ground surfaces as well as from seasonal streams (Gowing *et al.*, 1999). Water harvesting systems which harvest water from the ground surface and roofs fall under the term "rainwater harvesting" while all systems which collect runoff from seasonal streams are grouped under the term "flood water harvesting" (Anschutz *et al.*, 1997). Rainwater harvesting should be regarded as a continuum of techniques that links *in-situ* soil water conservation at one extreme to conventional irrigation at the other. It has been classified according to size ratio and transfer distance between runoff producing area or catchmet area (CA) and the runoff receiving area, normally called cropped basin (CB) (Prinze *et al.*, 1994; Siegert, 1994; Barrow, 1999; Hatibu *et al.*, 1999). The classification of rainwater harvesting techniques is as varied as the terminology itself. Different authors use different names and often disagree about the definition of the term (Siegert, 1994).

2.4 Rainwater Harvesting Techniques for Crops

The starting point of rainwater harvesting is to capture rainwater where it falls for `the purpose of meeting the water needs of that area. Any excess can then be transferred for use downstream (Hatibu and Mahoo, 2000a). In relation to rainwater harvesting for plant growth, capturing rain where it falls is called *in-situ* rainwater harvesting (Gowing *et al.*, 1999; Hatibu and Mahoo, 2000a). It is, basically, all the conventional approaches to soil and water conservation designed to enhance infiltration of rainwater into the soil.

The next stage in rainwater harvesting is micro-catchment system that involves two major components. These are the catchment area (CA) that generates runoff, and the cultivated basin (CB) where the runoff is concentrated, stored and productively used by plants (Anschutz *et al.*, 1997; Gowing *et al.*, 1999; Hatibu and Mahoo, 2000a). Systems with large catchments are called Macro-catchment. These include intermediate components such as means for collecting, transferring and storing the runoff.

2.5 *In-Situ* Rainwater Harvesting Techniques

In-situ rainwater harvesting, also known as soil-water conservation, comprises a group of techniques for preventing runoff and promoting infiltration. It aims at conserving rain where it falls (Gowing *et al.*, 1999). In implementation of the techniques it is necessary to use simple soil preparation techniques which may be undertaken by hand implements, animal traction or simple motorized power (FAO, 2000). The techniques include plough and planting on flat land, ridging after planting, ridging before planting, tied ridges, partial ploughing, pitting, conservation tillage, contour ridging and mulching (DANIDA, 1988; Gowing *et al.*, 1999; FAO, 2000). The *in-situ* rainwater harvesting technique can be put into two broad categories, conservative tillage and pitting (Gowing *et al.*, 1999).

2.5.1 Conservative tillage

Conservative tillage is a generic term for the use of tillage technique to promote *in-situ* moisture conservation. This can be achieved by creating micro-relief for retention storage (e.g. tie-ridging), by breaking subsurface pan by deep cultivation (e.g. chisel ploughing), or by contour ridges (Gowing *et al.*, 1999). In arid and semi arid tropical regions crop yields are limited by the low amounts of plant available water. Most of the rain falls with high intensity and is concentrated in a short period of time. Because of low infiltration capacity, a high proportion of rainfall is lost as runoff. To restrict runoff and give time to the rainwater to infiltrate, ridges are used (Lal, 1995). Ridge cropping is practised under a wide range of conditions. Crops are grown on ridges on shallow soils to increase the effective rooting volume. Ridges are formed on poorly drained soils to grow upland crops and on nutrient deficient soils to heap up the profile topsoil. Ridges also are made in manually powered farming to save labour by tilling only half of the land, on steep slopes to provide drainage channels up and down the slope for disposal of surplus water, and on sloping lands to conserve water and control erosion. Ridging facilitates easy harvesting of roots on tuberous crops. The ridge furrow system is usually stable for gentle slopes up to 7 % and for soils with relatively stable structure (Lal, 1995).

2.5.1.1. Tied ridging

Tied ridging is a variation in ridging technique in which lower ridges, also known as cross-ties (15-20 cm) are made every two metres across the contour furrows, creating mini-basins. In case of light rainfall the water remains in the basin (Anschutz *et al.*, 1997). Tie ridging and ridging with cross ties is an improvement over the traditional ridge furrow system. Tied ridges can be made before planting when preparing the ridges or the ties can be made by earthing up during weeding or 30 days after planting (IITA, 1981). Tie ridging is similar to mini basin as described in the semi arid regions of southern USA by Unger (1984). The tie ridge system was initially developed in semi-arid Tanzania, where it proved to be an effective water conserving technique (Lal, 1995). Tied ridges can be used only where the rainfall does not exceed the storage capacity of the furrows, otherwise severe erosion may result. Several studies carried out in Dodoma region have shown that ploughing coupled with tie ridging and application of farm yard manure can increase yield through moisture conservation (Hatibu *et al.*, 1995; Reuben *et al.*, 1998; Swai and Rwehumbiza, 1998). However, farmers have failed to adopt this technology due to the high demand of draught power for tilling the land that is undertaken before the onset of rainfall when the land is too hard (Rwehumbiza *et al.*, 2000).

2.5.1.2 Ridging before planting

The technique of *in-situ* rainwater harvesting by ridging before planting consists of ploughing the area then opening up furrows at 75 cm row spacing. For this system, hoeing is accomplished by ridging along the row and then using a hand hoe to weed between the plants. This system, owing to ridge defining the line of planting, allows better use of the rainwater, optimisation of weeding, and pest and diseases control operations (Davies *et al.,* 1997; Dregne,1990). Its use is, however, limited by the presence of stumps, stones and slopes steeper than 5 % (FAO, 2000).

2.5.1.3. Ridging after planting

This is a rainwater harvesting technique that consists of ploughing and sowing on a flat area followed by ridging between the crop rows. Ridging is done using either animal drawn or tractor operated ridgers. It can also be performed manually. When crops such as maize are well established it becomes difficult to use the toolbar equipment with more than single ridge body. The solution lies in using a single animal to pull a one row ridger body along the row or use of manual labour (FAO, 2000). The ridges can also be done simply by earthing up the soil along the row after weeding (IITA, 1981).

2.6. Effects of the *in-situ* RWH on Soil Properties and Plant Growth

2.6.1. Effects on soil properties

Water harvesting techniques tend to increase the amount of water stored within the soil and surface catchments, though this does not necessarily affect all soil properties (FAO, 1991). As stated earlier, the *in-situ* RWH is a generic term for conservation tillage. The effect of RWH on soil properties is then dependent on how the tillage operation was done (Pearson *et al.*, 1995). However, tillage systems have important influence on soil physical properties (FAO, 2000) and associated chemical and biological properties (Pearson *et al.*, 1995). The principal soil physical properties that are mostly affected by tillage are soil density, porosity, pore size, pore distribution, soil structure and infiltration rate (FAO, 2000). Soil fertility and soil temperature are also affected by tillage system (Hulugalle, 1990).

2.6.1.1 Surface bulk density

Bulk density is a measure of the packing or compression of the three constituents of the soil: solid, liquid and gaseous phase (Pearson *et al.*, 1995). Soils naturally possess different bulk densities owing to variations in their texture, porosity and organic matter content (FAO, 2000). Brady and Weil (1996) reports sandy soils as having a density of 1.2 to 1.8 Mg/m^{-3} and a porosity of 35 to 50 % whilst clay soils have a density of 1.0 to 1.6 Mg/m^{-3} and porosity of 40 to 60 %. However, the density and porosity vary according to the type and intensity of tillage, thus they are good indicators of the adequacy of various tillage systems, indicating the serious or minor compaction which the tillage operation might have caused (FAO, 2000). Adequate values for soil density are those that provide maximum moisture availability and adequate pore space. These optimum soil densities are around 1.75 Mg/m^{-3} for loam soils, 1.5 Mg/m^{-3} for sandy loam, 1.4 Mg/m^{-3} for silty loam and 1.2 Mg/m^{-3} for clay loam (Landon, 1991). The surface bulk density of the soil is largely affected by ridge tillage techniques (Hulugalle and Rodriguez, 1988) but the subsoil bulk density is not significantly affected by ridge tillage (Hulugalle, 1986a). The bulk density within plant rows with tie ridges is lower than that on flat plots (Hulugalle, 1990). Between row bulk density is not, however, significantly affected by tied ridging. Large differences in bulk density also occur between and within plant rows. In their study in the Sudan Savannah of Burkina Faso, Hulugalle and Rodriguez, 1988) found that the within row bulk density of a flat plot after hand hoeing was higher (1.32 Mg m^{-3}) than that of ridges constructed after hand hoe cultivation (1.14 Mg/m^{-3}). However the between row bulk density of flat cultivation was equal to that of tied ridges (1.50 Mg m^{-3}).

2.6.1.2 Infiltration rate

Infiltration is the term applied to the process of water entry into the soil, generally by downward flow through all or part of the soil surface (Hillel, 1980; Jury *et al.*, 1991). The rate of this process, relative to the rate of water supply, determines how much water will enter the root zone and how much if any will turn into surface runoff. The rate of infiltration affects not only the water economy of plant communities but also the amount of surface runoff and its attendant danger of soil erosion. Where the rate of infiltration is restricted, plants may be denied sufficient moisture while the amount of erosion increases. Knowledge of the infiltration process as it is affected by the soil properties and transient conditions and by mode of water supply is, therefore, a prerequisite for efficient soil and water management (Hillel, 1980).The evaluation of infiltration rates is at best a subjective exercise. It depends on the applicability of the method of measurement and the conditions expected during the project development (Landon, 1991). Infiltration categories in relation to texture and land use are as shown in Table 1a and 1b (Landon, 1991). Tillage systems largely affect the infiltration rate of soils due to their effect on surface soil properties (Hulugalle, 1990). Steady state infiltration rates measured between plant rows are, in general, greater with flat planting or open ridging than in tied ridging (Hulugalle, 1986a, Hulugalle and Rodriguez, 1988). The steady state infiltration rates measured within plant rows are however higher in tied ridges or open ridges than in flat cultivation. Also the steady state infiltration rates measured on ridges are, higher than those on furrows and on the flat (Smaling, 1988). When the steady state infiltration rate are exceeded by the rainfall intensity rates high rates of surface runoff occur. With tied ridging, however, water is retained *in-situ* by the ties and eventually infiltrates into the soil, albeit slowly, whereas with flat planting or open ridging it is lost as runoff (Halugalle, 1990).

2.6.1.3 Soil water retention and available water holding capacity

Soil water retention and available water retention capacity are greater in furrows of tied ridges than in either open ridging or flat planting (Hulugalle, 1986b). The water storage capacity of furrow soil in tie ridged plots is therefore greater. Crops planted on tied plots would, as a consequence, have more water available for consumption than would those under either open ridging or flat planting (Hulugalle, 1990; Osuji, 1984; Willcocks and Gichuki, 1996). Hulugalle and Rodriguez (1988) found that the available water capacity for planting on the flat after hand hoeing within row was lower (6.0 mm) than that of planting on tied ridges constructed after hand hoe cultivation (10.4 mm). Experiments done in Niger revealed that tillage with a traditional shallow cultivating hoe from West Africa had greater soil water storage than bare tilled plots. At a site with 550 mm total rainfall tilled plots had a maximum of 26 mm more water stored than bare (untilled) plots. For a site with 483 mm total rainfall tilled plots had 27 mm more water stored than untilled ones (Payne, 1999).

Table 1a: FAO classification of infiltration rates.

Class	Infiltration category	Basic infiltration rate
1	Very slow (non-irrigable)	<0.4cmh^{-1}
2	Slow	0.1-1.5
3	Moderate slow	0.5-2.0
4	Moderate	2.0-6.0
5	Moderate rapid	6.0-12.5
6	Rapid	12.5-25
7	Very rapid	>25

Source: Landon, 1991

Table 1b: Infiltration rates as related to texture.

Soil texture	Representative IR (cm h^{-1})	Normal range of IR cm h $^{-1}$
Sand	5	2 – 25
Sandy loam	2	1 – 8
Loam	1	0.1 –2
Clay loam	0.8	0.2– 1.2
Silt clay	0.2	0.03–0.5
Clay	0.05	<0.01 – 0.8

Source: Landon, 1991

2.6.1.4 Water runoff and soil loss

The different rainwater harvesting techniques have different efficiencies in conserving soil and water. Tie ridges are more efficient in reducing runoff and soil loss as compared to open ridge and hand hoe flat cultivation. For example in the Sudan savanna of Burkina Faso tied ridges reduced water runoff to 0-15 % of seasonal runoff (Hulugalle, 1986a). In other experiments runoff from open ridges and flat planting ranged from 20 % of seasonal rainfall for a 1 % slope (Roose and Piot, 1984) to 40-45 % of seasonal rainfall for a 4 % or greater slope (Hulugalle, 1990). In plots involving flat and ridge planting at Sokoine University of Agriculture (SUA) Morogoro Tanzania higher runoff (1570 m^3/ha) was also observed in flat cultivated plots than in ridges (352m^3/ha) (Gebremedhin, 1996). Soil loss in flat plots was also higher (12.5 Mg/ha) than loss in ridge cropping (2.5 Mg/ha) (Gebremedhin, 1996). Studies by Rawitz *et al.* (1983) in arid parts of Israel gave more evidence on the difference of the rainwater harvesting technique in conserving soil and water. In these studies it was observed that erosion loss from disk ploughed plots was approximately 10 times greater than that of plots managed by tie ridge system. It was also found that runoff from flat sowing (17.7 mm) and soil erosion (2.93 Mg/ha) was higher than that from tied ridges at 7.9 mm rainfall and 1.56 Mg/ha soil loss respectively (Morin, 1984). Due to the higher rainwater loss from flat cultivated plots, profile water content is consequently greater with tied ridging than flat planting (Hulugalle, 1986a, 1986b, 1987b). During dry periods, therefore, crops grown under tied ridges can subsist on stored water whereas those planted on either open ridges or on flat soil suffers from drought (Hulugalle, 1988a; Lal, 1995; Rwehumbiza *et al.*, 2000)

Studies done in Zimbabwe showed that tied furrows system increased rain water use efficiency by 29% and throughout the season, the 1.5 and 2.0 m tied furrows had greater water content than the traditional sites with 1.0 m row spacing on the flat (Nyamudeza, 1990).

2.6.1.5 Soil fertility

By minimising surface runoff and soil erosion (Hulugalle, 1986a) tied ridges reduce *in-situ* losses of exchangeable cations, organic carbon, clay and silt particles a major cause of soil nutrient loss (Lal, 1976). Hence level of clay, silt, organic carbon C/N ratio, exchangeable calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}) and total CEC are greater and sand content lower with tied ridging than in flat cultivation (Hulugalle, 1988d).

2.6.2 Effect of different Rainwater Harvesting Techniques on plant growth and development

2.6.2.1. Root growth

Tied ridging increases depth of root penetration and subsoil root density of maize millet and cotton in both dry and wet years (Hulugalle, 1986b, 1988b). Subsoil root proliferation is related primarily to soil water content in the subsoil (Hulugalle, 1987b, 1988b, d). Increasing soil water content stimulates root growth directly through a greater level of water availability and indirectly by reducing soil strength (Taylor, 1983). When comparing tied ridging and open ridges Hulugalle (1988d) found that the depth of root penetration and the root density of maize was higher for tied ridging than open ridges. In addition, root penetration in both tied ridging and open ridges was higher than in flat cultivation.

2.6.2.2 Vegetative growth

Plant height of maize, millet, cotton, sorghum and bambara nuts increased with tied ridging (Perrier, 1987; Hulugalle, 1988a,b,c,d). Other vegetative growth parameters such as leaf blade width of maize, millet and sorghum also increased in tied ridging (Hulugalle, 1987a, 1988b,c,d; Perrier, 1987). The vegetative growth increase of cereal crops with ridging is greater than that of non-cereal crops. Among cereal crops growth increase of shallow rooted, drought sensitive species or varieties resulting from ridges are greater than those of deep-rooted, drought resistant species or varieties (Hulugalle, 1990).

2.6.2.3 Yield

Grain and dry matter yields of maize, millet, sorghum and dry matter yield of bambara groundnuts increase with ridging in both wet and dry years (Rodriguez, 1987; Perrier, 1987; Hulugalle, 1988b,c, d). As for vegetative growth, yield increases of cereal crops with ridging are greater than those of non-cereal crops, with yield increase of shallow rooted, drought sensitive species being the highest. In comparing the effect of tied ridges, open ridges and flat cultivation on grain yield of maize, Hulugalle (1988d) found that tied ridges had higher grain yield (2.5 Mg/ha) than open ridges (1.7 Mg/ha) and flat cultivation. This was also the case for dry matter yield where tied ridges had higher yield (3.8 Mg/ha) than open ridges (1.6 Mg/ha) and flat cultivation. In assessing the effect of ridging after planting on maize yield in Burkina Faso it was found that earthing up at 30 days after planting (DAP) and tying all ridges under high management had higher grain yield (3.28 Mg/ha) than earthing up at 30 DAP and tying the ridges every other furrow (2.54 Mg/ha), earthing up at 30 DAP without tying (1.48 Mg/ha) and no earthing up (1.47 Mg/ha) (IITA, 1981).

There are contradicting reports regarding the beneficial effect of the tied-ridge system. Some workers have reported increased yield with tied ridging while others have reported no effect (Lal, 1995). In Malawi there was no significant increase in cotton yield when cotton was planted on tied ridges (Mitchel, 1987). On a similar soil in India, Ali and Prasad (1974) reported no effect of ridging on moisture conservation or on grain yield of pearl millet. At Kongwa, Tanzania Macartney *et al.* (1971) reported no beneficial effect of the tied ridge system on maize grain yield. Beneficial effects of tied ridges have been demonstrated in Botswana (Ministry of Agriculture Botswana, 1984). Grain yields of sorghum and cowpeas were markedly increased when every furrow was tied. The increase in yield was apparently due to greater availability of water in the root zone under the tied ridges. Similar results were reported in Shair Harege region of Israel, where, a 44% increase in yield of wheat sown on 1.6 m wide beds of tied ridges were observed. Also, there was a higher wheat grain yield (1.4 Mg/ha) in tied ridges than with flat sowing (0.975 Mg/ha) (Morin *et al.*, 1984). In Kenya, Itabari *et al.* (1998) reported that tied ridging with fertilizer application significantly increased the grain yield and water use efficiency of sorghum. They also had significant effect on total dry matter yields during the growing season with an average yield increase of 60 %. Recent studies at

Hombolo, Dodoma, in Tanzania showed that grain yield of sorghum was more than double (1.15 Mg/ha) for shallow tillage coupled with tied ridges compared to no tillage (0.509 Mg/ha) (Rwehumbiza *et al.*, 2000). Tillage coupled with tied ridges enhanced the capture of rainwater and improved sorghum grain yield (Reuben *et al.*, 1998; Swai and Rwehumbiza 1998; Rwehumbiza *et al.*, 2000).

Runoff plots involving flat and ridge cropping on a 4% slope at Sokoine University of Agriculture (SUA) in Morogoro, Tanzania showed that these treatments had no significant effect on maize grain yield (Gebremedhin, 1996). The yield was 2.3 Mg/ha for flat cultivation and 2.6 Mg/ha for ridge cultivation. At the Chiredzi Research Station in Zimbabwe, a 49% increase in yield was achieved on tied furrows when averaged on different population densities and row width as compared with crop production on the flat. The maize grain yield was 3.63 Mg/ha and 3.47 Mg/ha for tied furrows and flat cropping respectively for a season with 590 mm of rainfall, 2.74 Mg/ha and 1.75 Mg/ha for a season with seasonal rainfall 410 mm (Jones and Nyamudeza, 1991). The advantage of the tied furrows system is that it conserves and concentrates water, which results in good crop yield response on soils with a relatively high clay content as in vertisols, paragneiss and alluvium soils (Jones and Nyamudeza, 1991). Unfortunately, these advantages are not so evident on lighter soils, which are characterized by poorer water retention and poor fertility (Nyamudeza *et al.*, 1991).

The low yield in flat cultivated plots is also attributed to the effect of soil loss on yield. Several researchers have also reported the effect of soil loss on grain yield. Kaihura *et al.* (1996) reported 0.64 Mg /ha maize grain loss per cm of topsoil removed in Tanzania. Kilasara *et al.* (1995) observed an average 30 % yield reduction in the most eroded sites of Tanzania as compared to the less eroded ones. Soil lost its productivity in the short run due to loss in soil organic matter and fertility, crusting, compaction and other soil properties. In the long run erosion causes permanent and irreversible productivity loss by reducing the effective rooting zone (Dregne, 1990; Kilasara *et al.*, 1995).

2.7 Maize Production in Tanzania

Tanzania is characterized by a variety of environmental conditions. Rainfall, temperature, altitude, topography, vegetation and soils vary enormously within the country (Rwehumbiza *et al.*, 2000). Agricultural production is the principle source of well being for eight out of ten persons in the country (Mascarenhas, 1982). Despite this large investment in agricultural sector in terms of human power, yield is extremely low and only at subsistence level (Rwehumbiza *et al.*, 2000). In Tanzania maize remains the major food crop and its production ranks highest when compared to the other food crops. It contributes 67 % of the country's total cereal crops (President's Office, 2002). This shows how significant the crop is for food security in the country. In the Tanzania farmers have moved from traditional food crops such as bulrush millet and sorghum to maize, which has now become a preferred cereal crop despite its frequent failure resulting from unreliable rainfall. A five years development plan (1984/85–1989/90) for Morogoro region, blamed the increased area under maize in what was once predominantly a sorghum growing area as the main cause of frequent food shortages and crop failure (RDD, 1984).

Maize production in the country is almost exclusively rain fed (Rwehumbiza *et al.*, 2000). In investigating the poor performance of rain-fed maize in Morogoro, Rwehumbiza (2000) associated the poor performance with rainfall and soil characteristics. The onset and distribution of rainfall within the growing season create a difficult management situation in planting date and choice of cultivars. In Morogoro, long rains last from mid March to mid May and short rains last from mid November to mid January. During short rains there is a deficit in moisture supply throughout the season, it would be during tusselling stage for short maturing "Katumani"/"Kito" when the rains come to an end. The long rains are also too short for long maturing "Ilonga Composite"/"Staha" cultivars. The crop would be at tusselling stage when moisture deficit sets in. However, if surplus moisture is stored in the profile, the period of moisture sufficiency can be extended. The extra days would enable the long maturing "Ilonga Composite" to reach physiological maturity before moisture stress sets in. As stated above Tanzania is characterized by a variety of environmental conditions and, for that matter, the length of maize growing season differs from place to place, and therefore the crop water requirement also differs from place to place (Mahoo *et al.,* 1999). The crop water requirement for maize during long rains for Morogoro 750 mm (Hatibu *et al.,* 2000).

2.8 Rainfall Patterns

Rainfall in the semi-arid Tanzania is variable with respect to both time and space. The rainfall also varies greatly among different parts of the semi-arid areas of Tanzania, and, indeed, even within a catchment (Mahoo *et al.,* 1999). The most important characteristic of semi-arid areas is the factors that limit availability of adequate soil moisture for plant growth. These include high daily and annual temperature, low relative humidity, intense sunlight and strong winds. (Hatibu and Mahoo, 2000b). These factors encourage very high rates of potential evapotranspiration in many parts of the country, to the extent that rainfall amounts exceed potential evapotranspiration only in very few and scattered days (Hatibu and Mahoo, 2000b; Rwehumbiza, 2000). The most critical factor that makes most of the country semi arid is the dry spells, which occur during the growing, season (Nyenzi *et al.*, 1997; Venalainen and Mhita, 1998). These dry spells occur with significant variation from season to season in the same place and from place to place within the same season. In most cases a lot of rain is received at the wrong time and place. There are districts in Tanzania where long term average rainfall is more than 1,600 mm per annum yet crop production is very low. This is partly due to poor distribution of rainfall that leads to water stress to plants during one or more stages of crop growth (Hatibu and Mahoo, 2000b). Consequently, plants may use all the rainwater but still produce low yields, especially if the water stress occurred during a critical growth stage. Thus, the productivity of rainfall, land and inputs becomes low.

Based on the work by De Pauw (1984) and LRDC (1987), more than 50% of main land Tanzania can be categorized as semi arid. These areas receive less than 570 mm of rainfall in nine out of ten years with potential evapotranspiration exceeding rainfall during more than nine months of the year. The coefficient of variation of the seasonal rainfall ranges between 60 to 190% (Ngana, 1990). A large part of the country receives, on average, less than 800 mm of rain. Rainfall is also poorly distributed and very unreliable in terms of time of on set and duration (Msaky, 2002).

As mentioned earlier, Morogoro receives bimodal rainfall comprising short rains "vuli" and long rains "masika". The long rains last from mid March to mid May and short rains mid November to mid January (Dumelow and Coe, 1981; Rwehumbiza, 2000). During "masika" the mean seasonal rainfall is 504 mm and in "vuli" the mean rainfall is 359 mm. However, studies by Shayo-Ngowi and Mtakwa (1994), Gebremedhin (1996) and Mkoga (1998), reported 467 mm rainfall during long rains. This amount is very much below the crop water requirement for maize that requires about 750 mm, and therefore there is a need of conserving the little water through RWH (Mahoo *et al.*, 1999).

2.9 Water Stress and Plant Growth

2.9.1 General

In most plants water constitutes more than 90% of the fresh weight and it is only in few that it constitutes less than 70% (Turner and Burch, 1983). Plant roots must absorb enough water to satisfy the plant needs for growth and development depending on the type of soil and irrespective of the actual amount of water it contains. The plant will have to use increasingly more energy to counter the increasing force with which the soil holds the water as it is depleted. As the reservoir of water in the soil is depleted, plant dehydration increases such that physiological and morphological processes in the plant are adversely affected (Turner and Burch, 1983).

2.9.2 Critical water demand periods

For good performance plants should be supplied with adequate moisture as per growth stage. Experimental findings from various sources indicate that the sensitivity of maize grain development to moisture stress is related to the physiological stage of development at which the stress occurs (Harder *et al.*, 1982). Some field experiments have shown that wilting conditions for only 1 to 2 days during pollination reduced maize yield by as much as 22 % and 6 to 8 days by 59 % (Bennet and Hammond, 1983). Moisture stress at silking stage was more harmful to grain yield than stress at any other growth stage. Experimental evidence shows that maize is especially sensitive to water stress during pollination but becomes progressively more tolerant of water deficits as maturity approaches (Hall *et al.*, 1981). Water stress imposed during vegetative growth can cause reduction of maize stalk weight by 17% (Bennett and Hammond, 1983). Other studies reported about 50.5% reduction in maize yield in pot experiments stressed for 5 days within tusselling and silking stages while similar stress conditions prevailing at ear development and senescence stages gave 25% and 21% reduction in yield, respectively (Cleassen and Shaw, 1970a). Studies by Cleassen and Shaw (1970b) on plants subjected to various irrigation programs also showed that stresses of up to 4 days rendered significant effect on crop vegetative growth. Dry matter and grain yield dropped by about 15 and 17 %, respectively, when crops were stressed for three weeks during tusselling period. Yield reduction of more than 50 % was reported for events where drought conditions persisted at 75 % tusselling stage. In all these studies water stress at silking stage was more critical to grain yield ruduction than stress at other phenological stages. It is, therefore, important to conserve soil water by RWH so as to avoid stresses at these stages.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Study Area

3.1.1 Location:

The study was conducted at Sokoine University of Agriculture farm along the Dar es Salaam-Iringa road. The study area is on the northern foot slopes of the Uluguru Mountains (Plate 1) at latitudes 6^0 49.18^0 S and longitudes 37^0 38.49^0 E. The area is 502 m above sea level.

3.1.2 Soils

The soils of the study area are shallow, well-drained, reddish brown sandy clay loam. The soils are classified as Dystric Nitisol (FAO-UNESCO), Oxic paleustalf (USDA Soil taxonomy) (Kaaya; 1989). The soils have originated from colluvial material from the Uluguru Mountains. The land slope of the study area is 3.8 %.

3.1.3 Climate

The study area experiences bimodal rainfall. There are short and lighter rains locally known as "vuli" that fall between November and January. These are followed by a short dry period from January to mid February. Long rains, called'Masika', occur from early March to the end of May (Mahoo *et al.*, 1999). The average annual rainfall is 861 mm, with seasonal rainfall of 504 mm during 'Masika' and 372 mm during "vuli" (Mahoo *et al.*, 1999). The rainfall distribution pattern of the study area is irregular and unreliable (Kaaya, 1989; Shayo-Ngowi and Mtakwa, 1994 ; Gebremedhin, 1996; Mahoo *et al.*, 1999; Rwehumbiza, 2000) and thus there is water stress at times. The mean monthly temperatures vary from 20^0C in June, to 26^0C in November to February.

Plate 1: Position of the experimental site in the foot slopes of Uluguru Mountains.

3.1.4 Land use

The study area has been under maize cultivation for more than 10 years. The area was left uncultivated in the year 2000/01 after it was inter-cropped with maize and cowpeas in some plots. A map of eastern Tanzania agro-ecological zone describes the study area as tropical low land, mainly plains with low to moderate fertility having one medium but unreliable growing season. The area is suitable for a wide range of annual and perennial crops with some degree of drought tolerance (Mowo *et al.*, 1993).

3.2 Experimentation

3.2.1 Experimental design and layout

A Randomised Complete Block Design with four treatments replicated three times was used for the experiment (Snedcor and Cochran, 1989). The runoff plots had a size of 28 x 3 m with the length running down slope. The upper and lateral sides of the plots were enclosed by soil bands sandwiched with polythene sheets that prevented water inflow and outflow. The lower ends of each plot were constituted of an apron made of concrete and cement wall 15 cm high (Plate 2). The apron was fitted with a one and half-inch plastic pipe for conveying runoff from the runoff plot to runoff tanks. The runoff tanks were made of two metal drums fixed with concrete and mortar in trenches. The upper drum in each plot had fifteen holes 19 mm in diameter of which, one was connected to the lower drum to collect one fifteenth of the total runoff.

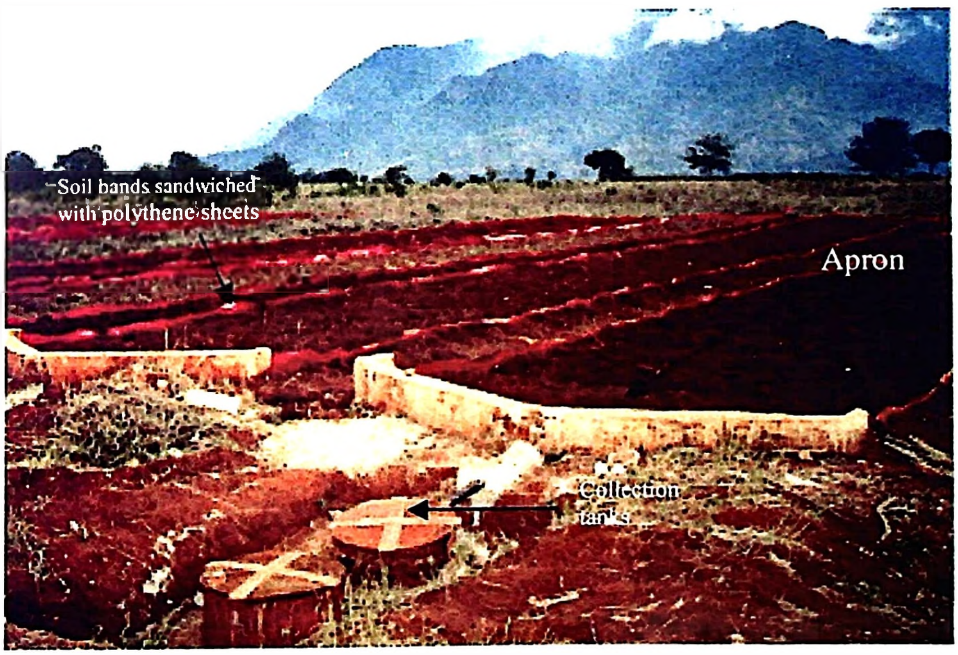

Plate 2: Runoff plots at the experimental site

3.2.2 Treatments

The study consisted of four treatments namely:

Treatment 1 (Control)

No primary tillage called "Kuberega" (K). Superficial scratching of land to remove weeds was done by using a hand hoe before planting.

Treatment 2

Ridging after planting (RA): Ridges were made along rows of flat hand hoed plots at thirty days from planting. This was done by earthing up the plant rows.

Treatment 3

Ridging before planting (RB): The ridges were made during land preparation. This was done by a hand hoe at 90 cm inter-ridge spacing.

Treatment 4

Tie-ridging (TR): The ridges were made and tied during land preparation. This was done by a hand hoe at 90 cm inter-ridge spacing. The ties were also made by using hand hoe at 150 cm spacing.

3.3 Land Preparation and Planting

The experimental plots were hand hoed according to treatments requirements. Maize (*Zea mays L.*) variety TMV1 was planted on March 2, 2002 at a spacing of 50 cm x 90 cm. Rows were made across the slope. Three seeds were planted per hole and thinning was done to 2 plants per hill 15 days after planting. The estimated plant population was then 44,444 plants per hectare.

3.4 Crop Management

3.4.1 Fertilizer and pesticide application

The recommended rates for Nitrogen and Phosphorus for Morogoro namely 60 kg N ha^{-1} and 40 kg Pha^{-1} were used (Mowo *et al.*, 1993). For phosphorous all 40 kg P ha^{-1} was applied at planting using Triple Super Phosphate (47% P_2O_5 = 21% P) and Diammonium Phosphate fertilizers (20% P and 20% N). The two different sources of P ware used so as to maintain the required rate of both N and P and at the same time maintaining the required rate of N at each split application. The combination of TSP to DAP was at a ration of 1:1.7 respectively. For nitrogen the 60 kg N ha^{-1} was applied in three splits. 20 kg N ha^{-1} was applied at planting by using Diammonium Phosphate fertilizers; 20 kg ha^{-1} was applied three weeks after planting using Sulphate of Ammonia fertilizer (21% N) and the last 20 kg N ha^{-1} was applied at tusselling by using Calcium Ammoniam Nitrate fertilizer.

For pest control, a pesticide, Thionex (endosulfan 35 % w/v) was applied to control stalk borers two weeks after emergence at a rate of 1mls/litre. A pesticide "Gammaline" (gamma-HCH 200 g/litre) was also applied for controlling termites, however, this was not effective and tobacco wastes were then used for the same purpose this was done at six and seven weeks after emergence respectively.

3.4.2 Weeding.

Weeding was done two times by using hand hoe. The first weeding was done two weeks after emergence followed by the second weeding at six weeks after emergence. In all plots the weeds were left to dry within the plots.

3.5 Data Collection

3.5.1 Soil sampling

Composite soil samples were taken from each plot at the beginning of the growing season for soil chemical analysis. Undisturbed core samples were also taken before planting, at the middle of growing season and at the end of the season for bulk density determination at both 0-15 and 15-30 cm depths.

3.5.2 Soil analyses

The soil was analysed for physical and chemical properties before planting. The soil pH was determined electrometrically in 1:2.5 soil water: suspension (Thomas, 1996). Organic carbon was determined by the wet oxidation method of Wakley and Black (Nelson and Sommers, 1996; Moberg, 2000). Total nitrogen was determined by the semi-micro Kjeldahl digestion distillation method (Bremner, 1996). Cation exchange capacity (CEC) was determined by saturation and extraction with NH_4-acetate buffered at pH 7.0 (Sumner and Miller, 1996). Exchangeable bases were determined in the NH_4-acetate leachates by AAS (Summer and Miller, 1996). Particle size distribution was determined by the Bouyoucos hydrometer method (Juo, 1979; Gee and Bauder, 1986). The extractable phosphorus was determined by the Bray and Kutz-1 method (Shiou, 1996; Moberg, 2000).

3.5.3 Rainfall

Total rainfall at the experimental site was obtained using a totalising rain gauge placed within the plot (Plate 3). The data were taken at 0900 hours every day throughout the growing season.

Plate 3: Experimental plot showing the position of the rain gauge.

3.5.4 Runoff determination

Runoff from each plot was collected into runoff tanks at the bottom end of each plot. The amount of runoff was obtained by dipping a calibrated wooden rule into the drum. The metre rule was calibrated by placing a mark for every five litres added to a drum until the water began to flow from the holes. The runoff volume obtained from each plot was summed up to get total seasonal runoff per plot and finally total runoff loss per hectare was obtained using equation 1 below.

$$Y = 199X \quad \ldots\ldots 1$$

Where:

Y =Runoff water m^3ha^{-1}

X =Runoff water m^3plot^{-1}

199 =Plot constant obtained by dividing area of one hectare by plot area (84 m^2)

3.5.5 Soil loss

Soil loss from the plot was obtained by taking 500 ml of runoff water from each plot. The samples were taken after thorough stirring of the runoff water in the drums by using a circular wooden stirrer. The samples were put in 500 ml plastic bottles and then taken to the laboratory where they were filtered through a Whatman filter No.42 (18 cm diameter). Before filtration the weight of dry filter paper (W_1) was taken. The weight of moisture can to be used for drying the sample (W_2) was also taken. After filtration the sample and filter paper were placed in a moisture can and then oven dried to constant weight at 105 °C. The dry weight of filter paper + sediments + can (W_3) were also taken.

The sediment load in the runoff was obtained as follows:

The weight of filter paper + sediments (W_4) was obtained by finding the difference between W_3 and W_2 (Equation 2).

$W_4 = W_3 - W_2$ 2

W_4 = weight of filter paper + sediments, (g)

W_3 = weight of can + filter paper + sediments, (g)

W_2 = weight of can, (g)

The sediment weight, W_t, was then obtained by finding the difference between W_4 and W_1 (equation 3).

$W_t = W_4 - W_1$..3

Where: W_t = weight of sediments, (g)

W_4 = weight of filter paper +sediment, (g)

W_1 = weight of filter paper, (g)

Sediment load per plot (Wp) was obtained using equation 4

Wp =Wt x X/Vb...4

Where: Wp = Sediment load per plot (Kg)

Wt = weight of sediments per sample, (Kg)

X =Runoff water m^3plot^{-1}

Vb =Volume of sampling bottle (m^3)

The sediment load per hectare was then obtained multiplying the sediment load per plot by the plot constant 199.

3.5.6 Infiltration

On site infiltration tests were done on top of the ridge and in the furrows. On ridge infiltration was determined using a modified tension infiltrometer (disc permeameter) (UNCEL type) developed by the University of Newcastle Environmental Laboratory. The in furrow infiltration measurement was done using double ring infiltrometer as described in the procedure below.

Procedure for Modified Tension Infiltrometer (Disc permiameter).

The soil surface was cleaned without disturbing the surface structure. Stones and loose plant material were also removed in order to avoid empty air space. Vegetation was carefully cut at the soil surface with a small pair of scissors (White *et al.,* 1992). Cottoncloth was laid out on the surface. Empty spaces between the cottoncloth and the soil surface which result in air pockets was avoided. On top of the cottoncloth a layer of fine and moist sand was spread. The sand was levelled by means of a small spirit level. The cottoncloth allows re-using and transporting the fine sand from one site to the next. The fine moist sand is crucial to ensure a good and level contact between the membrane of the tension-infiltrometer. If the tension-infiltrometer is not level and tilted, small pressure differences between the higher and lower end of the membrane can lead to leaks and inaccuracies in tension. The reservoir and bubble tower of the tension infiltrometer were filled with water. For the bubble tower, water was added up to the calibrated zero level mark. This level served as the zero reference level for the tension tubes (air entry tubes, Fig.1) Before connecting the air-exit tubes, air inside the tube was gently blown out by mouth. This eliminated the air and water inside the air inlet tube. The infiltrometer was then carefully placed on top of the smoothed soil surface, covered with a thin piece of cotton cloth (to avoid damage to the membrane). Before starting infiltration, the infiltrometer was kept undisturbed for five minutes. This enabled observation of air leakage. To avoid air entry from the outside, a layer of Vaseline was spread around all the air entry tubes and the water reservoir tube. Initial water height in the reservoir was recorded on a data sheet. The valve for the smallest negative pressure (5 cm) was then opened. Shortly after that, air began to bubble through the open-air entry tube in the tension regulating chamber. After observing the first bubble, a stopwatch was started and time recorded on the data sheet. The amount of water infiltrating into the soil was recorded against time by reading a measuring tape attached to the water reservoir. The steady state measurement was approximated by observing the change of water level over a fixed time interval. This observation was repeated until successive infiltration rates were the same for at least three consecutive readings.

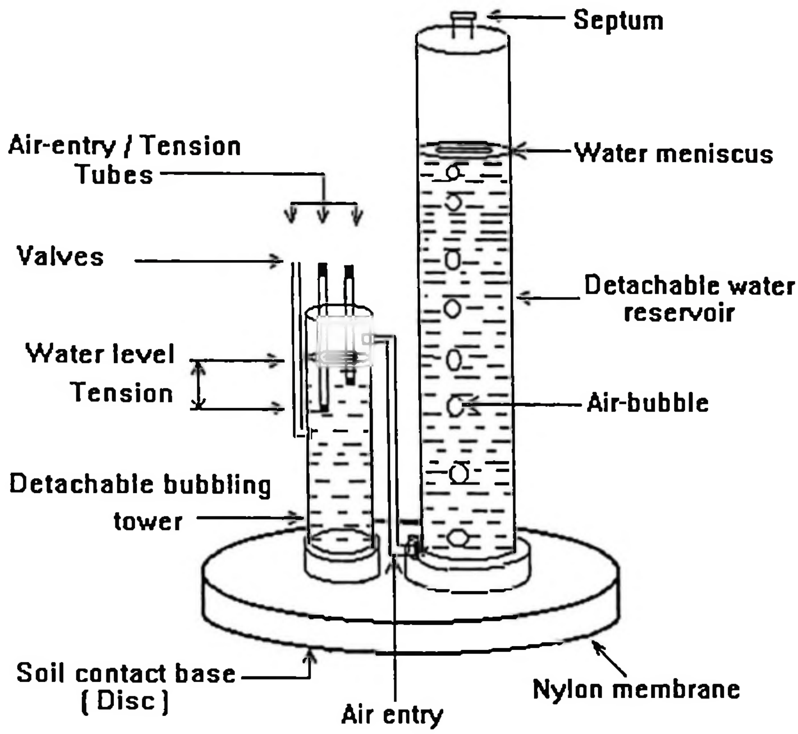

Figure 1: Modified Tension Infiltrometer (UNCEL, 1995)

After reaching a steady state, the 7 cm tension valve was opened. The procedure for determining steady state infiltration with this tension and the 10 cm tension was the same as that described for 5 cm tension measurement. The steady state infiltration rate, q (mm/hr) was then obtained using the equation $q_t=Q/\pi r^2$ (White *et al.*, 1992) where Q is the total intake rate through the disc r the radius of the disc.

Procedure for double ring disc infiltormeter

At each setting the inner and outer rings of the infiltrometer were placed on the ground with the cutting edges on the surface. A driving plate was then attached on the rings. The rings were then driven into the soil by striking firmly at right angles to a depth of 10 cm by using an impact-absorbing hammer. The outer ring was then filled with water to saturate the soil. The inner ring was also filled with water and a measuring bridge (including float and measuring rod) was attacked. The measuring started by noting the initial position (in cm below reference level) against the time reference t = o, and subsequently the reading of the water level during a fixed period of time. The measuring was ceased once infiltration rate reached a constant reading. The average infiltration rates were then obtained by driving the total water depth to the total time taken (Landon, 1991).

3.5.7 Soil moisture content

Soil moisture content was monitored gravimetrically twice a week at 0–15 and 15–30 cm depth throughout the growing season from February 28 to May 2002. Soil samples were taken at random from three positions, that is from the upper, the lower and the middle of the plot. The samples were placed in moisture cans whose lids were tightened and sealed with masking tape and taken to the Soil Science Laboratory of the Sokoine University of Agriculture for soil moisture determination. The moisture content was obtained by taking the weight of soil samples before and after oven drying for 24 hours at 105 ^{0}C, and then expressing the loss in weight after oven drying as percentage of the weight of the oven dry soil (w/w). Moisture content was expressed as percentage as shown in equation 3.

Percentage moisture= $W_1 - W_2 / W_2 \times 100$..5

Where W_1 = weight of moist soil, (g)

W_2 = weight of oven dry soil, (g)

3.5.8 Field capacity

The moisture percentage at field capacity was obtained by field method (Landon, 1991). In the field, representative spots in each plot were selected. In each spot an area of 2.5 m^2 was banded on all four sides and all weeds were removed. In each square water was then poured until the soil was sufficiently wet. Straw mulch of 40 cm thickness was then spread on the surface to prevent evaporation. Soil samples at 0 – 15 and 15 – 30 cm depth were then taken by using a soil auger to determine moisture content at 24 hours interval until the value of successive samples were nearly equal (this was reached after 72 hours). Moisture content versus time curve was then plotted (Appendix. 3); the lowest influx value represented the soil field capacity.

3.5.9 Seedling emergence

At 75 % emergence, the total number of emerged seedlings from each treatment was counted. This was then expressed as a percentage of the total number of sown seeds.

3.5.10 Plant height

Plant height was taken four times: three weeks after emergence, six weeks after emergence, at booting stage and lastly at maturity just before harvesting. The heights were measured by using a measuring tape from the ground level to the tip of the highest leaf.

3.5.11 Grain and biomass yield

Harvesting was carried out 15 weeks after planting. Above ground biomass yield and grain yield were obtained by harvesting the whole plots. The plants were cut just above soil surface and respective weights taken. The ears were then removed and stover weight taken. The ears were shelled by hand and the grains and cobs were left to dry naturally to average moisture content of 12.5%. The moisture content of maize grain was determined using an electronic grain moisture meter FARMEX-PREAGRO 35 type. The grain weight per plot was taken and converted to yield per hectare. After shelling, five cobs from each plot were dried in an oven at 60 ^{0}C to constant weight. The weight was then taken for an estimate of cob yield per plot. Ten plants were taken at random from each plot. The plants were then oven dried to constant weight for determination of dry matter yield per plot. The total above ground biomass was obtained by summing grain, stover and cob weights per plot. The total above ground biomass per plot was converted into yield per hectare.

Bt= weight of grain + weight of stover + weight of cob Mg/ha..........................6

Where: Bt=Total above ground biomass

3.5.12 Seeds per cob and seed weight

Five cobs were selected at random from each treatment. The cobs were shelled by hand and seeds were left to dry naturally to a moisture content of 12.5 %. The average seed number per cob was obtained by counting the number of seed for the five cobs and then dividing by five. Seed weight was obtained by taking average weight of one hundred seeds from each treatment.

3.5.13 Analysis of results

The MSTAT computer program was used for statistical analysis. The analysis of variance (ANOVA) was done to determine the effect of the different treatments on maize yield, runoff, infiltration, plant height and soil loss. The Duncan New Multiple Range Tests were done for comparing mean yield, plant height, runoff, bulk density, infiltration and soil loss from the treatments. Simple correlation and linear regression analysis were used to test the relationship between rainfall versus runoff, soil loss versus runoff and rainfall versus profile moisture.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Rainfall

The long rains at the experimental site lasted from February 27 to May 29 2002 (Appendix 1). The total amount of rainfall received during this season was 562 mm. This amount is above the long-term average rainfall of 504 mm reported by Mahoo *et al.*, (1999). It was also above the seasonal values of 467 mm (Gebremedhin, 1996) and 327 mm reported by Bazugba (2001). This value was however below the water requirement for maize during long rains which is 700 mm (Rwehumbiza, 2000. Rainfall during the season reported here-in had a series of dry spell with the longest spell being 20 days (Fig 2). In week 8 the dry spell coincided with the critical moisture demand period of the crop, at flowering. There was a total of 35 rainfall events of which the highest amount of rainfall in a single event was 84 mm. This constituted 17 % of the seasonal rainfall. Out of the 35 rain events, 20 generated runoff, constituting 57 % of the rainfall events. The least amount of rainfall that generated runoff was 7 mm. Generally, the results showed that the rainfall was inadequate for optimal maize production in both amount and distribution. Most of the rainfall events generated runoff and this shows that in most of the rainfall events rainwater was lost as runoff. The results conform to other results that the rainfall at Morogoro is inadequate for optimal maize production (Kaaya, 1989; Shayo-Ngowi and Mtakwa, 1994 ; Gebremedhin, 1996; Mahoo *et al.,* 1999; Rwehumbiza, 2000; Msaky, 2002). The comparison of the monthly rainfall received and the ten years mean rainfall is shown in Fig.3.

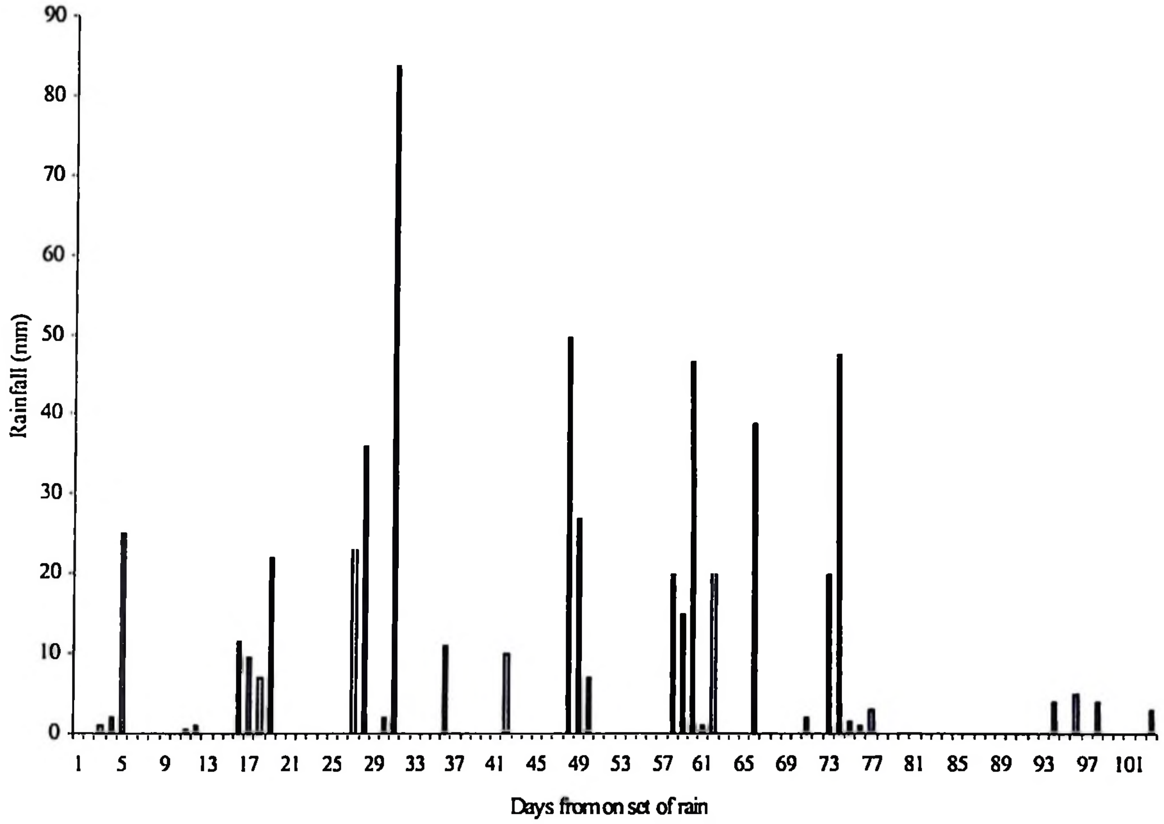

Figure 2: Daily rainfall recorded at the experimental site indicating dry spells

As shown in the figure, the total seasonal rainfall was higher than the long-term average rainfall. Also in March and April the monthly rainfall during this season was higher than the long-term average but for February and May the long-term average was higher than the recorded seasonal rainfall.

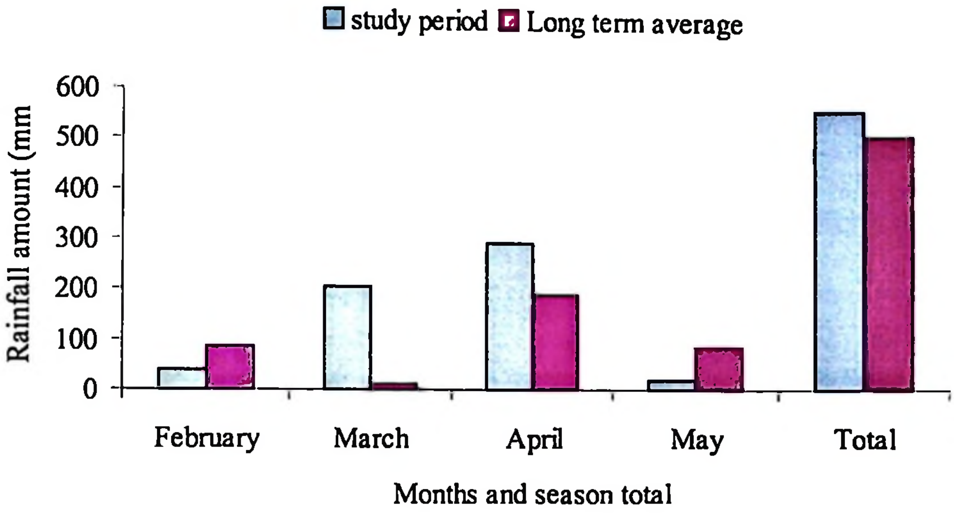

Figure 3: Comparison of the monthly observation and ten years rainfall average.

4.2 Runoff

The amount of runoff from each treatment is as shown in Table 2.

Table 2: Effect of treatments on total amount of runoff generated

Treatment	Runoff loss		
	m^3/ha	mm	Percentage
K	851.3[a]	8.5[a]	16.2[a]
RA	779.8[a]	7.8[a]	14.9[a]
RB	128.2[b]	1.3[b]	2.4[b]
TR	107.7[b]	1.1[b]	2.1[b]
LSD	511.7	1.2	6.1
s.e.	3.421	1.2	1.1
CV	52	52	52

Values with the same letter in the same column are not significantly different at $P<0.05$

Where: K-No primary tillage (Control) RA-Ridging after planting,

RB-Ridging before planting TR-Tie ridging.

No primary tillage (K) had more runoff than all other treatments. Tie ridging, on the other hand, produced the least amount of run-off. The effect of different treatments on surface runoff was significant ($p<0.05$). By ranking, surface runoff from the different treatments the it was in the order K = RA > RB = TR. Similarity in runoff between K and RA ($p<0.05$) is due to the fact that large runoff losses were recorded at the early stage of maize growth before the ridges were made in RA (Fig. 4). This indicates that ridging after planting is not an efficient system of water conservation in the area because a lot of water is lost at the period between planting and making ridges. The percentage runoff from the treatments was 2.05 % for TR, 2.44 % for RB 14 % for RA and 17 % for K. This clearly indicates the superiority of tie ridging as well as ridging before planting over ridging after planting and no tillage practice in water conservation. This could be attributed to the effect of ridges in retaining rainwater and enhancing prolonged infiltration, hence generating less runoff. The results imply that ridging could be an important soil and water conservation technique in semi arid areas where rainfall is variable and scanty. The results from this study are in agreement with findings by other researchers, including Rawitz *et al.* (1983); Hullugale (1988a) Nyamudeza, (1990); Gebremedhin (1996); Shayo-Ngowi and Mtakwa (1996); Nindi (1999); Rwehumbiza *et al.* (1999) and Bazugba (2001).

In comparing tie ridging and ridging before planting, the results show no significant difference ($p<0.05$) in runoff between the two treatments. This is contrary to findings by Hulugalle (1986a) and Nyemudeza (1990) who reported that runoff was higher on ridging before planting than on tie ridging.

Simple correlation and linear regression analysis relating runoff amount and associated rainfall are shown in Table 3. In all treatments runoff was significantly and positively correlated to rainfall ($P < 0.05$). About 82 percent of the variation in runoff from K could be explained by the variation in rainfall, while only 39% and 21 % of variation runoff for RB and TR, respectively, can be explained by the variation in rainfall.

Table 3: Correlation and linear regression equations relating runoff to rainfall

Treatment	Correlation coefficients	Regression equation	Adjusted R^2
K	0.903	Y=0.0024X-0.0152	0.815
RA	0.878	Y=0.0024X-0.0126	0.7724
RB	0.617	Y=0.0197X-0.272	0.3957
TR	0.443	Y=0.0092X+0.0138	0.2081

Where: Y is dependent variable, (runoff mm)

X is independent variable, (rainfall mm)

A higher regression coefficient in the K treatment implies that a unit increase in rainfall will cause more runoff from treatment K than in the other treatments. This is clearly shown in Fig. 4 where more runoff is observed in K than the other treatments for all rainfall events. This then emphasizes the adoption of rainwater harvesting so as to conserve the valuable water for optimum plant growth.

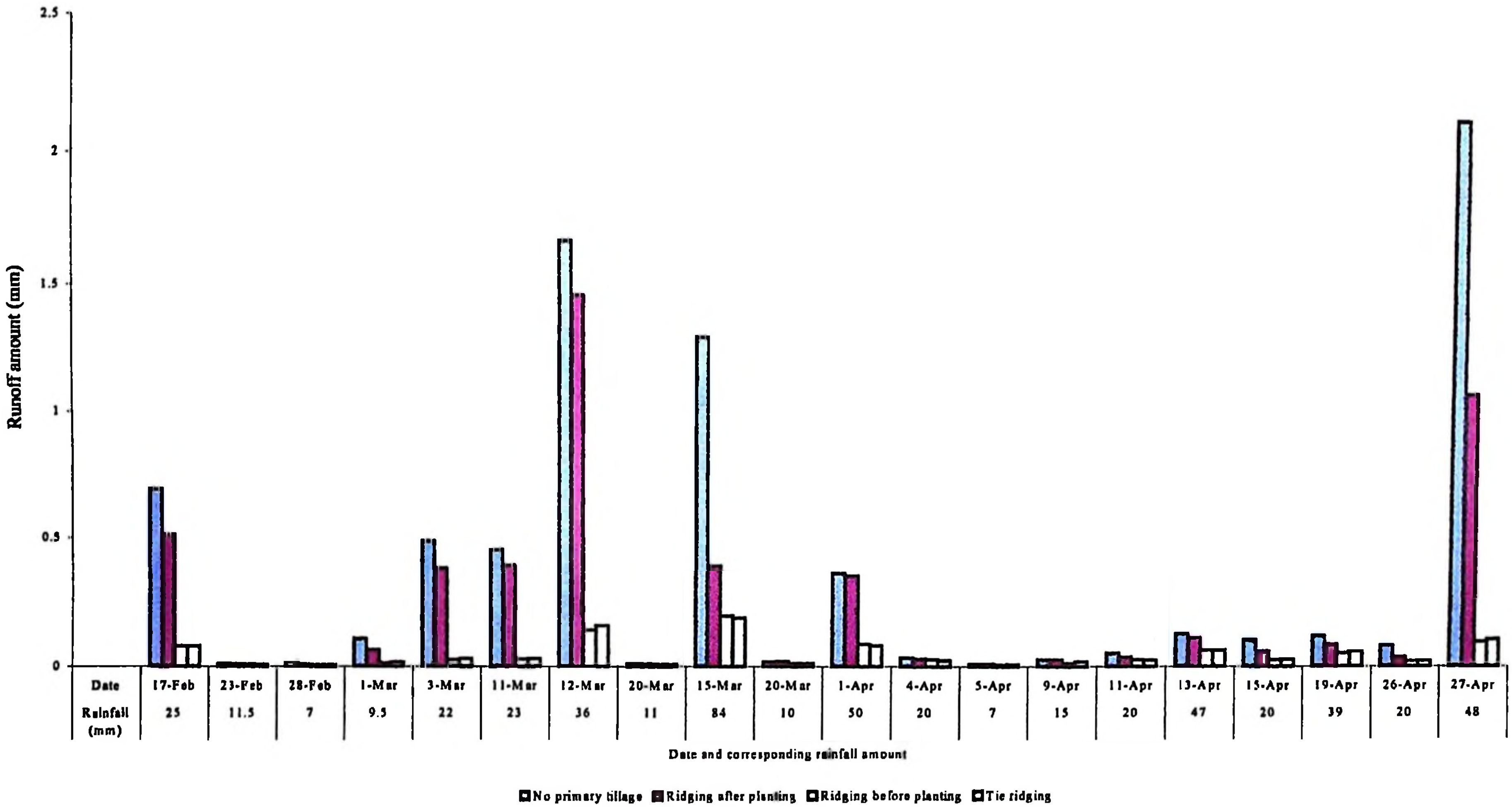

Figure 4: Variations in runoff collected at different dates and rainfall events

4.3 Soil Loss

The amount of soil lost from each treatment during the current study ranged from 9.2 Mg/ha in the K plots to 3.67 Mg/ha in the TR plots (Table 4).

Table 4: Effect of rainwater harvesting techniques on soil loss (Mg/ha)

Treatment	Soil loss (Mg/ha)	Percent reduction in soil loss
K	9.2[a]	
RA	5.6[b]	39
RB	4.2[b]	59
TR	3.6[b]	60
LSD	4.7	
s.e	6.8	
CV	37.9	

Values with the same letter in the same column are not significant different at P<0.05

Soil loss from RB, TR and RA did not differ significantly from each other but differed significantly ($p<0.05$) from K. The relatively high soil loss that occurred in RA treatment could be attributed to the high runoff loss in the beginning of the season where ridges were not yet made. Soil loss from K was significantly higher than that from RB and TR by about 2 fold. This proves that the ridges are very effective in protecting the soil from being eroded by retaining runoff water and providing prolonged time for water to infiltrate. The ridges also reduce the velocity of flow and retain suspended particles in their channels. The reduction in soil loss by RA was only 39 %, while RB and TR the reductions in soil loss were 59 and 60% respectively compared to the control. These findings underscore the importance of the ridges in conserving soil and hence increasing productivity of the soil. They indicate further more, that for effective soil loss reduction the ridges have to be tied and also be made before planting.

Simple correlation and regression analysis between soil loss and amount of runoff (Table 5) show that soil loss was positively and significantly correlated to runoff in all treatments ($p<0.05$). In treatment K about 99 % of variations in soil loss was attributed to variation in runoff loss. The regression coefficient was closely related to that of runoff against rainfall and this indicates that there is a similar trend between soil loss and rainfall. This further indicates that higher runoff loss caused higher soil loss. The amount of soil loss obtained in the current study did not differ much from values obtained by Gebremedhin, (1996) which were 12.49 Mg/ha for flat cultivation and 2.48 Mg/ha for ridge cultivation at a site near present site, and those obtained by Bazugba (2001), namely 1.6 Mg/ha for ridge cultivation and 10.9 Mg/ha for flat cultivation in the site used during the current study.

Table 5: Correlation coefficient and linear regression equations relating soil loss to run off

Treatment	Correlation coefficients	Regression equation	R^2
K	0.998	Y=4793.98X+57.14	0.992
RA	0.9412	Y=4773.467X+24.46	0.880
RB	0.893	Y=2671.761X+0.33	0.795
TR	0.880	Y=1717.70X+0.50	0.772

WhereY= Dependent variable, soil loss (Mg/ha)

X= Independent variable, runoff (mm)

4.4 Soil Moisture Content

The variation in soil moisture content with time and rainfall is shown in Figs 5a to 6b. The results show that there were high variations in soil moisture content in treatment K than in the other treatments. For the depth of 0-15 cm, at the beginning of the season nearly all treatments had the same moisture content; the difference between treatments was not noticeable. This could be attributed to the fact that at the onset of rains the soils were very dry and the first rains were not enough to make any storage in any of the treatments and hence differentiate the treatments. From week 5 to 8 there was a big difference in moisture content between the treatments. Treatment K recorded very low moisture content as compared to the other treatments. This is likely due to the fact that this is the period when the first dry spell was experienced and the higher moisture content in the other treatments was due to the moisture stored in the ridges. In the rest of the growing period treatment K had lower moisture content than the other treatments.

At 15-30 cm depth, at the beginning of the season, no noticeable difference in moisture content between the treatments was observed. This could be attributed to the fact that at the onset of rainfall the soils were very dry and the first rains were not enough to make any storage in any of the treatments. From week three a great difference in moisture content at this depth was observed. Treatment K had lower moisture content than the other treatments. This shows that less water reached this depth in this treatment. This could be attributed to the fact that much water was lost as runoff and much of the little water that infiltrated was retained in the upper part of the soil. Throughout the season, treatment TR had higher moisture content in the 15-30 cm depth than all other treatments followed by RB, RA and K ranked the lowest.

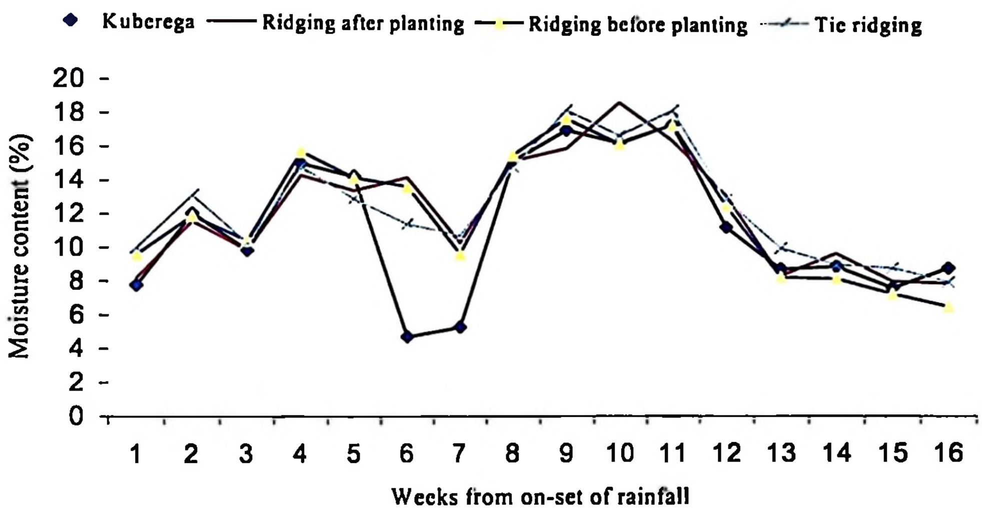

Figure 5a: Moisture variations with rainfall from onset of rainfall at 0-15 cm depth

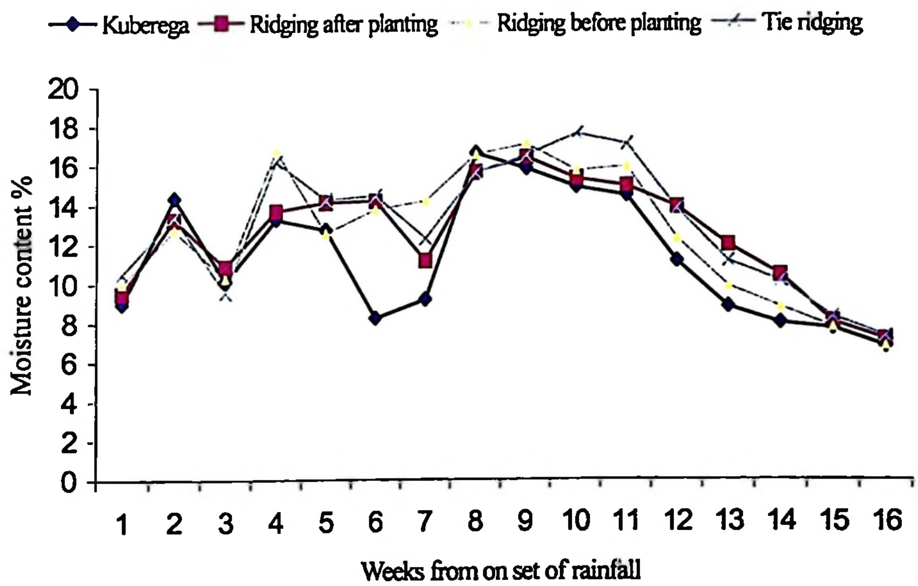

Figure 5b: Moisture variation with rainfall from onset of rainfall at 15-30 cm depth.

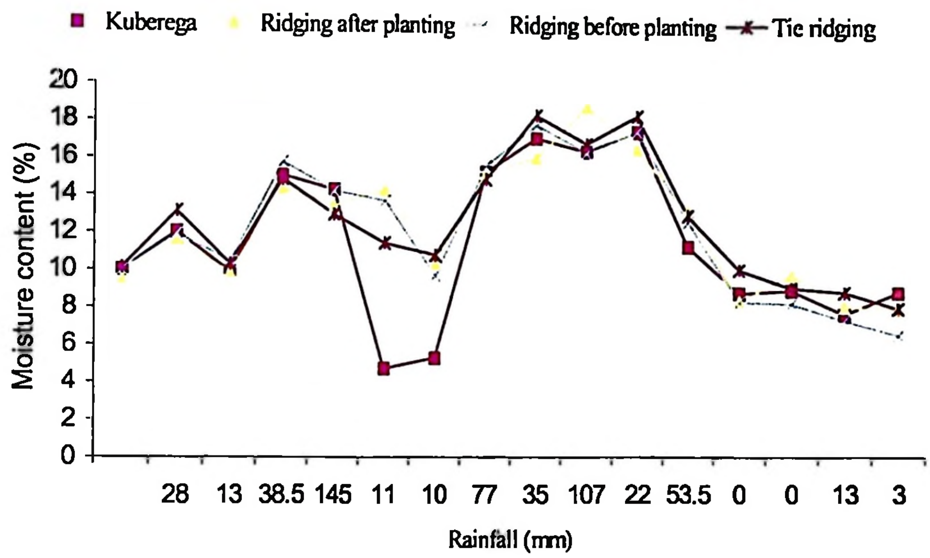

Figure 6a: Soil moisture variation with rainfall and treatments in the 0-15 cm depth

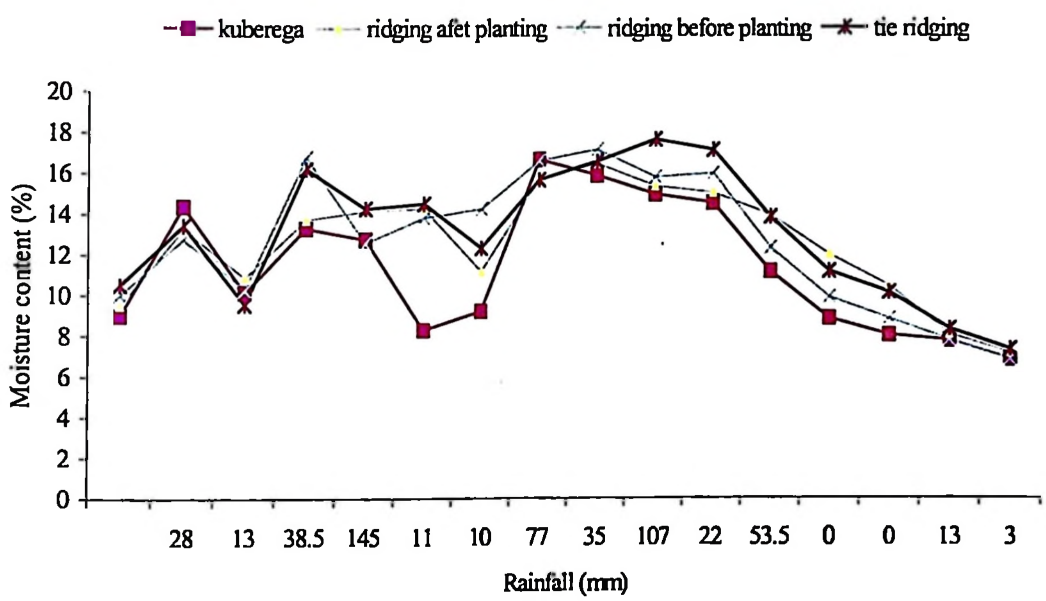

Figure 6b: Soil moisture variation with rainfall and treatment in the 15- 30 cm depth

Generally, there was high moisture variation in the 0-15 cm depth than in the 15-30 cm depth and this could be attributed to the fact that the surface soil is more subjected to evaporation loss than the deeper layers (Hillel, 1971). As the sampling was done from the top of the ridge the water that ponded in furrow was likely percolating within the 15-30 cm soil layer. The results then show that tie ridging is superior in moisture conservation as compared to RB, RA and much more superior than K. These results are in agreement with those reported by Hulugalle, (1990), in which, profile water content for tie ridging was greater than that in open ridges and flat planting. This then suggests that during dry spells crops grown on ridges can subsist on the stored soil water, whereas those grown on flat soil suffer from drought. As it can be summarized from Figures 4a and b to 5 a and b the dry spells in weeks 5, 6 and 7 were mitigated by the stored soil water in treatments RA, RB and TR. The relationship between moisture content and rainfall as depicted in Fig. 5a and b reveals that the profile water content varies in response to rainfall amount. The variation is higher in the topsoil than in the deeper profile. Presumably this is because the soil physical properties in the subsoil are more homogeneous.

The regression and correlation analysis between profile moisture content and rainfall shows that there is a positive correlation between the two moisture and rainfall (Tables 6 a and b). However, the higher correlation coefficients in treatment K (0.692 and 0.584) for the 0-15 cm and 15-30 cm depths, respectively, indicates that higher percent of the variation in soil moisture is explained by rainfall variation. The lower coefficients for treatments RA, RB and TR show that there is less variation in moisture in response to rainfall variation. This is due to the stored water in the profile.

Table 6a: Correlation coefficient and linear regressions equation relating rainfall to profile moisture at a 0-15 cm depth

Treatment	Correlation coefficient	Regression equation	r^2
K	0.692**	Y=0.09X+11.01	0.477
RA	0.584*	Y=0.05X+10.5	0.331
RB	0.548*	Y=0.05X+10.2	0.300
TR	0.447*	Y=0.04X+11.2	0.211

WhereY= Dependent variable, profile moisture content (mm)

X= Independent variable, rainfall (mm)

*=Correlation is significant at 0.05 level (2-tail)

**=Correlation is significant at 0.01 level (2-tail)

Table 6b: Correlation coefficient and linear regression equations relating rainfall to profile moisture at a 15-30 cm depth

Treatment	Correlation coefficient	Regression equation	r^2
K	0.584*	Y=0.043X+11.5	0.34
RA	0.544*	Y=0.035X+11.4	0.296
RB	0.524*	Y=0.044X+11.2	0.275
TR	0.432	Y=0.035X+11.22	0.187

WhereY= Dependent variable, profile moisture content (mm)

X= Independent variable, rainfall (mm)

*=Correlation is significant at 0.05 level (2-tail)

4.5 Bulk Density

The bulk density recorded at the beginning, at the middle and at the end of the study for the different treatments is shown in Table 7. The results show that the bulk density from all plots at the beginning of the season that is before application of the treatments was not significantly different (P< 0.05). The results also show that the bulk density at 0-15 cm was less than that at 15-30 cm.

Table 7: Effect of the different rainwater harvesting technique on surface and subsurface bulk density

Treatment	Bulk density (Mg m^{-3})					
	Beginning of the season		Middle		Harvest	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 cm	15-30 cm
K	1.17^{a}	1.69^{a}	1.53^{a}	1.65^{a}	1.54^{a}	1.46^{a}
RA	1.48^{a}	1.58^{b}	1.44^{b}	1.59^{a}	1.44^{b}	1.62^{a}
RB	1.48^{a}	1.62^{b}	1.63^{b}	1.63^{a}	1.46^{b}	1.59^{a}
TR	1.48^{a}	1.53^{b}	1.43^{b}	1.54^{a}	1.48^{b}	1.50^{b}
Lsd	0.06	0.14	0.05	0.06	0.06	0.06
s.e.	0.02	0.03	0.02	0.02	0.02	0.02
CV	6.8	3.5	6.8	5.9	5.0	4.1

Values with the same letter in the same column have no significant difference (p<0.05)

At the middle of the growing season the bulk density differed significantly between the treatments (p<0.05). At a depth of 0-15 cm K had significantly higher bulk density (p<0.05) than other treatments. However, bulk density values for treatments RA, RB and TR were not significantly different at P< 0.05. At a depth of 15-30 cm the bulk density for all treatments was statistically the same (P< 0.05). This shows that the treatments have no effect on the subsurface bulk density. This could be attributed to the fact that the ridges and ties were made by a hand hoe that did not go as deep as 30 cm. The higher bulk density in treatment K may also have affected the infiltration rate in this treatment and hence contributed to the higher runoff loss that was in the treatment. These findings agree with those reported by Gebremedhin (1996) and Bazugba (2000). Both reported higher bulk densities for flat cultivation than ridging and higher bulk densities for subsoil than topsoil.

4.6 Infiltration

The infiltration rates recorded at the beginning, at the middle and at end of the study for the different treatments are shown in Table 8. The results show that the average infiltration rates for the plots before application of the treatment was not significantly different ($p<0.05$). After application of the treatments the on ridge infiltration rate for treatments RA, RB and TR was significantly higher ($p<0.05$) than that of K. This could be attributed to the lower bulk density. The between row infiltration also showed significant difference between the treatments. Treatment K had significantly higher ($p<0.05$) infiltration rate than that of the ridge systems the order was K > RA > RB = TR. This is probably due to the fact that during ridging the top soil between the ridge was moved to the top of the ridge leaving the subsoil which is comparatively more compact and hence with low infiltration. These findings are in agreement with those reported by Hulugale and Rodrigueze (1988). The low infiltration rate in furrows for the ridge treatments is not problematic because water is retained within the ridges by the ties and eventually infiltrates into the soil. This result shows that the ridge treatment has an effect on infiltration and water management. The portion of rain that falls on the ridge infiltrates quickly and the portion that falls on the furrow is retained on site and infiltrates slowly.

Table 8: Effect of *in-situ* rainwater harvesting technique on infiltration

Treatment	Infiltration rate (cm/h)						
	Before treatment	Early season		Middle of season		At harvest	
		On ridge/ Within Row	In furrow/ Between row	On ridge/ Within Row	In furrow/ Between Row	On ridge/ Within Row	In furrow / Between Row
K	6.0	5.6d	5.53b	6.0c	6.0a	6.0c	6.0a
RA	6.1	10.8c	10.8a	16.8b	5.0b	15.93b	5.0b
RB	6.0	18.2b	5.0c	17.8ab	5.3ab	17.0ab	5.0b
TR	6.2	20.1a	4.6d	18.8a	5.2b	17.3a	4.8b
LSD	-	0.17	0.26	1.246	0.7	10.1	0.67
s.e..	-	0.48	0.075	0.36	0.2	0.32	0.19
CV	-	4.22	6.0	10.6	9.7	6.8	16.2

Values with same letter in the same column have no significant difference ($p<0.05$)

4.7 Percentage emergence

The emergence percent results are shown in Table 9. High emergence percent was in RA (85) followed by RB (82.5), TR (75) and K was the least with only 66.3 %. The ridge treatments were not significantly different from each other ($p<0.05$) in terms of emergence percent. However, ridging after planting had comparatively the best emergence compared to the other ridge treatments. Probably this was due to the fact that seeds were sown at a depth of 5 cm and on top of the ridges. At this depth and position the soil dries up quickly for RB and TR compared to RA.

Table 9: The effect of RWH technique on maize seed emegernce

Treatment	Emergence Percent
K	66.3^{b}
RA	85.0^{a}
RB	82.7^{ab}
TR	75.0^{ab}
Se	4.707
lsd	16.29
CV	10.55

Values with same letter in the same column are not significantly different ($p<0.05$)

4.8 Plant Height

The effect of the rainwater harvesting techniques on plant height at different maize growth stages is shown in Table 10 and Figure 6. Maize plant heights measured three weeks after planting had no significant difference ($P< 0.05$). The difference showed up six weeks after planting where RB and TR had slightly but significantly taller plants than those in K ($P< 0.05$). The RA and K treatments did not differ significantly in plant height ($P< 0.05$). At tusselling plants were shorter for K and RA as compared to RB and TR treatments. The effect of *in-situ* rainwater harvesting technique on maize plant height was significant ($P< 0.05$). This may be attributed to a slower growth rate for maize in treatments K and RA early in the season because these two treatments lost a significant amount of water as runoff. The maize plant roots would also have been impeded by the compact soils in K and RA compared to RB and TR treatments. Plate 4 depicts maize plants at seven weeks after planting. At this time, differences in plant height were not visibly noticeable. Figure 7 presents a graphical version of the effect of rainwater harvesting system on plant heights.

Table 10: Effect of *in-situ* rainwater harvesting techniques on maize plant height

Treatment	Growth stage			
	3weeks	6 weeks	Tusselling	Grain filling
K	40.63a	105.5b	152.5b	261.6b
RA	42.60a	110.4ab	164.1b	263.5b
RB	43.47a	115.5a	178.6a	274.0a
TR	44.67a	155.6a	179.2a	275.0a
Se	4.197	1.452	3.739	1.39
Lsd	14.52	4.024	11.739	7.44
CV	16.97	2.25	0.05	2.15

Values with same letter in the same column are not significantly different at $P<0.05$

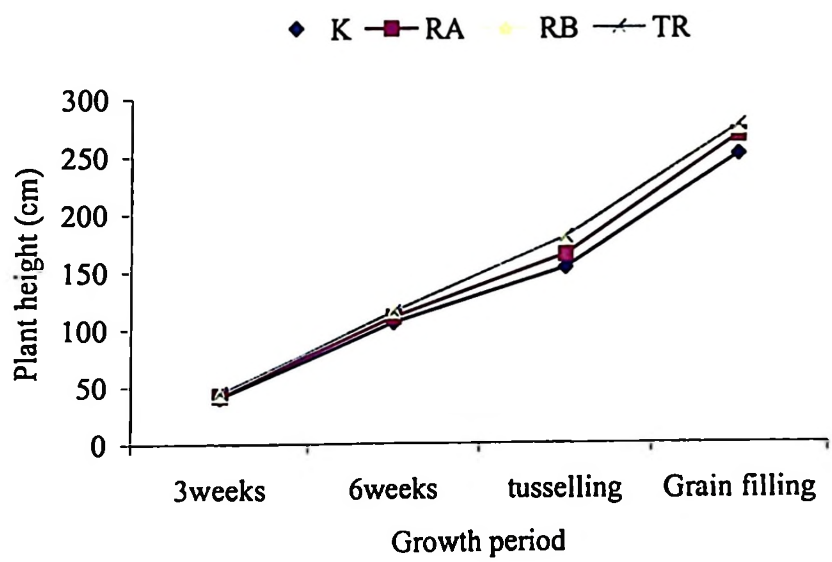

Figure 7: Variation of plant height with time and rainwater harvesting techniques

Plate 1: Field observation on plant height showing no significant variation

4.9 Yield

4.9.1 Grain yield

The effect of *in-situ* rainwater harvesting techniques on maize grain yield is shown in Table 11. The effect of the treatment on grain yield was significant ($P < 0.05$). Yield was least for treatment K, (2.97 Mg/ha and highest in RB (3.79 Mg/ha. The grain yield from the treatments was in the order: RB ≥ TR ≥ RA ≥ K. The percentage yield increase over the control was 31, 26, and 22 for RB, TR and RA treatments, respectively (Table 11). The low grain yield in treatment K may be attributed to higher water loss by runoff, low profile moisture content, and high un-bridged moisture stress during dry spell as compared to other treatments. This indicates the superiority of the *in-situ* rainwater harvesting in improving maize grain yield as compared to the control. These results agree with other reporters, e.g. IITA

(1981), the Ministry of Agriculture Botswana (1984), Perrier (1987), Rodriguez (1987) and Hullugale (1988b, c, d), who compared the beneficial effects of ridge cropping systems on soil water conservation and grain and dry matter yield of maize, sorghum and millet. The higher yield in RB as compared to TR is contrary to results by Mitchel (1987), Ali and Prasad (1974) and Macartney *et al.* (1971) who reported that tied ridges had beneficial effect over open ridges. However, the results by IITA (1981), Hullugale (1988d) and those reported by Ministry of Agriculture Botswana (1984) indicated that tied ridges had no beneficial effect on yield. This proves Lal's (1995) observation that there is a contradiction regarding the beneficial effect of tie ridging system on maize grain yield.

Table 11: The effect of RWH technique on maize yield and other growth components.

Treatment	Yield and growth components						
	Grain (Mg/ha)	Biomass (Mg/ha)	Stover (Mg/ha)	100 seed weight(g)	Seed / cob	Emergence (percent)	Grain Increase percent
K	2.97^{c}	13.86^{d}	1.08^{b}	25^{c}	417^{b}	66.3^{b}	
RA	3.61^{cb}	16.38^{c}	1.52^{ab}	27^{bc}	442^{b}	85.0^{a}	22
RB	3.89^{a}	18.23^{a}	2.23^{a}	33^{a}	510^{a}	82.7^{ab}	31
TR	3.75^{ab}	17.20^{b}	2.11^{a}	31^{ab}	476^{ab}	75.0^{ab}	26
Se	0.67	2.08	25.35	4.97	18.57	4.707	
lsd	0.16	0.68	0.88	1.43	67.5	16.29	
CV	9.6	0.20	0.25	8.53	6.97	10.55	

Values with the same letter in the same column are not significant different at $P<0.05$

Comparing treatment K and RA the yield in RA was slightly higher than that of K. This may be attributed to the moisture stored in RA during the dry spells most of which appeared after the earthing up in RA. The yield results, however, do not follow the trend of total runoff loss in which K and RA had nearly the same amount of runoff loss. This result agrees with the result by IITA (1981) that reported less yield in flat cultivation than in earthing up at 30 days after planting.

4.9.2 Total aboveground biomass and dry matter yield

The total above ground biomass at harvest ranged between 13.4 Mg/ha and 18.2 Mg/ha for K and RB treatments respectively (Table 11). The significantly higher biomass ($p<0.05$) in RA, RB and TR treatments could be attributed to higher soil moisture conserved in these treatments as compared to treatment K. The lower biomass for treatment RA as compared to RB and TR could be attributed to higher water loss as runoff in this treatment before earthing up. The results then show that at the 5 % significance level the rainwater harvesting techniques have a significant effect on total biomass production of maize.

The effect of *in-situ* rainwater harvesting techniques on maize above ground dry matter yield (stover) is also shown in Table 11. Generally all plots with rainwater harvesting treatments had higher above ground biomass and stover yield than the control plots. The trend for above ground dry matter yield was $K \leq RA \leq TR = RB$.

4.9.3 Seed number per cob and cob size

The seed number per cob is shown in Table 11. In terms of seed number per cob RB had the highest number of seed per cob (510) followed by TR (476), RA (442) and K had the lowest with only 417 seeds per cob. This trend is like that of cob size where treatment K had significantly ($p<0.05$) the smallest cobs size (Plate 5). Treatment K and RA did not differ significantly form each other. The higher number of seeds per cob in the TR and RB treatments probably contributed to the higher grain yield in treatments TR and RB and the lower number of seeds per cob in treatment K also contributed to the lower yield in treatment K.

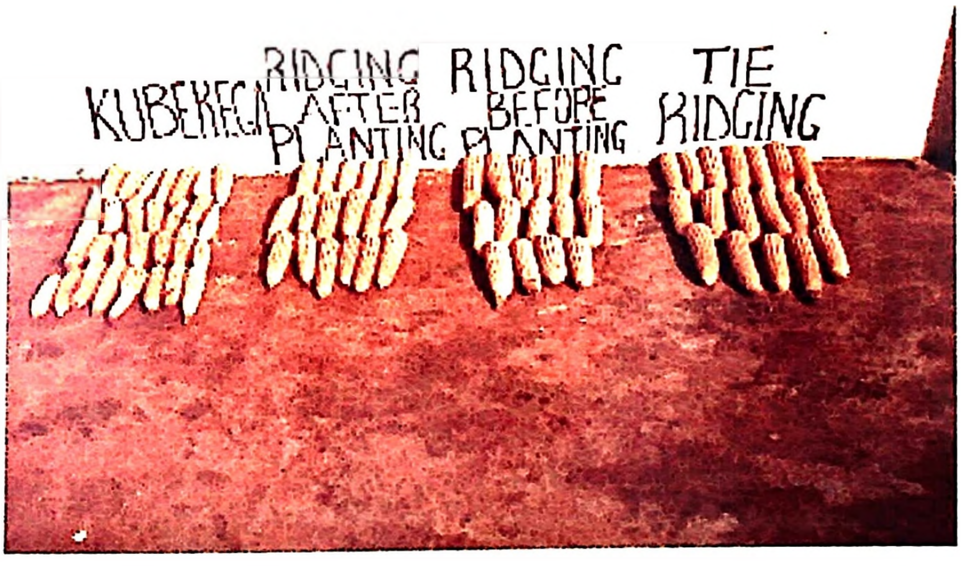

Plate 5 :Variation in cob size for the different treatments

4.9.5 Seed weight

The results show that there was a significant difference ($p<0.05$) in seed weight among the treatments. Treatment RB had the heaviest seeds compared to the other treatments while treatment K had the lightest (Table 11). The order was RB ≥TR ≥ RA ≥K. This result could be attributed to the moisture stress that appeared during grain filling that affected plants in K while the others capitalized on moisture stored in the root zone. This signifies the importance of the *in-situ* rainwater harvesting techniques in improving maize seed weight.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The experiment demonstrates that,

- The rainfall in the study area was inadequate and poorly distributed and with series of dry spells that caused moisture stress to the maize plant.
- The *in-situ* RWH techniques had significant effect on maize yield. Ridging before planting significantly increased maize yield as compared to no tillage practice ('Kuberega').
- In the ridge (*in-situ* rainwater harvesting) plots the moisture stress period during dry spells was bridged by moisture stored in the root zone of the plants. This maintained a favourable root environment until another rainfall event.
- There was a significant difference in runoff loss between the treatments. No tillage practice 'kuberega' had the greatest loss.
- When ridging after planting is used as a rainwater harvesting technique a big portion of water is lost as runoff at the beginning of the season before earthing up is done. This technique may not mitigate dry spells that appear early in the season.
- Apart from conserving water the ridges lowered the soil bulk density, reduced soil loss and improved on ridge infiltration.
- The *in-situ* rainwater harvesting techniques had no significant effect on maize plant height.

5.2 Recommendations

From this study the following recommendations can be made.

1. Ridging before planting and tie ridging should be used for *in-situ* rainwater harvesting in low rainfall areas.

2. Further research should be done on:-

   (i) The social economic aspect of the technique to give details on labour demand, overall output and adaptability of the technique.

   (ii) Other *in-situ* rainwater harvesting techniques like pitting so that the potential of these other technique is known and later be developed.

3. Similar studies should also be conducted in other dry parts of Tanzania to see if the results found here holds in those other areas.

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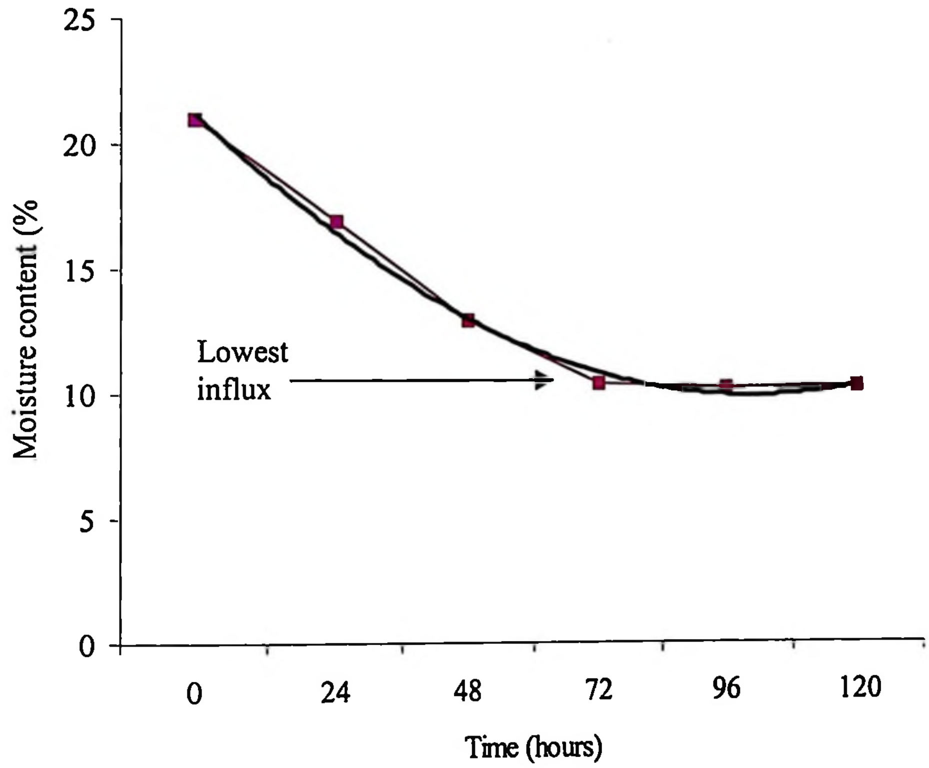
APPENDICES

Appendix 1 Rainfall received during the growing season.

Event number	Date	Rainfall (mm)
1	15/2/2002	1
2	16/2/2002	2
3	17/2/2002	25
4	23/2/002	0.5
5	28/2/2002	11.5
6	1/3/2002	9.5
7	2/3/2002	7
8	3/3/2002	22
9	11/3/2002	23
11	12/3/2002	36
12	14/3/2002	2
13	15/3/2002	84
14	20/3/2002	11
15	26/3/2002	10
16	1/4/2002	50
17	4/4/2002	20
18	5/4/2002	7
19	9/4/2002	15
20	11/4/2002	20
21	13/4/2002	47
22	14/4/2002	1
23	15/4/2002	20
24	19/4/2002	39
25	24/4/2002	2
26	26/4/2002	20
27	27/4/2002	48
28	28/4/2002	1.5
29	29/4/2002	1
30	30/4/2002	3
31	17/5/2002	4
32	19/5/2002	5
33	21/5/2002	4
34	26/5/2002	3
35	29/5/2002	7
	TOTAL	562

Appendix 2 A graph showing variation of soil moisture with time after saturation for determination of field capacity



Appendix 3.Soil properties at the experimental site.

	Particle size distribution (%)			Texture	pH in H_2O	%		Ext P ppm	CEC	Exchangeable Bases me/100g			
Treatment	sand	silt	clay		1:2.5	TN	OC		me/100g	Ca	Mg^{2+}	K^+	Na^+
K	71.6	1.8	26.6	Sand clay loam	6.77	0.08	1.09	1.64	17.93	7.58	1.67	0.38	23.02
RB	71.6	2.2	26.2	Sand clay loam	6.68	0.08	0.89	1.96	20.13	6.38	1.76	0.36	22.79
RA	72.1	2.5	25.4	Sand clay loam	6.4	0.08	1.13	2.74	19.23	5.55	1.85	0.36	23.53
TR	71.3	2.5	26.2	Sand clay loam	6.85	0.08	1.09	2.33	20.13	7.17	1.65	0.35	22.85

Key:

K = No primary tillage ('Kuberega')
RB= Ridging before planting
RA= Ridging after planting
TR= Tie ridging