INVESTIGATION OF THE POTENTIAL OF CONSERVATION TILLAGE PRACTICES ON SOIL EROSION CONTROL ON THE SLOPES OF THE ULUGURU MOUNTAIN RANGES

SILVESTER COSMAS FULGENCE KOMBA

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN IRRIGATION ENGINEERING AND MANAGEMENT OF SOKOINE UNIVERSITY OF AGRICULTURE MOROGORO, TANZANIA.

2015

ABSTRACT

This study was conducted in Kolero village in the Uluguru Mountain ranges to investigate the potential of conservation tillage on soil erosion control on steep slopes. Randomized complete block design was employed, zero and strip tillage conservation methods were practised versus the conventional shallow tillage in controlling soil erosion. The effect of using cover crops namely; lablab and cowpea were also investigated. The main crop was maize. The study area has an average slope of 56% and the soil is sand clay loam for the top arable soil which has erodibility ranging from 0.012 to 0.019 t-ha-h/ha-MJ-mm. The area has annual rainfall of 1936.5 mm and rainfall erosivity of 8676.5 MJ mm/ha-h-yr. For every rainstorm, runoff and soil loss generated were measured. The multidivisor system was set to collect one eighth of the runoff into the drum. The crop management factor (C), was determined throughout the season. Conservation tillage treatments had small C values as compared to conventional tillage treatments hence reduction in soil losses. Soil loss for shallow tillage treatments without cover crops on contrast registered the least soil loss of 91.8t/ha as compared to zero and strip tillage which registered 159.3 and 118.3t/ha, respectively. Soil loss for strip tillage with cowpea produced the least soil loss of 53.5 t/ha and zero tillage with lablab gave the highest soil loss of 227.3 t/ha. Predicted long term soil losses under same runoff plots conditions show high values' ranging from 99.67 to 623.77 t/ha/yr. Indicating that the Uluguru Mountains are highly prone to severe soil erosion. Hence there is a need for the conservation tillage practices to be supported by mechanical measures. Introducing improved ladder (reverse slope narrow bench) terrace can reduce soil

loss to a great extent (*i.e.* 0.9 to 5 t/ha-yr) from typical field plots found on steep slopes of the Uluguru Mountains.

DECLARATION

I, **Silvester Cosmas Fulgence Komba**, do hereby declare to the Senate of Sokoine University of Agriculture, Morogoro, Tanzania, that this dissertation is my own original work, and that it has never been submitted nor concurrently being submitted for a degree award in any other University.

____________________________ _____________________

Silvester Cosmas Fulgence Komba **Date**

(MSc. Candidate)

The declaration is confirmed by:

____________________________ _____________________

Prof. M.K. Mulengera **Date**

(Supervisor)

____________________________ _____________________

Dr. B.A. Salim **Date**

(Supervisor)

____________________________ _____________________

Prof. A.K.P.R. Tarimo

(Supervisor) **Date**

COPYRIGHT

ACKNOWLEDGEMENTS

The completion of this study would not have been possible without the considerable support from a number of individuals. Primarily, I would like to extend my sincere thanks to my supervisors Prof. M.K. Mulengera, Dr. B.A. Salim and Prof. A.K.P. R. Tarimo for their dedicated assistance during field work and dissertation writing. My supervisors were carefully, critically and tirelessly reading my drafts by giving constructive suggestions and technical guidance during the entire process of this dissertation work. I express sincere gratitude to the Principal Investigator of the Rockefeller Foundation Project Dr. B.A. Salim for allowing me to take part in their project "Enhancing smallholder farmers' resilience and adaptive capacity to climate change through the sustainable (climate smart) agriculture approach in the South Uluguru Mountains" and for guiding me technically whenever it was necessary. I greatly appreciate the support rendered to me by the project.

I am indebted to the Ministry of Agriculture, Food Security and Cooperatives for its generous sponsorship to my studies. I would also like to extend my gratitude to the Head of Department, academic and supporting staff of the Department of Agricultural Engineering and Land Planning for their cordial support during my study. The companionship of my only course mate Shida Lushinge, and a PhD student Ndabhemeye Mlengera meant a lot to me. Special thanks to my other MSc. colleagues at the Department namely Emmanuel Lwesha, Theodory Kahwili, Naomi Mcharo, Mohamed Mwabumba and Danford Nyenyema for their cooperation. I would also like also to thank the Kolero villagers, the local masonry artisans namely;

Hamis Sadick, Festo Kilongole, Jackson Mande, Aboubakar Chinga, Kahewanga, Reuben and Lazaro John for the work and collaboration during my stay at Kolero. I sincerely thank my wife Sophia for being ready to endure loneliness during my absence from home during the period of my studies. Her encouragement and wise handling of family matters in my absence were a working force behind my success. I also wish to express my heartfelt appreciation to my children Josephine, Fulgence and Opportuna for their prayers and great patience during my extended absence from the family. It is not easy to mention all individuals who contributed to the success of this work. As a matter of representation, those mentioned individuals will stand as a tower for all people who have been generous and ambitious to see this study a success. To all of you I say thank you very much. All in all, I would like to thank the Almighty God in the name of our Lord Jesus Christ for giving me the strength and good health throughout the study period to completion of this research work.

DEDICATION

This work is dedicated to my late parents COSMAS KOMBA PUSSA and OPPORTUNA KOMBA who laid the foundation of my education**.** .

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

a.s.l	Above sea level
Al	Aluminium
ANOVA	Analysis of Variance
CA	Conservation Agriculture
CARE	Cooperative for Assistance and Relief Everywhere
CC	Canopy Cover
CCT	Maize Crop Canopy Cover in Treatment
CoT	Crop cover in treatment
CT	Conservation tillage
CV	Coefficient of Variation
DAELP	Department of Agricultural Engineering and Land Planning
DAS	Days after sowing maize
DMRT	Duncan's Multiple Range Test
ESA	East and Southern Africa
FAO	Food and Agriculture Organization
Fpr	F Probability
ha	Hectare
I	Rainfall intensity
IAHS	International Agriculture and Hydrology Society
ISRIC	International Soil Reference and Information Centre
ISSS	International Society of Soil Science
Ke	Kinetic energy
kg	Kilogram

LSD	Least Square Difference
MAFC	Ministry of Agriculture, Food Security and Cooperatives
MICCA	Mitigation of Climate Change in Africa
NASCO	National Agriculture Scientific Conference
RCBD	Randomized Complete Block Design
REP	Replication
RNM	Monthly runoff
Se	Mean error square
SCS	Soil Conservation Society
SUA	Sokoine University of Agriculture
RUSLE	Revised Universal Soil Loss Equation
SWC	Soil and Water Conservation
TotRN	Seasonal total runoff
ToSL	Seasonal total soil loss
URT	United Republic of Tanzania
USA	United States of America
USDA	United States Department of Agriculture
USLE	Universal Soil Loss Equation
UM	Uluguru Mountains

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Conservation tillage (CT) is but one aspect of global, regional and national interest and importance in environmental conservation. Major goals of conservation tillage are improved maintenance of surface residue for erosion control and efficient water conservation. Efforts have been advocated worldwide to promote CT for controlling soil erosion and increasing agricultural productivity. The practices which are included in CT include zero tillage, mulch tillage, strip or zonal tillage, ridge till and reduced or minimum tillage.

Approximately 47% of agricultural land under the zero tillage technology is practiced in South America, 39% is practiced in the United States and Canada, 9% in Australia and about 3.9% in the rest of the world, including Europe, Africa and Asia. There is a big potential to bring this soil conserving technology to Africa, Asia and Europe (Dumanski *et al.*, 2006). CT emerged in the 1970s mostly in the USA and became an acceptable practice in the USA, Brazil, Argentina, Canada and Australia mainly because of its ability to combat increased soil erosion and land degradation (Dumanski *et al.*, 2006). Conservation tillage is being promoted as a potential solution to the production problems faced by smallholder farming families in sub-Saharan Africa (Hobbs, 2008). For East and Southern Africa (ESA), CT is very important as it touches directly on agricultural production and more so, in the majority semi-arid and arid tropics, which carry over 50% of the population of Africa

(Kaumbuto *et al*., 1999). Conservation tillage controls the loss of soil, hence it is important to know the effect of soil erosion in the Uluguru Mountains and how conservation tillage will help to address the problem of soil erosion in the area. Several studies on soil erosion and its magnitude in the Uluguru Mountains have been conducted (Kingamkono *et al.*, 2005; Kimaro *et al.*, 2008).

1.2 Justification

Uluguru Mountains (Plate1) are part of the Eastern Arc Mountains and are occupied by relatively high population density. This leads to intensive agricultural activities on these steep slopes making them vulnerable to soil erosion. The effect of conservation tillage on slopes above 50 % needs to be studied because Uluguru Mountains have such slopes with intensive agricultural activities. In addressing this problem this research aims to study the effect of zero till and strip digging in controlling soil erosion in such slopes. The study will also investigate the impact of incorporating covers crops with conservation tillage methods in reducing soil erosion on steep slopes and increasing productivity.

CARE Tanzania (Mvena and Kilima, 2009) has recently introduced interventions of reduced tillage and use of cover crops as conservation measure to this area. However, little is known on the potential of conservation measures (CT and cover crops) in such steep slopes, and thus the need of the study.

Plate 1: Agricultural activities on the steep slopes of the Mountains

1.3 Objectives

1.3.1 Overall objective

The overall objective of this study is to investigate the potential of conservation tillage practises in controlling soil erosion on steep slopes of the Uluguru Mountains.

1.3.2 Specific objectives

The specific objectives include to:

i. Evaluate the extent of soil erosion control achieved through zero tillage and strip digging on steep slopes.

ii. Evaluate the impact of incorporating cover crops in the conservation tillage practices for enhanced soil erosion control on the steep slopes.

iii. Advise the farmers on conservation tillage on steep slopes.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Background on Soil Erosion

Soil erosion is a process of detachment and transport of soil particles by water (raindrops and flowing water) and wind. Soil erosion that takes place without the influence of man is known as normal, geological or natural erosion. The geological soil erosion is always taking place, is slow and is not harmful as the soil is usually regenerated by natural means at the same rate as it is removed (Lal, 1990a). Soil erosion influenced by man is rapid and higher than the rate of soil formation. This rapid or accelerated soil erosion is generally what the term soil erosion means (Mulengera, 2011). The accelerated soil erosion is caused by disturbance in the land – vegetation- climate equilibrium by human activities. The human activities causing soil erosion include bad farming practices, deforestation / vegetation clearance, cultivation of marginal lands, overgrazing and construction works. Once these activities have disturbed the balance, the climatic erosivity determined by rainfall and / or wind characteristics acts on the soil, causing soil detachment and transport, the magnitudes of which are determined by soil properties and slope (Lal, 1990a).

Soil erosion has increased throughout the 20th century (Angima *et al*., 2003), and is becoming an extremely serious environmental problem, if not a crisis (Morgan, 2005). The prevention of soil erosion, which means reducing the rate of soil loss to approximately that which would occur under natural conditions, relies on selecting appropriate strategies for soil conservation. Much effort has been put into understanding the processes of soil erosion and predicting soil loss (Morgan, 2005). Soil degradation due to the loss of soil fertility, as well as mismanagement and the accidental relief with high steep slope, coupled with irregular rainfall intensity and the rapid population growth for many African countries are of high importance to the study of global environmental awareness (Nkeshimana, 2008).

2.2 Factors Affecting Soil Erosion by Water

Six factors influence soil erosion caused by water, namely rainfall erosivity, soil erodibility, slope steepness, slope length, vegetation cover and tillage practice, and crop residue management.

2.2.1 Rainfall and rainfall erosivity

Rainfall erosivity is the potential power of rain to cause erosion through the double effect of rainfall splash detaching soil particles and the total amount of rainfall giving water to overland flow to transport detached soil particles (Stocking, 1988). Intensity, duration, mass, diameter and velocity of the raindrops contribute to the erosivity of rain (Morgan, 2005). The erosive power of rain is expressed in terms of kinetic energy or momentum. Drop size distribution which is useful in the calculations of the energy and momentum is difficult to measure (Hudson, 1985; Lal, 1990a). Empirical equations have been established relating intensity and kinetic energy or momentum following the difficulties observed. The kinetic energy equations developed by Wischimeier and Smith (1978), Kinnel (1981) and Brown and Foster (1987), shown in Eq.1, 2, and 3 respectively are more widely used than momentum equations.

$$Ke = 0.119 + 0.0873 \log_{10} I \quad \text{(1)}$$

$$Ke = 0.29233(1 - e^{-(0.0477I + 0.112)}) \quad \text{(2)}$$

$$Ke = 0.29(1 - 0.72e^{-0.05I}) \quad \text{(3)}$$

where;

Ke	=	kinetic energy (MJ/ha-mm)
I	=	Rainfall intensity (mm/hr)

Generally it is assumed that the amount of rainfall governs the amount of soil eroded. Rainfall amount governs the overall water balance and the relative proportions which turn into runoff. Statistically the correlation between rainfall and soil erosion is poor (Hudson, 1995), as sometime the same amount can result in different amounts of soil loss during different storm events. A wide range of rainfall erosivity parameters have been developed based on very strong correlation between the parameter used and soil erosion observed (Moore, 1979).

2.2.2 Soil erodibility

Susceptibility of soil to erosion differs with soil properties. Important soil properties affecting its susceptibility to erosion include texture, structure, water transmission and retention properties and the internal forces within soil mass (shear and compressive forces). Soil erodibility varies with time. Some of the soil properties affecting erodibility are dynamic and temporal (e.g. water content and structure) while others are inherent (mineralogy and texture) and others are induced by man (e.g. tillage operations). Reasonable soil erodibility value can be obtained after a long field experimentation taking into account the above variations (Lal, 1990a). Good estimates of soil erodibilty for tropical soils can be obtained using the following equations (Mulengera and Payton 1999):

$$K = 2.459 \times 10^{-5} Mn + 1.333 \times 10^{-4} \qquad (4)$$

$$K = 2.0114 \times 10^{-5} M - 0.00155 \qquad (5)$$

Where,

K	=	soil erodibilty (t – ha – h/ha – MJ –mm)
Mn	=	*Si (Si+Sa)*
Si	=	silt (0.002-0.05mm) (%)
Sa	=	sand (0.05-2.0mm) (%)
M	=	*a (a + b)* as defined by Wischimeier *et al*., (1971)
a	=	silt (0.002-0.05 mm) + very fine sand (0.05-0.1mm) (%)
b	=	coarse sand (0.1-2.0mm) (%)

2.2.3 Vegetation and cover

Vegetation protects the soil against crusting which would otherwise reduce its infiltration capacity. Vegetation cover protects soil from rain splash. Runoff and soil loss decreases with increased ground cover and canopy cover but increases with increased canopy height due to the fact that intercepted raindrops can regain substantial fall (terminal) velocity, coalesce and form larger drops than those falling through the canopy, or may reach the ground as stem flow thus contributing to runoff erosion (Dismeyer, 1982; Morgan, 1985; Stocking, 1988 cited by Mulengera, 2011).

The amount of organic matter added to soil from decaying plant parts improve soil structure, soil moisture holding capacity and infiltration rate, all of which result into reduced soil erosion. Growing and decayed roots and their associated chemical and biological activities increase soil porosity, which also results into increased water storage capacity, and infiltration capacity, and thus reduced soil erosion (Mgina, 2000).

Low levels of surface contact cover can have a dramatic effect in reducing sediment concentration in runoff; e.g., 10 % cover reduces sediment concentration to 30 %-50 % of that measured in bare plots, while for 30 % cover, sediment concentration is reduced by 90% (Rose *et al.*, 1997). These are consistent with the high degree of non-linearity commonly observed in such relationships when erosion is dominantly driven by overland flow (Rose *et al.*, 1997).

2.2.4 Topographic factor

The topographic factor (LS) combines the slope steepness (S) and slope length factors (L). The slope steepness, length and shape affect soil erosion because they affect rainfall splash and flow velocity, thus shear and transport capacity of runoff. Erosion increases with increase in the slope steepness and slope length (Liu *et al.*, 1999). The topographic factor (LS) can be calculated as (Liu *et al.*, 1999):

$$LS = \left(\frac{\lambda}{22.13}\right)^m \left(24.748(\sin\theta)^{1.2656}\right) \quad (6)$$

$$m = \frac{f}{1+f} \quad (7)$$

$$f = \frac{\sin\theta}{0.05 + 0.269(\sin\theta)^{0.8}} \quad \text{..........} (8)$$

where,

LS = Topographic factor (dimensionless)

λ = Field slope length

m = An exponent which vary from 0 to 1.0

θ = Slope steepness in degrees

2.2.5 Tillage and crop residue management

Research findings have shown that tillage which incorporates crop residues reduces erosion as the incorporated material offers more resistance to erosion forces and improves soil structure after decomposition (Chuma, 1993). Direction of ploughing in relation to land slope also influences soil erosion. Minimum tillage results in much more rough surface, which has more water storage capacity and reduced runoff, thus leading to less soil erosion.

2.3 Consequences of Soil Erosion

Population increase has made the cultivated land to increase six times since 1700 (Pimentel *et al*., 1995). By the year 2020 it is estimated that the world population will be about 7.7 billion of whom 84 % will be in the developing countries (Scherr, 1999). Thus, per capita cultivable land will decline from the 0.25 ha of the late 1980s to 0.15 ha by 2050 (Lal, 1993). Research concerning soil loss has been well documented in many countries across the world. In Thailand in areas with steep slopes of 20-80 % soil loss varies between 5 t/ha-yr and 90 t/ha-yr. In Bangladesh with shifting agriculture, soil loss varies from 11.5t/ha-yr to 41t/ha-yr. The average soil loss rate of 150t/ha-yr has been reported in China's Loes Plateau reaching a maximum of 390 t/ha-yr (Tangtham, 1991; Borggaard *et al.,* 2003; Chen and Luk, 1989). In Nepals soil erosion assessment show that annual soil loss rates are up to 56 t/ha-yr in the areas with rainfed cultivation (Shrestha, 1997). In Sub Saharan Africa soil erosion is considered to be one of the greatest environmental problems.

Soil erosion and land degradation are serious problems in Tanzania especially in the central semi-arid areas and steep slopes in the mountainous areas which are highly populated and cultivated like the Uluguru Mountains (Mulengera *et al.*, 2009). Human activities causing soil erosion include bad farming practices, deforestation or vegetation clearance, cultivation of marginal lands, overgrazing and construction works. Once these activities have disturbed the balance the climatic erosivity determined by rainfall or wind characteristics acts on the soil, causing soil detachment and transport, the magnitudes of which are determine by soil properties and slope (Lal, 1990b).

Soil erosion studies in Uluguru Mountains have been conducted in western part of the ranges, for example Kingamkono (2005) did a study in Mgeta area on the efficiency of ladder terraces as a soil and water conservation method in the mountains. The study showed that soil loss from non terraced plots is 3.85 times more than in terraced plots. The soil erosion and sediment yield at Mzinga river catchment in the Uluguru Mountains was studied (Mulengera *et al.*, 2009). Soil erosion measurements and sediment yield modelling were done to monitor land use practices that contribute to catchment degradation. The results showed high soil erosion losses on agricultural lands (33 t/ha) and low soil losses from fallow (4.8 t/ha) and degraded *miombo* woodlands (2.4 t/ha) (Mulengera *et al.*, 2009). Studies on the magnitude of soil erosion have been done on the northern part of Uluguru Mountains (Kimaro *et al.*, 2008). The results showed that interrill and rill erosion vary significantly between major geomorphic units. Higher erosion rates of 88 and 210 t/ha/year were observed in the mountain ridges compared to 49 and 116 t/ha/year in the mountain foothills (Kimaro *et al.*, 2008). In the southern slopes of the Uluguru Mountains e.g. Kolero ward in Morogoro district less effort has been done to study the magnitude of soil erosion and consequent loss in soil productivity. There are less efforts on the uses of conservation practises in Kolero ward (Mvena and Kilima, 2009). Most of the farmers of Kolero prepare the land by slash and burn which is not environmentally friendly. In addressing this CARE has recently introduced Conservation Tillage in the area although its effectiveness is not yet known.

2.4 Conservation Tillage

Conservation tillage (CT) is any tillage or planting system in which at least 30% of the soil surface is covered by plant residue after planting to reduce erosion by water (Mulengera, 2011). Zero tillage is the 'cornerstone' of CT which is the only tillage operation with low-disturbance seeding techniques for application of seeds directly into the remains of the previous crop after slashing (Dumanski *et al.*, 2006). Conservation tillage is a set of practices that leave crop residues on the surface. It increases water infiltration and reduces erosion. It is a practice used in conventional agriculture to reduce the effects of tillage on soil erosion. In other words conservation tillage uses some of the principles of conservation agriculture (Hobbs, 2008).

2.4.1 Effect of zero tillage

Conservation tillage in Yunnan, China showed reduction of soil erosion from erosion plots as it resulted in soil loss of 0.73 tha^{-1}, 3.04 tha^{-1}, 6.10 tha^{-1} under no-till treatment at different slopes 3^0 (5 %), 10^0 (18 %), and 27^0 (51 %) compared to soil loss of 0.83 tha^{-1} , 4.17 tha^{-1} and 7.50 tha^{-1} under conventional tillage. The grain yield also increased to 7.42 tha^{-1} under no till as compared to 7.13 tha^{-1} under conventional tillage (Barton *et al.*, 2004). Conservation measures greatly reduce soil losses and conserve surface runoff. If no conservation is practiced, the average annual soil loss from a 60% bare slope may reach 36.5 kg/m^2 (Wu, 1997).

2.4.2 Effect of strip tillage

With strip tillage, alternate bands of soil are tilled and cropped and kept bare, both under well controlled experimental conditions and in farmer's fields (Kaumbuto *et al.,* 2009). The field is divided into seedling zone and a soil management zone. The seedling zone about 5 to 15 centimetre wide is tilled to optimize seed germination. The area between the strips is left undisturbed and covered by the ground cover crop or mulch slowing down the runoff and capturing the soil particles washed from the tilled row (Woltering, 2005). The strip widths depend on the soil type and slope. In controlling the runoff as the velocity is slowed, the rate of the infiltration of the runoff is increased. In Zimbabwe tillage involving mouldboard plough is a factor causing erosion. In order to alleviate this problem, communal agriculture requires conservation tillage systems which reduce runoff, soil loss and draught power and are both practical and acceptable to the farmer (GTZ, 1992). The use of mouldboard ploughing, ripping into bare ground and no till tied ridging gave results that sheet erosion rates were in the order of 0.1 to 0.3t/ha/yr (GTZ, 1992).

2.4.3 Conservation tillage and soil loss

Results from Chuma (1993) who did experiment applying mulch ripping, no-till tied ridging and hand hoeing showed that total soil losses from no-till tied ridging and mulch ripping were lower than soil loss from the other treatments. Five years monitoring of conservation tillage on erosion and penetration resistance, organic carbon content, clay content in the upper root zone, structural stability, infiltration and soil strength showed that conservation tillage treatments had lower organic carbon reductions than conventional tillage and mulch ripping treatment. However, it also showed slightly better structural stability than conventional tillage. Hand hoe treatment showed high soil strengths which were likely to inhibit root penetration. The results also showed that minimal soil disturbance as by ripping operation combined with improved soil fertility and ground cover could contribute to improved erosion resistance (Kaumbuto *et al*., 1999). In Southern highlands of Tanzania, in addition to standard mechanical structures such as channel terraces conservation tillage systems are in use in Mbinga and Njombe with implements capable of retaining 70% crop residues on the surface after tillage operation (Ley,1990). Weed control is achieved with the use of herbicides such as round-up. Problems cited included lack of appropriate machinery, experience and grazing of stover by livestock. Traditional techniques locally developed in the southern highlands of

Tanzania and suitable for use on steep slopes include the Matengo pit or "Ngoro" (a series of pits 2.4 m long x 2.1 m wide x 0.14 – 0.30 m deep) and the "*Matuta*" (ridge) systems (vegetation slashed and aligned across the hillsides and buried with soil thrown down-slope (Temu and Bisanda, 1996). These techniques have shown immense benefits in terms of soil and moisture conservation for crops as well as fertility improvements (Kaumbuto *et al*., 1999).

2.4.4 Cover crops and erosion control

A cover crop is any crop grown to protect soil from erosion and to add the soil organic matter once it dies. Green mulches are mostly leguminous plants that cover the ground and are grown together with other crops (Sullivan, 2003; Gachene and Mwangi, 2006).

Legumes are also termed as green manure because of their ability to fix nitrogen in the soil. Cover crops can be annual, biennial or perennial plant species that serve varying purposes. These cover crops belong to legumes and grass families. Some of these include field peas, beans, white clover, red clover, buckwheat, alfalfa, oats, *etc* (Dick, 1982). Providing adequate soil cover is a cornerstone of conservation agriculture. Yet most farmers face great difficulties in achieving it. Cover crops protect the soil from splashing rains where they reduce rain drop impact leading to reduced surface run-offs. Runoff and soil loss decreases with increased ground cover and canopy cover but increases with increased canopy height due to the fact that intercepted rain drops can regain substantial terminal velocity, coalesce and form larger drops than those falling through the canopy (Stocking, 1988).

Increasing canopy cover decreases runoff and sediment losses (Kang *et al.*, 2001). This suggests that an effective way of conserving soil and water is to improve canopy cover and to reduce slope length by digging level ditches across a slope to intercept runoff and reduce erosion power. The runoff volume and sediment losses are both closely related to rainfall volume and maximum intensity (Kang *et al.*, 2001). Cover crops protect soil from excess solar radiation and reduce surface crusting and high fluctuation in soil temperature and moisture in semi-arid areas.

In Tanzania, farmers tend to collect residues or allow livestock herds to graze freely on crop residues. This may be an individual decision, or it may be the result of agreements and traditions regulating the relationships between farmers and pastoralists, such as with the Maasai in northern Tanzania (Shetto and Owenya, 2007). Producing enough biomass to cater for both adequate soil cover and livestock demands is a challenge.

Replacing legume used traditionally in intercropping (such as beans) by cover crop (such as canavalia or mucuna) might not be attractive to a farmer whose primary objective is achieving food security. This may explain the success that *Dolichos lablab* is having with Kenyan and Tanzanian farmers, as it is a multiple-purpose cover crop, able to provide food (both grain and leaves), income, forage and soil cover (Shetto and Owenya, 2007). With its vinyl habit, fast early growth, and ability to grow with little applied water, lablab can be effective to smother weed growth and quickly provide an effective ground cover to protect the soil from erosion (Valenzuela and Smith, 2002).

One of the best ways to reduce erosion is to protect the soil surface with a cover of growing plants or crop residue. Cover crops, particularly mucuna, lablab and pigeon pea, are managed by slashing them after harvest and leaving them to sprout and provide soil cover for another crop, usually maize. In some cases, the cover crop is left to dry after harvesting the beans. Increase in infiltration is directly related to a decrease in runoff (Shetto and Owenya, 2007). Cover crops were found to be effective, not only on gentle slopes but also on steep ones (Wu, 1997). They can greatly reduce soil losses and conserve surface runoff. If no conservation (use of cover crops) is practiced, the average annual soil loss from an average gradient of 60 % (31°) bare slope may reach 365 t/ha (Wu, 1997). Wu (1997) showed that soil loss rates in all fields decreased slowly as the crop canopy cover increased. The effect of the temporal variation of rainfall and cover crops provide ground cover for individual storms. Effectiveness of crop cover can be greatly increased if it is combined with good soil management practices. A unit increase of crop cover can bring greater reduction in soil loss if the soil is properly managed (Zegeye *et al.*, 2009). The role of crop cover is extensively studied in the literature. Cover reduces the direct impact of raindrops on the soil, it increases the flow depth, infiltration and surface roughness and it reduces the speed of runoff. Thus, cover reduces the amount of soil detached by flowing water and the capacity of water flow to transport sediment (Mureithi *et al.*, 2003).

2.5 Type of Crops Produced in the Uluguru Mountains

Agricultural production varies according to the altitude of the area. From the social interaction with the farmers in the area it is evident that the lower altitudes such as

Lubasazi and Bungu differ significantly in the type of crops grown as compared to the higher altitude areas such as Ukwama, Temekelo and Kasanga. The lower altitudes areas grow sorghum, maize, cassava, sesame, pigeon peas, cowpeas and paddy as major crops (Mvena and Kilima, 2009). However, as you go to the higher altitudes the crops change to those which withstand cold weather. The crops grown in such areas include beans, garden peas, cabbages, cardamom, yams, bananas, *etc*. The villages located between the high and low altitude areas are transitional areas producing crops from either the low lands or highland areas. Most crops grown are for home consumption rather than commercial. The production is primarily for domestic consumption with little surplus if any being sold. Few crops mainly cassava, sorghum, paddy, sesame, bananas and beans bear commercial value (Collbesa *et al*., 2010).

2.6 Current Degradation Status of the Uluguru Mountains

The loss of land potential is directly linked to low production and productivity. Soil erosion and deforestation are the major types of land degradation in the Uluguru Mountains (UM). The major causes of soil erosion, deforestation and destruction of water sources are inappropriate farming practices, bush fires, tree cutting for fuel wood and for making charcoal (Madulu and Chalamila, 2000). Soil erosion is a serious problem in these areas, especially when subjected to heavy rains. Inappropriate farming practices, lack of plant cover brought about by tree felling, clearing of marginal land for agricultural use and cultivation on steep slopes are the major cause of soil erosion (Collbesa *et al*., 2010). Continued use of fire as an agricultural practice in clearing of bushes for virgin farms have further led to the encroachment of desert-like features and reduction of plant cover exposing the top soil to variations in temperature which enhance the destruction of soil structure, increasing compaction, reduction in the population and species of soil organisms.

Exposure of the soil makes it vulnerable to erosion hence removing the upper layer of soil which is fertile and potentially productive. Very high amounts of soil loss 312 t/ha/yr were reported from the arable lands of Morogoro catchment in the Uluguru Mountains (Rapp *et al*., 1972). The exposure of land has increased the interrill and rill erosion processes in the area, rill erosion amounting to 58 % of the total soil loss (Kimaro *et al*., 2008). Uluguru Mountains inhabitants are approximately 151,000 people in 50 villages this human pressure causes rapid land use (Collbesa *et al*., 2010; URT, 2005), the changes include indiscriminate felling of trees for various uses like fire wood, timber and building poles collection (Buckley and Bhatia, 1998). Introduction of the cash crop simsim also has impact in deterioration of the land. Farmers uncontrollably clear land and set fire in order to get virgin land for the crop. Land and water resources have been deteriorated, this has led to increased soil erosion, increase in sediment load in rivers and loss of soil fertility. This has resulted into declination of crop yields, household incomes and any other hope of livelihood security. Potentially there is a change in climatic conditions in the area (Collbesa *et al*., 2010).

2.7 Conservation Practices in the Area

Low percentage of households in the Uluguru Mountain have been undertaking land improvement practices such as ridge making, contour making and terraces (Madulu and Chalamila, 2000). The traditional conservation techniques used by the Luguru's are "*sesa*", trash barriers and ladder terraces (Temple and Murray-Rust, 1972). These normal cultivation practices of this area are destructive of the soil (*i.e sesa* or cultivation of original slope without protective measures after the burning of trash). In overcoming the situation conservation measures need to be introduced to the Uluguru Mountains. Conservation tillage practices will minimize soil disturbance on the steep slopes of the UM. The practices include minimum tillage (strip digging and zero tillage), cover cropping (i.e. using leguminous crops), crop rotation and permanent organic cover.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 Study Area

3.1.1 Location

The study was conducted at Kolero village in the southern side of the Uluguru Mountains. The village is located at 37°48'E and 7°15'S and is about 120 km from Morogoro municipality (Figure 1). The Uluguru Mountains are part of a chain of mountains which are collectively called the Eastern Arc Mountains. The altitude of the study area ranges from 410 m to the highest peak, Mkumbaku, which is about 2634 m.a.s.l. and the general slope is 56 % (29.25°) (Mvena and Kilima, 2009).

3.1.2 Climate

Uluguru Mountains are generally cooler in the higher altitudes and warmer in the lower altitudes. The area has bimodal rainfall pattern receiving an estimated amount over 1,200 mm per annum (Lovett and Pocs, 1993; Chamshama *et al.*, 2006). The short rains ("*vul*i") occur between October and January while the long rains ("*masika*") start from February to June (Mvena and Kilima, 2009).

3.1.3 Geomorphology and soils

Uluguru Mountains are a horst block of Precambrian rocks. They are believed to have been uplifted as a block several times since the formation of the Karoo basins (Rapp *et al.*, 1972). The soils on the mountain ridges based to FAO system of soil classification (FAO,1998) are *Endoskelic* and *Leptic Cambisols*, the subsidiary soils to them are *Haplic* and *Chromic Phaeozems* and *Orthieuric Regosols*. The dominant soils on the foothills are *Chromic Lixisols* and *Profondic Acrisols* associated with *Hypeferralic Cambisols* and *Endoleptic Cambisols* (Kimaro *et al*., 1999; Kimaro *et al*., 2005). All the soils are thin and eroded. As a result shallow soils and emerging rocks are commonly found on steep slopes (Rapp *et al.*, 1972; Kimaro, 2003).

3.1.4 Vegetation and land use

The major types of land use are mainly agriculture and forest reserves. The vegetation type varies with altitude. The forests are covered with montane and sub-montane forests and occupy about 7% of the Uluguru Mountains land surface area. Lower altitude areas below 800 m.a.s.l. areas have sub-montane and coastal rain forest occurring on the southern slopes with rainfall estimated at over 1 200 mm per annum. The montane forests occur in areas above 800 m from sea level. The present agricultural land use in the study area includes smallholder rainfed and irrigated farming. There is a complex relationship between households and their fields. The farmers have a number of small farm units (*shamba's*) scattered in several places. The main crops grown in the area are maize, rice, cassava, millet, cowpea, pigeon pea, simsim, *etc* (Mvena and Kilima, 2009). The cropping systems include monocropping, intercropping and sequential cropping. Farmers intercrop various crops such as cassava and paddy, cassava/maize/pigeon pea, maize/paddy *etc*. Land preparation is normally done before the onset of the rains by clearing the land slash and burning ready for cultivation.

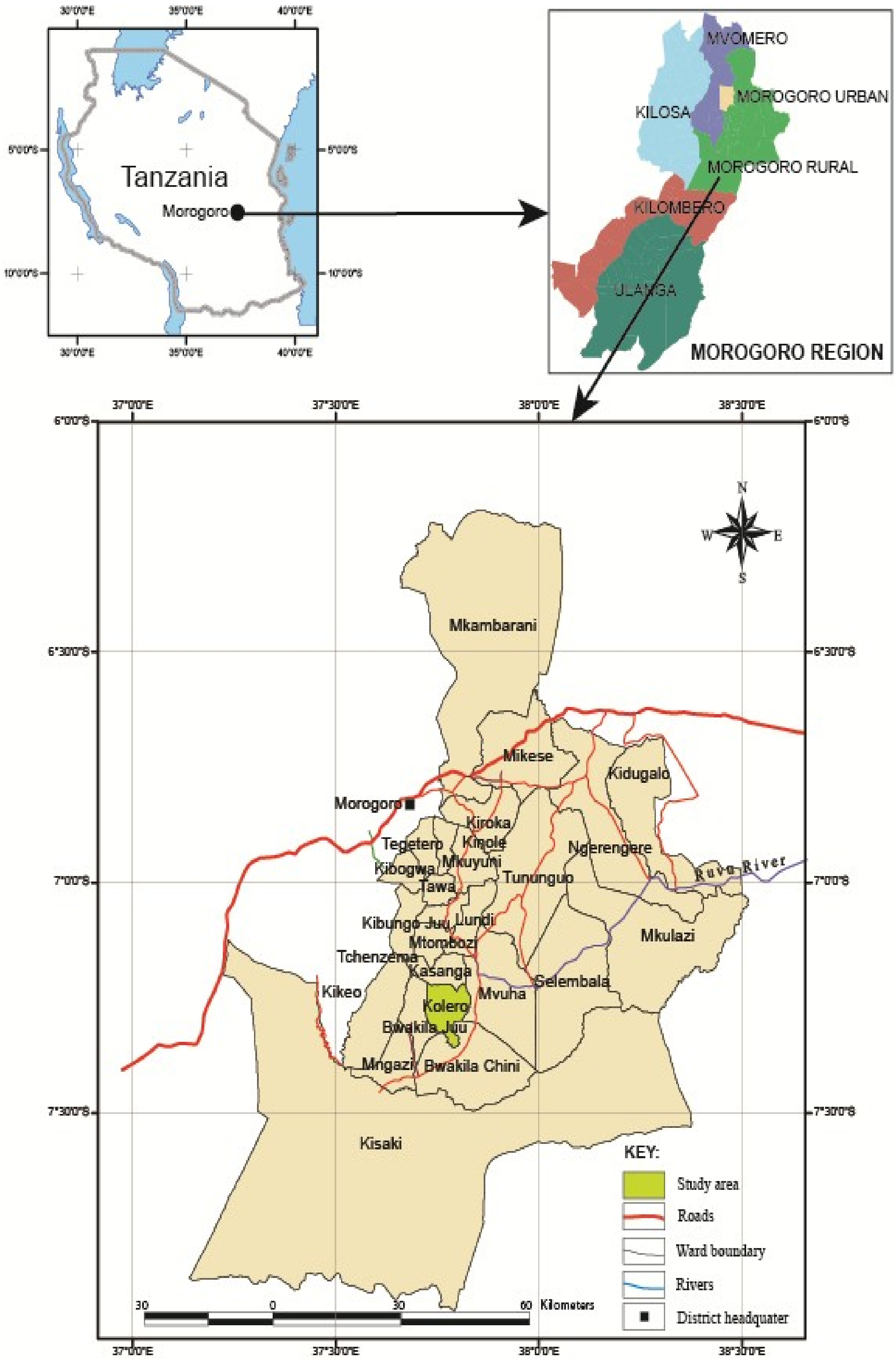


Figure 1: Location map of the study area

Source: Arc GIS Map

3.2 Experimental Set – up and Data Collection

The preparation of the experimental site was done from November 2012 to February 2013. This included the general cleaning of the site (i.e. slashing, removing of tree stumps and moving soil to fill troughs and small channels to have uniform slopes, installation of runoff plot boundaries and construction of sediment collection systems. The site was fallow for two years before the set up of the plots. The dimensions of the runoff plots were 10 m long and 1.8 m wide to ensure riling process and to minimize boundary effects (Lal, 1988). The plots were bounded by corrugated iron sheets, buried to a depth of 200 mm and protruding 100 mm above the ground to prevent water from outside the plots to enter into the plots. At down slope end of each plot, channel divisor system was constructed allowing 1/8th of runoff to be collected in cleaned 220 litres oil drum (Plate 2) (FAO, 2000).

Plate 2: Plot multi divisor system

3.2.1 Layout plans and treatments of runoff experimental plots

The experiment was laid as Randomized Complete Block Design (RCBD) with three replications, each consisting of 9 treatments (Table 1 and Figure 2). Distance between different runoff plots treatments was 0.5 m while distance between different replication blocks of runoff plots was 5 m.

Treatments in runoff plots involved three types of soil management or tillage methods i.e., the shallow tillage (farmer practice), strip tillage and zero tillage and use or no use of cover crops under maize cropping i.e. lablab or cow pea (Plate 3).

Table 1: Treatments in each replication of runoff plots

Treatment	Description
T1	Shallow tillage + maize
T2	Shallow tillage + maize + lablab
T3	Shallow tillage + maize +cowpea
T4	Zero till + maize
T5	Zero till + maize +lablab
T6	Zero till + maize +cowpea
T7	Strip tillage + maize
T8	Strip tillage + maize +lablab
T9	Strip tillage + maize +cowpea

Maize variety used was *Situka* composite. *Situka* is an early maturing maize variety grown in semi arid areas as it can tolerate moisture stress. It matures after 110 days and its yield is in the range of 4.0 – 6.0 t/ha (MAFC, 2009). Maize was planted on 6th March 2013 with spacing of 30 cm x 75 cm.

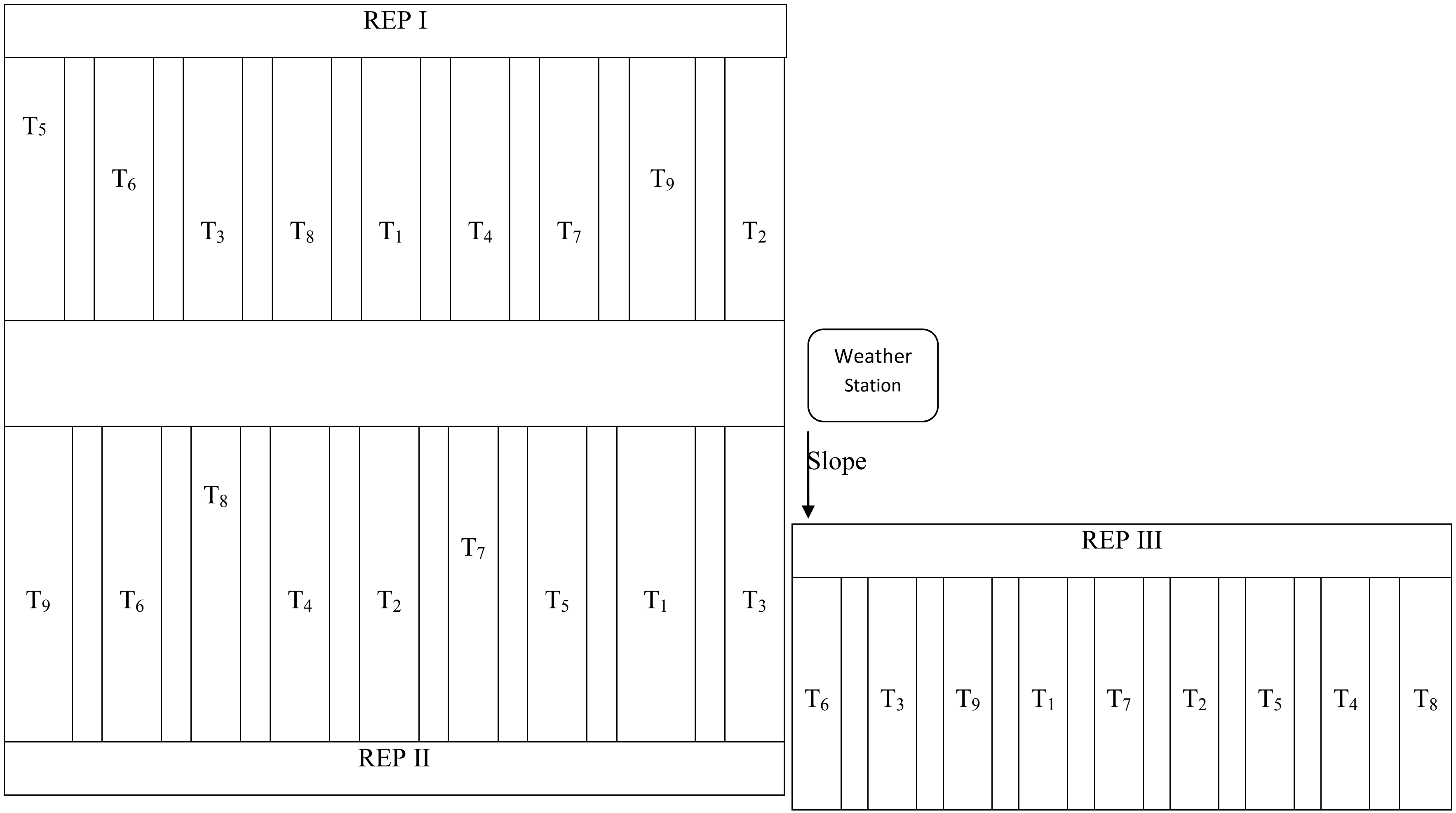


Figure 2: Layout of experimental plots

The cover crops lablab and cowpea were planted two weeks after maize, the spacing for both crops were 20 cm x 75 cm between maize lines. The cover crop was planted two weeks after maize to avoid competition between maize and cover crops especially lablab which has a tendency to climb over maize plant.

Plate 3: A plot of maize with lablab

3.2.2 Rainfall measurements

Rainfall measurements were made using standard rain gauge located at the plot site and automatic rain gauge with a data logger located at the Mitigation of Climate Change in Africa (MICCA) Project CARE Tanzania research site (FAO, 2011) located on the North Western side at about 300 m from the runoff plots.

3.2.3 Runoff and soil loss measurements

One eighth (1/8) of the total runoff and sediment was collected in the 220 litres drum at the bottom of each runoff plot. A three stage divisor system divided the runoff to one eighth by first splitting the runoff into a half, then into a quarter and then to one eighth. The rest of the runoff was collected in the drainage channel designed to remove unrequired runoff (Plate 2). The runoff and sediments in the drum were vigorously stirred and about 1 litre of the mixture of runoff and sediments was collected in a one litre bottle and the rest was measured using calibrated buckets to measure their volumes. Aluminium sulphate (Al_2SO_4) flocculating agent was used to separate water and sediments in the one litre bottle sample as described by FAO, (2000). Sediment weights of the samples were measured when wet and kept in PVC bags for transportation to the SUA Soil Science Laboratory for analysis. Using the normal particle density of soil, 2650 kg/m^3, the sediment volume was calculated (Mgina, 2000). Runoff water volume was determined by subtracting the runoffs sediments volume from the total runoff volume.

3.2.4 Canopy cover and crop height measurements

The cover development (canopy cover and crop cover) was monitored in order to determine the crop management (C) factor values (Wischmeir and Smith, 1978) given by

$$C = \sum \frac{Ei}{\sum_{i=1}^{n} Ei} \times Ci \qquad \text{..................} (8)$$

Where,

Ei = Rainfall erosivity of storm

The C factor was estimated using the sub factor equations based on crop stage periods (Dissmeyer, 1982).

$$Ci = CCi \times GSCi \times SRi \times PLUi \quad \text{.......... (9)}$$

where,

C_i = Cover and management factor

CC_i = Canopy cover sub factor

GSC_i = Ground surface cover sub factor

SR_i = Surface roughness sub factor

PLU_i = Prior land use sub factor

The canopy cover development was monitored by determining leaf area of the maize plant at different time intervals. The length and breadth (width) of each leaf of the plant were measured. The leaf area was determined using the expression:

$$Leaf\ area = (leaf\ length \times leaf\ breadth) \times calibration factor \quad \text{.......... (10)}$$

The calibration factor was determined from regression of the calculated leaf area against area of leaves measured with a leaf area meter. Such calibration factors can be determined for specific experiments but in this research the calibration factor for maize and sorghum which equals to 0.75 as established by McKee (1964) and Bueno and Atkins (1981) was adopted. The Canopy Cover (CC) was obtained from the following relationship developed by Hsiao *et al*. (2009):

$$CC = 100.5[1 - \exp(-0.60LAI)]^{1.2} \quad \text{.......... (11)}$$

$$LAI = \frac{Leaf\ area(m^2)}{Plot\ area(m^2)} \quad \text{.......... (12)}$$

where;

LAI = Leaf Area Index

The ground surface cover was also measured using a 50 cm by 50 cm frame made of timber and PVC ropes (Plate 4). It consists of 25 squares of 10 cm by 10 cm. The frame was locally made at the research site by the local carpenters. An observer simply counts the number of squares covered by the vegetation. A square which is covered more than a half of it was considered as full (Mgina, 2000). Three observations were done per treatment at both ends and middle and the average taken and then converted into percentage (Mgina, 2000).

Plate 4: Quadrant frame

The crop height was estimated using the photograph pictures which were taken when the leaf area was measured because the height was not measured at some dates and they were related to the maize crop height curves present (Hsiao *et al*., 2009). An area of 5.4 m^2 (four lines of maize crop, 3 m by 1.8 m) was used to harvest the maize grain and the biomass from all plots. The selected rows of crops were the middle rows for all plots. The harvested grain and biomasses were then interpolated for the whole plot area and in tons per hectare.

3.2.5 Soil sampling

Soil samples for laboratory analysis of physical and chemical properties were collected at the beginning of the experiment and on the harvesting day. Soil samples were collected at two depths, 0-15 cm and 15-30 cm. The samples were randomly collected at three points (following the diagonal lower, middle and upper) within each treatment and thoroughly mixed spread on a PVC sheet and split into a quarter to obtain 0.25 kg of the sample (Landon, 1991). The cores were used to take soil samples for bulk density and moisture content determination.

3.3 Data Analysis

The collected sediments from the 1 litre sample of known weight was oven dried at 105° C for 24 hours (Lal,1988) at the SUA Soil Science Laboratory for weight determination. The weight was correlated to the original weight of wet soil collected from concrete tanks by linear interpolation to obtain total dry soil weight for the entire plot, and then converted to soil loss per hectare. Daily rainfall records were used to calculate the rainfall erosivity of the area. The daily, monthly and annual rainfall volumes were used to determine the monthly and annual erosivities using the empirical equation relating erosivity to rainfall volume for Morogoro which was observed to be more precise at $R^2 = 0.95$ and standard error (σ) of 505.85 (Omar, 2013).

The linear regression model is:

$$R = 4.887Ar - 791.03 \quad \text{.......} (13)$$

Where;

R	=	Annual rainfall erosivity (MJ-mm/ha-h-y),
Ar	=	Annual rainfall volume (mm)

Soil analysis on particle size distribution, bulk density *etc* was done according to the standard soil analytical procedures (Landon, 1991; Blake and Hartage, 1986). The analysis was conducted at SUA Soil Science Laboratory. The soil erodibility was determined from soil texture data. The cover and erosivity values were used to determine the crop management factor, C. The values for erosivity, erodiblity, crop management factor were used in the Revised Universal Soil Loss Equation (RUSLE) to predict soil loss from the runoff plots (Renard and Freimund, 1994). The Equation is expressed as:

$$A = R \times K \times LS \times C \times P \quad \text{.......} (14)$$

where,

A	=	Soil loss (t/ha-yr)
R	=	Annual rainfall erosivity (MJ-mm/ha-hr-yr)
K	=	Soil erodibility (t-ha-hr/MJ-mm-ha)
LS	=	Topographic factor (dimensionless)
C	=	Crop and management factor (dimensionless)
P	=	Support practise factor (dimensionless)

3.3.1 Statistical analysis of results

Statistical analysis using Genstat 14th Edition statistical software and regression analysis was done for soil loss and rainfall amount on seasonal and monthly basis. The volume of runoffs and weights of sediments registered for individual rainstorms was summed up to get the seasonal amounts of eroded soil per plot and converted to mm and t/ha, respectively. Analysis of variance (ANOVA) was done to compare the effect of treatments and blocks on runoff and soil losses.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results and discusses the findings with regards to the research overall and specific objectives. The timing of rainfall events in relation to crop development was a critical influence on erosion rates. The results relate and discuss the research objectives with the findings which have been observed during the research work.

4.2 Rainfall and Rainfall Erosivity

4.2.1 Rainfall

The month of March had more rains than April and May, thus expected to have more erosive storms (Figure 3). The total amount of rainfall recorded at the experimental site during the study period (March to June 2013) was 927.73 mm. The cropping season started in March and ended in May 2013. The annual rainfall at the study area was 1936.65 mm.

Annual rainfall deviates from the long term average of rainfall in Uluguru Mountains by a standard deviation of 515.94.The area has two rainy seasons as shown in Figure 4 and Table 2. The amount of rainfall is within the range for Uluguru Mountains which have rainfall estimated at over 1,200 mm per annum (Mvena and Kilima, 2009).

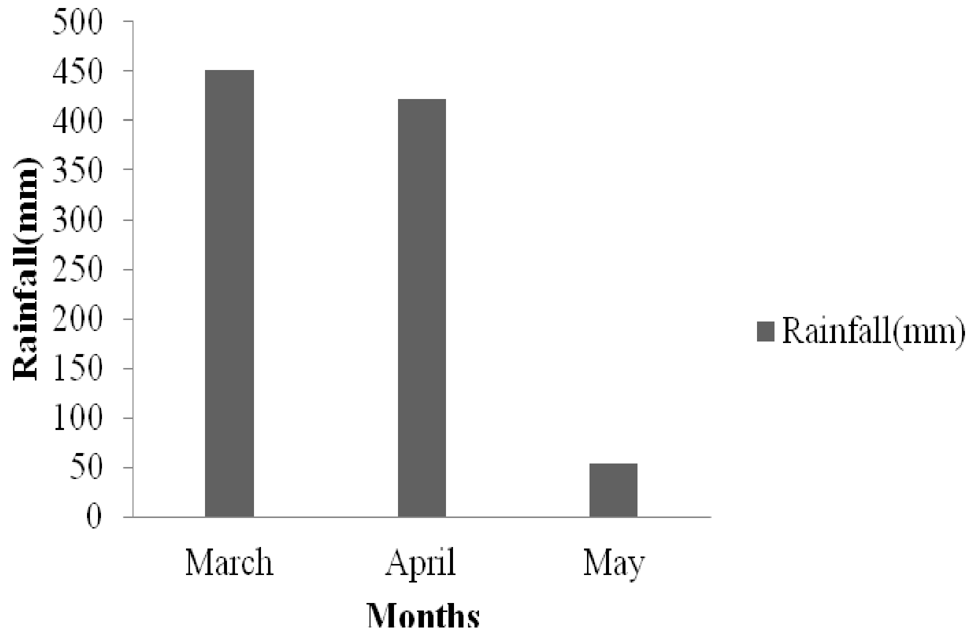


Figure 3: Monthly rainfall for 2013 cropping season at Kolero research site for 2013

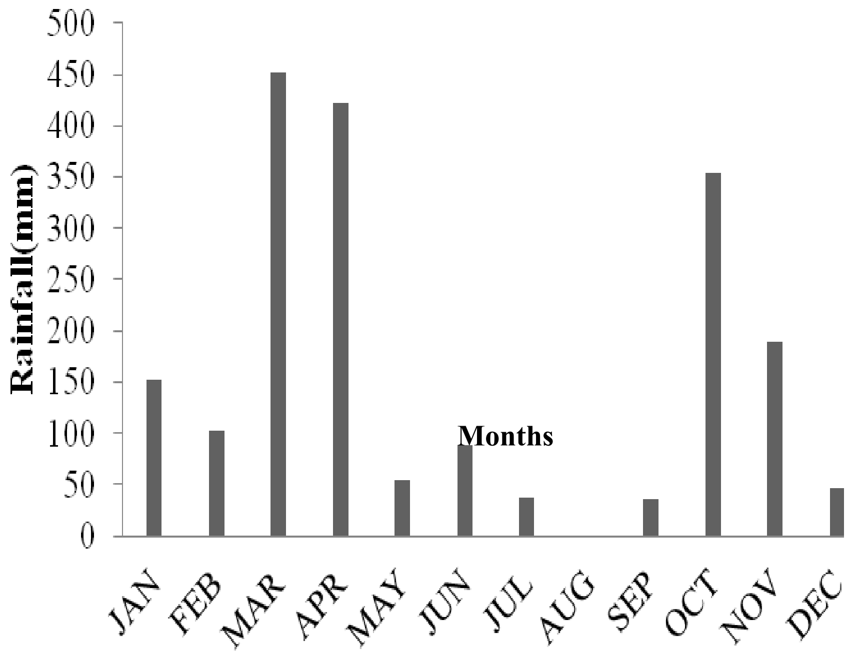


Figure 4: Annual rainfall distribution in the year 2013 at Kolero resarch site

Table 2: Annual Rainfall at Kolero for 2013

Month	Rainfall (mm)
JAN	152.59
FEB	103.19
MAR	452.1
APR	421.7
MAY	53.97
JUN	89.3
JUL	37.2
AUG	0
SEP	36.3
OCT	354.4
NOV	188.8
DEC	47.1
Total	**1936.65**

4.2.2 Rainfall erosivity

The annual erosivity for 2013 was calculated using Equation 13 and was found to be 8676.5 MJ mm/ha-h-yr. The total erosivity of the area for March, April and May 2013 amounted to 4156.52 MJ mm/ha-h-yr. The area is subjected to frequent erosive storms. The monthly erosivity values during the cropping season were 2025.45, 1889.28 and 241.79 MJ mm/ha-h-yr for March, April and May, respectively (Table 3).

Table 3: Rainfall Erosivity at Kolero for 2013 rainy season

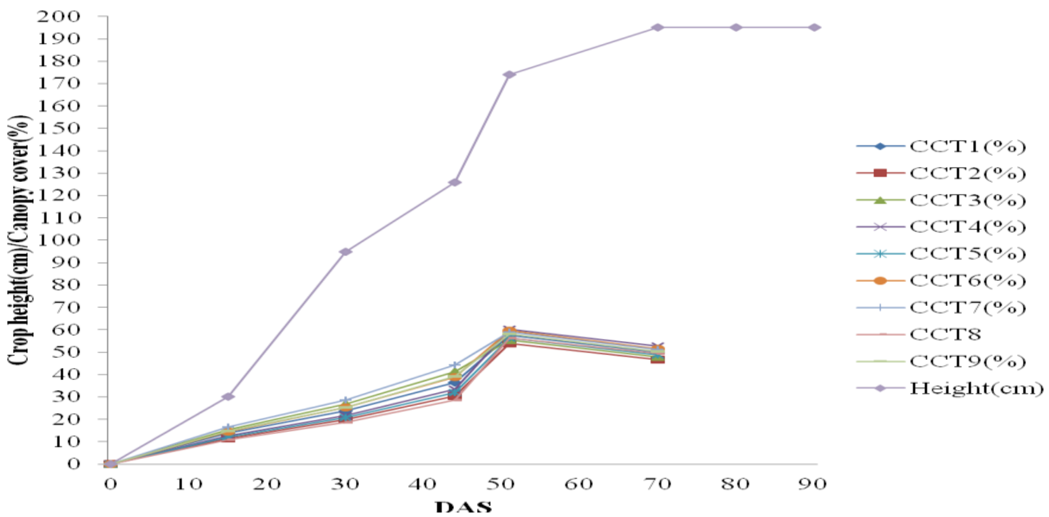
Month	Rainfall(mm)	Erosivity (EI_{30}) (MJ mm/ha-h-yr)
January	152.59	683.63
February	103.19	462.31
March	452.1	2025.48
April	421.7	1889.28
May	53.97	241.79
June	89.3	400.08
July	37.2	166.66
August	0	0.00
September	36.3	162.63
October	354.4	1587.77
November	188.8	845.85
December	47.1	211.02
Total	**1936.65**	**8676.50**

4.3 Crop Cover and Height Development

Figure 5 shows the results for the development of canopy cover and height of the maize plant at the experimental plots. The highest canopy cover was achieved with the treatments with lablab T2, T5 and T8 which implies that lablab provide good cover. The trend for height and canopy cover show response similar with the relationship established by Hsiao, *et al*. (2009).

The ground surface cover due to weeds, and cover crops (lablab and cowpea) also were high in May (51 DAS, Appendix 1). The ground surface cover trends in Appendix1 show that cowpea developed good cover fast and also tended to diminish after 51 DAS, but for the lablab they developed the ground cover slowly and peaked up towards the end of the season. Mlengera (2008) reported lablab as drought resistant crop.

The crop management factor (C values) for the season were determined using Figure 5 and the Figures in Appendices 4 and 5 and Equations 8 and 9 and results are shown in Appendix 2. The results in Table 4 show that the treatments which were combined with cover crops (lablab and cowpea) were relatively having smaller C values as compared to treatments which were not intercropped with cover crops per tillage system. Considering the tillage system without cover crops in the research area, the C values were 0.632, 0.317 and 0.364 for shallow tillage, zero tillage and strip tillage respectively (Table 4). The difference between the C factor for the shallow tillage and conservation tillage indicates that the soils are responsive to conservation measures (Kabanza *et al.*, 2013).



Note: CCT is maize crop canopy cover in the treatment

Figure 5: Maize crop height and canopy cover at Kolero research site

Table 4: Cropping season (2013)-RUSLE crop management factor

Treatment	Tillage system	Cover crop	C factor
T1	Shallow tillage		0.632
T2	Shallow tillage	Lablab	0.461
T3	Shallow tillage	Cowpea	0.517
T4	Zero tillage		0.317
T5	Zero tillage	Lablab	0.255
T6	Zero tillage	Cowpea	0.259
T7	Strip tillage		0.364
T8	Strip tillage	Lablab	0.311
T9	Strip tillage	Cowpea	0.326

Intercropping of cover crops relatively reduced the value of crop management factor C (Table 4) relative to the tillage system. The least C factor value of 0.255 was for the zero tillage with lablab treatment. The farmers' practice of shallow tillage with sole maize gave the highest C value of 0.632 indicating that it has low effect on the reduction of soil loss in the Uluguru Mountains. Combining the cover crops (lablab and cowpea) with the farmers' practice reduced the C value to 0.461 and 0.517, respectively. A C value of 0.55 was obtained in Lake Alaotra in Madagascar when lablab was used as a cover crop (Van Hulst, 2011). Crop management factor C of 0.7 was obtained in Makonde plateau at slopes of 15 % for maize (Kabanza *et al.*, 2013).

4.4 Biomass and Yield

At the end of the season, maize was harvested and the biomass of maize and cover crops and maize yield were determined. Comparatively less studies have been conducted to find out if at all live crop cover lead to increased yield (Hellin, 2006). Results of the Duncan's Multiple Range Test (Table 5) show that there is significant

Table 5: Mean biomass and maize grain yield from Kolero research plots

Treatment	Tillage system	Cover	MAIZE BIOMASS (t/ha)	COVER BIOMASS (t/ha)	TOTAL BIOMASS (t/ha)	YIELD (t/ha)
T1	Shallow tillage		7.991[a]		7.991[ab]	4.734[b]
T2	Shallow tillage	Lablab	6.039[a]	4.03[c]	10.069[bc]	3.512[ab]
T3	Shallow tillage	Cowpea	6.704[a]	1.021[a]	7.725[ab]	4.514[ab]
T4	Zero tillage		6.629[a]		6.629[a]	4.117[ab]
T5	Zero tillage	Lablab	5.533[a]	2.51[b]	8.043[ab]	3.299[a]
T6	Zero tillge	Cowpea	6.383[a]	1.182[a]	7.565[ab]	4.071[ab]
T7	Strip tillage		7.048[a]		7.048[ab]	4.268[ab]
T8	Strip tillage	Lablab	6.283[a]	4.833[c]	11.116[c]	3.807[ab]
T9	Strip tillage	Cowpea	5.831[a]	0.972[a]	6.803[a]	3.926[ab]

The means along the same column bearing similar letter(s) are not statistically different at 5% level of probability based on Duncan's Multiple Range Test.

difference between the total biomass production in treatments. Results show that treatment T8, strip tillage with lablab, produced the highest total biomass of 11.11 t/ha and zero tillage (T4) registered the least total biomass of 6.63 t/ha. The biomass for treatments without cover crops were not statistically diffferent as they all had maize only. The biomass yield is essential for production of mulch for the next season hence improving the crop and management factor C. Conservation tillage leaves biomass undisturbed or little disturbed hence improvingn the soil cover and reducing the C factor (Sarrantonio and Gallandt, 2003).

In treatments combined with lablab, the total biomass produced was higher as compared to other treatments (Table 5). This is because lablab continued to grow even when maize and cowpea stopped to grow (Mlengera, 2008). The treatments combined with cowpea as cover crop produced similar total biomass (Table 5). Cowpea developed cover very fast and dried completely after maturity. Dense residue of cowpea helps to improve soil texture but breaks down quickly in hot weather (Sarrantonio and Gallandt, 2003).

Considering the tillage systems, maize biomass was not significantly different (Table 5) Lablab produced more biomass as compared to cowpea, this is due to the reasons stated above. Maize grain yield results in Table 5 showed that shallow tillage produced a yield of 4.7 t/ha and zero tillage with lablab produced the least maize grain yield of 3.299 t/ha. The maize grain yield range of 3.299 to 4.734 t/ha is reflected by the maize biomass produced which ranged from 5.533 to 7.991 t/ha. Shallow tillage had minimum competition for nutrients as compared to other conservation treatments (Mlengera, 2008). Lablab treatments gave less maize grain yield as compared to other treatments because lablab is also a heavy feeder so there was competetion of the nutrient uptake between lablab and maize crop. The results for treatments with lablab agree with the results obtained in Karatu where the maize grain yield ranged from 1.25 t/ha (2004) to 7.0 t/ha (2009) (Owenya *et al*., 2011) indicating that maize grain yield in the study area was within the acceptable range. Crop yield increases with time under conservation tillage (Owenya *et al*., 2011), it is a fact that conservation tillage promotes soil health and improves yield levels over time (Enfors *et al*., 2010). The results are also within the FAO specification of the yield potential for maize (FAO,1978) (Appendix 8). According to Appendix 8 the land is suitable for maize production. Lablab is a good cover crop as it needs time to give positive results from the biomass it produces and nitrogen fixation my results are only for a single season.

In this experimental season the cover crop did not develop well because of the site preparation activities. The cover crops were planted two weeks after maize planting. The lablab tend to compete with maize for moisture and food. Shallow tillage treatments gave the highest yield. Fertilizer was equally applied in all treatments, this contributed to high yield result for the shallow tillage (Farmers' practise) treatment as it had no competition with cover crops (cowpea and lablab).

4.5 Runoff

The runoff in litres was converted into volumes in millimetres. The monthly runoffs were analysed and their sum gave the seasonal runoff for the 2013 season.

The cropping season runoffs collected varied within the treatments (Figure 6). The general trend of runoffs (Table 6 and Figure 6), for the three months shows a reduction in runoff volumes with increasing cover establishment. Zero tillage with lablab registered the highest amount of runoff volume of 363.2 mm and the least runoff of 125.8 mm was collected from treatment T9 (strip tillage with cow pea) (Table 6 and Figure 7).

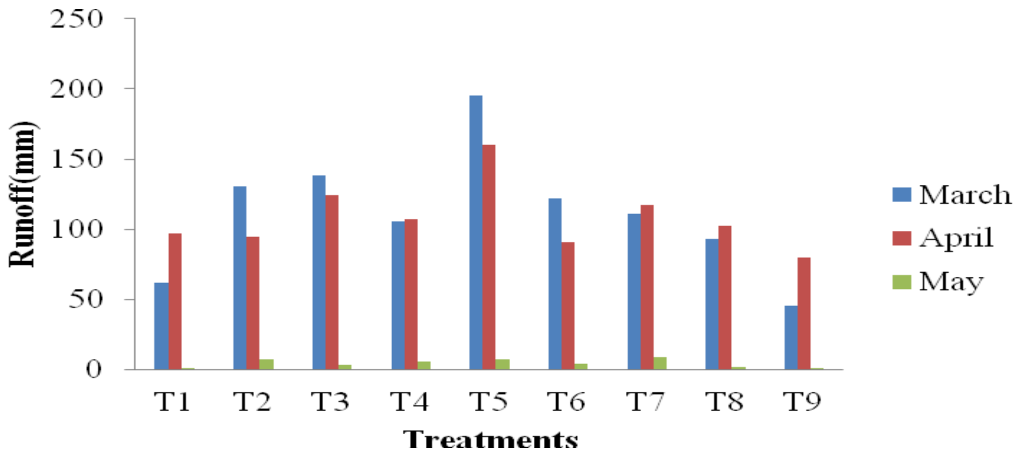


Figure 6: Cropping season (2013) monthly runoffs from the Kolero village research plots

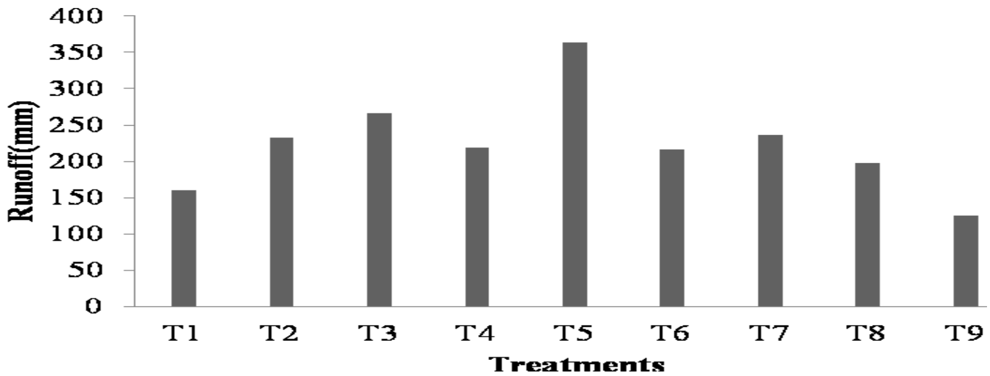


Figure 7: Total runoffs for cropping season 2013 from different treatment plots at Kolero research site

Table 6: Monthly and seasonal runoffs (mm) from the runoff plots at Kolero village

Treatment	Tillage system	Cover	March	April	May	Seasonal
T1	Shallow tillage		62.1a	96.9ab	1.32a	160.3a
T2	Shallow tillage	Lablab	130.6ab	94.3a	7.06ab	232.0ab
T3	Shallow tillage	Cowpea	138.3ab	124.3ab	3.6ab	266.2ab
T4	Zero tillage		105.4ab	107.4ab	5.50ab	218.3ab
T5	Zero tillage	Lablab	195.3b	160.4b	7.58ab	363.2b
T6	Zero tillage	Cowpea	121.7ab	91.1a	3.97ab	216.8ab
T7	Strip tillage		111.0ab	116.9ab	8.78b	236.7ab
T8	Strip tillage	Lablab	93.0a	102.3ab	2.08ab	197.4a
T9	Strip tillage	Cowpea	445.2a	80.0a	0.58a	125.8a

The means along the same column bearing similar letter(s) are not statistically different at 5% level of probability based on Duncan's Multiple Range Test.

Results show that zero tillage registered the highest seasonal runoff of 363.2 mm when compared to all other treatments (Table 6). Under tillage systems with sole maize crop, shallow tillage registered the least seasonal runoff volume of 160.3 mm while zero tillage and shallow tillage registered runoff volume of 218.3 mm and 236.7 mm, respectively (Figure 7 and Table 6). The reason was that shallow tillage created artificial reservoirs which retained the runoffs. When the tillage systems with cover crops were compared, the strip tillage treatments did well in reducing runoffs as shown in Table 6. This indicates that improving the cover decreases runoff on the slopes of the Uluguru Mountains. Reduction in runoff volume was also observed in the slopes of Loess Plateau, China by improving cover crops (Kang *et al*., 2001).

However, if the land is not to be planted then keeping the residue of the last season can also decrease runoff to a lesser extent according to Kang *et al*. (2001).

4.6 Soil Properties

Soil properties in the treatments were analysed at the beginning and at the end of the experiment. The texture analysis results show that the texture of the soil at the research site was sand clay loam at the 0 -15 cm depth and sand clay at the 15 – 30 cm (Table 7). Sand clay loam and sand clay soils are moderately good in retaining moisture because clay and loam content have good water holding capacity (Msaky *et al*., 2005).

The bulk density ranged from 1.24 to 1.56 g/cm^3 and based on an index for assessing the long term productivity of the soil by Pierce *et al*., 1983 values for bulk density were found to be non-limiting to root development. Analysis of the soil chemical properties of the plots showed that initial soil pH ranged from 4.98 to 5.86 indicating that the soil was slightly to moderately acidic. The range allows sufficient microorganism's activity and nutrient availability. Organic carbon and cation exchange capacity ranged from 0.59 % to 1.44 % and 8.6 to 12.8 CmolK/gm, respectively. These values for organic carbon were attributed to the area being fallowed for two years. Total nitrogen percentage ranged from 0.08 to 0.13 indicating low initial nitrogen content. The other exchangeable bases ranges are as shown in Table 7. After the cropping season soil samples were taken in June 2013 and the soil properties were also analysed and the results are shown in Tables 8 and 9. The soils pH ranged from 5.56 to 6.02 (moderately acidic) for the soil depth of 0 – 15 cm. At the lower depth of 15 -30 cm, the pH ranged from 5.41 to 5.98 (moderately acidic) as shown in Table 9. This range of acidity is favourable for maize crop production, maize performs well in soils with pH range from 5.0 to 6.5 (Msaky *et al*., 2005). When soil erosion occurs it is believed to increase the levels of soil pH (Malhi *et al*., 1994). The soil pH for the shallow tillage, zero tillage and Strip tillage with sole maize was 5.61, 5.92 and 5.93 respectively. The organic carbon (OC) at the depth of 0-15 cm (Table 8) ranged between 1.52 and 1.94% indicating increment as compared to the initial status. Organic carbon is often taken as a measure of the quality of organic matter in soils, which in turn is considered as a measure of soil fertility status (Moukam and Ngakanou, 1997). The soils in plots with cover crops had a high percentage of organic carbon. Strip tillage with cowpea and zero tillage with cow pea had high organic carbon of 1.91 and 1.94 respectively. Cowpeas decompose more easily than lablab as they started to decompose even before being incorporated in the tilled soil (Dick, 1982).

The total nitrogen ranged from 0.18 to 0.28% at the depth of 0-15 cm and ranged from 0.16 to 0.33% at the lower depth of 15-30 cm. The subsoil had more total nitrogen than the topsoil due to leaching process (Tables 8 and 9). The total nitrogen content of 0.10 % to 0.20 % is considered as low and that of 0.21 % to 0.50 % is considered as medium (Msaky, *et al*., 2005). Conservation tillage treatments with cover crops had more total nitrogen as compared to the initial status. The cover crops lablab and cowpea are legumes and they have the ability of fixing nitrogen. The total nitrogen of 0.28 % in the zero tillage with lablab treatment was statistically different at $p < 0.05$ compared to values in the other treatments.

Table 7: Initial soil characteristics of the experimental site (Kolero) before setting the experiment – March 2

	Depth	SoilpH (1:2.5) (in H_2O)	% Clay	P.S.D. % Silt	% Sand	Textural Class	TN-Kjeld (%)	OC-BlkW (%)	Ext.P mg/kg) PBry-1	CEC (cmolK g^{-1}) CEC	Exch. Bases (cmolKg^{-1}) Ca^{2+}	Mg^{2+}	K^+	Na^+
REP I	0-15 cm	5.44	31.56	12.92	55.52	Sand clay loam	0.13	1.13	3.57	9.2	2.58	2.04	0.4	0.17
REP I	15-30 cm	4.98	45.56	6.92	47.52	Sand clay	0.09	1.21	4.08	8.6	2.23	2.23	0.2	0.19
REP II	0-15 cm	5.79	27.2	13.28	59.52	Sand clay loam	0.11	1.19	2.03	9.8	3.38	2.98	0.3	0.18
REP II	15-30 cm	5.5	37.2	15.28	47.52	Sand clay	0.08	0.7	2.03	9.6	2.32	2.83	0.1	0.19
REP III	0-15 cm	5.69	27.2	9.28	63.52	Sand clay loam	0.13	1.44	3.57	12.8	4.88	3.29	0.3	0.16
REP III	15-30 cm	5.86	35.2	13.28	51.52	Sand clay	0.1	0.59	2.03	12	4.27	3.46	0.1	0.18

The weeding processes in the shallow tillage treatments might have accelerated the decomposition of weeds as the weeds were buried in the soil. It is understood that agricultural management practices such as weeding influence the rate of decomposition of weeds as it increases aeration of soil. Variations of other exchangeable bases are as shown in Tables 8 and 9.

4.7 Soil Erodibility

The soil erodibility (K) values were determined using Equation 4 (Lal, 1988). Result shows that erodibility of soil for the top layer (0-15 mm depth) ranged from 0.012 to 0.019 t-ha-h/ha-MJ-mm across the treatments (Appendix 3). Strip tillage treatments had less K values hence were less erodible. Soil erodibility, values for shallow tillage (Appendix 3) were larger than for the other treatments increasing their susceptibility to erosion. From the textural classes of the Uluguru Mountain soils (Kimaro *et al*., 2005 and Mulengera *et al*., 2009), calculated soil erodibility values for Uluguru Mountain's ranges between 0.013 and 0.068 t-ha-h/ha-MJ-mm.

Thus, the soil at the Kolero research site which is in the southern part of Uluguru mountain slope has relatively low erodibility values affected by steep slopes which increase its susceptibility to erosion. Erodibility values of the top soil layer (0 – 15 cm) are considered because the depth of eroded soil calculated using bulk density ranged from 0.52 mm to 2.45 mm hence not exceeding the 15 cm.

Table 8: Soil fertility status after cropping season (0 –– 15 cm) soil depth) for the runoff plots at Kolero village

Treatment	Tillage system	Cover	pH	Ca2	P mg/kg	K+	Mg2+	Na+	OC	Total N
T1	Shallow tillage		5.61[a]	8.10[a]	6.58[a]	0.45[ab]	5.15[a]	0.50[a]	1.81[a]	0.23[ab]
T2	Shallow tillage	Lablab	5.56[a]	6.98[a]	4.24[a]	0.38[ab]	5.39[a]	13.24[a]	1.60[a]	0.19[ab]
T3	Shallow tillage	Cowpea	5.70[a]	6.21[a]	2.45[a]	0.58[bc]	4.67[a]	0.23[a]	1.71[a]	0.20[ab]
T4	Zero tillage		5.92[a]	7.40[a]	5.50[a]	0.44[ab]	5.19[a]	0.20[a]	1.52[a]	0.22[ab]
T5	Zero tillage	Lablab	5.65[a]	6.07[a]	7.52[a]	0.36[a]	4.55[a]	0.24[a]	1.73[a]	0.19[ab]
T6	Zero tillage	Cowpea	5.93[a]	8.10[a]	4.41[a]	0.72[c]	4.39[a]	13.21[a]	1.91[a]	0.28[b]
T7	Strip tillage		5.93[a]	7.54[a]	5.19[a]	0.45[ab]	4.44[a]	0.22[a]	1.52[a]	0.16[a]
T8	Strip tillage	Lablab	6.02[a]	7.75[a]	4.16[a]	0.44[ab]	4.98[a]	0.28[a]	1.71[a]	0.20[ab]
T9	Strip tillage	Cowpea	5.77[a]	8.52[a]	2.77[a]	0.42[ab]	4.80[a]	0.32[a]	1.94[a]	0.18[ab]

Note: SI units for the cations is $cmolKg^{-1}$

The means along the same column bearing similar letter(s) are not statistically different at 5% level of probability based on Duncan's Multiple Range Test.

Table 9: Soil fertility status after cropping season (15 – 30 cm soil depth) for the runoff plots at Kolero village

Treatment	Tillage system	Cover	pH	Ca^{2}	P mg/kg	K^{+}	Mg^{2+}	Na^{+}	OC-BlkW	Total N
T1	Shallow tillage		5.52^{a}	6.56^{ab}	4.41^{b}	0.45^{abc}	4.45^{a}	0.28^{a}	**(%)**	0.22^{a}
T2	Shallow tillage	Lablab	5.79^{a}	6.77^{ab}	2.90^{ab}	0.33^{ab}	5.56^{a}	0.49^{a}	1.56^{a}	0.22^{a}
T3	Shallow tillage	Cowpea	5.71^{a}	5.79^{ab}	1.57^{ab}	0.40^{abc}	4.45^{a}	0.22^{a}	1.54^{a}	0.19^{a}
T4	Zero tillage		5.60^{a}	6.77^{ab}	1.59^{ab}	0.36^{abc}	5.54^{a}	0.24^{a}	1.31^{a}	0.16^{a}
T5	Zero tillage	Lablab	5.41^{a}	5.08^{a}	0.260^{a}	0.24^{a}	4.69^{a}	0.20^{a}	1.84^{a}	0.18^{a}
T6	Zero tillage	Cowpea	5.98^{a}	6.42^{ab}	1.17^{ab}	0.61^{c}	4.31^{a}	0.23^{a}	1.31^{a}	0.19^{a}
T7	Strip tillage		5.58^{a}	6.70^{ab}	2.17^{ab}	0.39^{abc}	4.43^{a}	0.24^{a}	1.66^{a}	0.21^{a}
T8	Strip tillage	Lablab	5.56^{a}	6.42^{ab}	1.60^{ab}	0.47^{abc}	5.22^{a}	0.41^{a}	1.52^{a}	0.19^{a}
T9	Strip tillage	Cowpea	5.55^{a}	7.47^{b}	2.21^{ab}	0.53^{bc}	4.86^{a}	0.50^{a}	1.61^{a}	

Note: SI units for the cations is $cmolKg^{-1}$

The means along the same column bearing similar letter(s) are not statistically different at 5% level of probability based on Duncan's Multiple Range Test.

4.8 Soil Erosion Under Conservation Tillage Practices

4.8.1 Extent of soil erosion rates for zero and strip digging on steep slopes

The general trend of soil loss shows a reduction of soil losses from months of March to May of the season (Table 10). Erosive storms occurred almost equally in March and April but soil loss decreased subsitencially for the two months (Table 10).

The establishment of the soil cover as maize crop grew also contributed to the reduction in soil loss. Seasonal results on the shallow tillage, zero tillage and strip tillage with sole maize practice show that shallow tillage registered the least total seasonal soil loss as compared to strip tillage and zero tillage (Table 10 and Figure 8) which are conservation tillage practices. This is because much of the soil was lost in the first month of the season , because the soil was not well consolidated due to the land preparation activities.

In terms of effectiveness of the conservation tillage practices in decreasing erosion rates, zero tillage and strip tillage were less effective than the farmers' practise of shallow tillage. This might be due to disturbance of the soil during the site clearance, tree uprooting and plots levelling. Results obtained by other researchers have shown that the magnitude of soil loss in slope gradients above 40% varies between 49 and 258 t/ha/yr in the Uluguru mountains (Kimaro *et al.*, 2008). The values obtained are very high as compared to the maximum allowable rate of 15 t/ha-yr (Morgan, 2005).

Zero tillage in this scenario experienced the highest soil loss as compared to plots with strip tillage practice, this could be attributed to the land operations during the experimental site layout done in January, 2013. Also the short rains didn't consolidate well the soil before the "*masika*" rains.

Furthermore, the timing of rainfall events in relation to crop development had critical influence on erosion rates. The soil was more exposed to erosion agents during the critical part of the season when cover was incomplete. Erosion was greater due to poor crop establishment in March 2013.

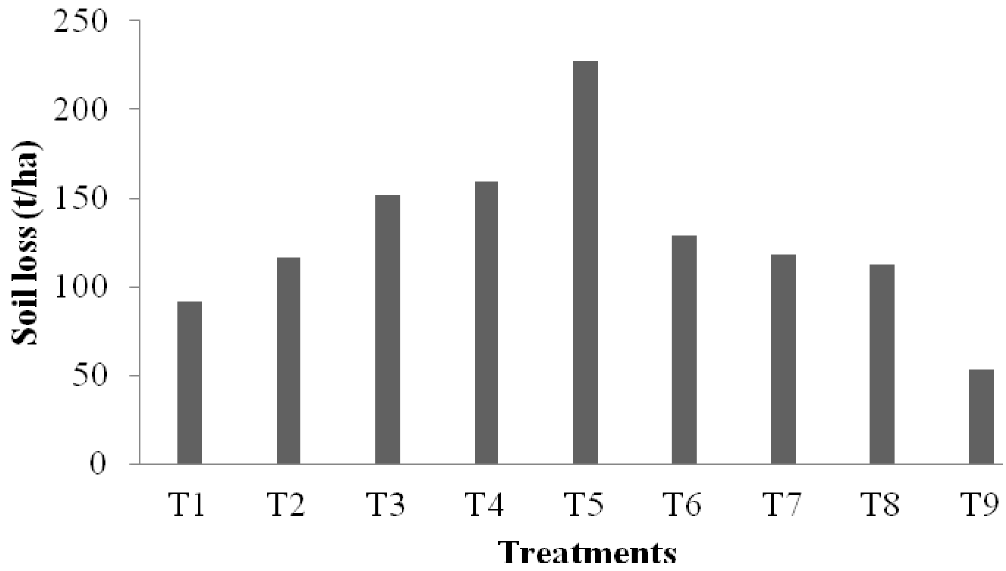


Figure 8: Cropping season soil losses in t/ha from runoff plots at Kolero village

4.8.2 Effect of using cover crops in the conservation tillage practices for enhanced soil erosion control on the steep slopes

When the tillage systems were combined with cover crops (lablab or cowpea) to reduce soil loss, seasonal results show that strip tillage planted with cowpea had the least amount of soil loss of 53.5t/ha while zero tillage with lablab registered the highest amount of soil loss of 227.3 t/ha (Table 10). This is due to the fact that lablab cover was not well established in March which had more erosive storms and more soil loss than other months. The soil loss of 227.3 t/ha was registered from runoff plots with lablab cover crop and zero tillage while shallow tillage with lablab and strip tillage with lablab treatments had 116.1 t/ha and 112.3 t/ha, respectively (Table 10).

Table 10: Monthly: Monthly (2013) and seasonal soil losses (t/ha) from runoff plots at Kolero village

Treatment	Tillage system	Cover	March (t/ha)	April (t/ha)	May (t/ha)	Seasonal (t/ha)
T1	Shallow tillage		52.91^{a}	36.37^{b}	2.56^{b}	91.8^{a}
T2	Shallow tillage	Lablab	89.52^{ab}	25.58^{ab}	0.95^{ab}	116.1^{ab}
T3	Shallow tillage	Cowpea	103.07^{ab}	46.90^{b}	1.31^{ab}	151.3^{ab}
T4	Zero tillage		113.40^{ab}	44.90^{b}	0.98^{ab}	159.3^{ab}
T5	Zero tillage	Lablab	183.71^{b}	43.27^{b}	0.33^{a}	227.3^{b}
T6	Zero tillage	Cowpea	87.84^{ab}	40.63^{b}	0.51^{a}	129.0^{ab}
T7	Strip tillage		91.62^{ab}	25.35^{ab}	1.31^{ab}	118.3^{ab}
T8	Strip tillage	Lablab	69.46^{a}	42.07^{b}	0.79^{a}	112.3^{ab}
T9	Strip tillage	Cowpea	38.43^{a}	14.58^{a}	0.47^{a}	53.5^{a}

The means within the same column bearing similar letter(s) are not statistically different at 5% level of probability based on Duncan's Multiple Range Test

Cowpea as cover crop perfomed well in the runoff plots with strip tillage which had soil loss of 53.5 t/ha. The shallow tillage and zero tillage plots when combined with cowpea experienced seasonal soil loss of 151.3 t/ha and 129 t/ha, respectively.

Amount of soil loss in the strip tillage with cowpea and zero tillage with lablab treatments were significantly different at 5% level of significance. Soil loss from the research plots ranged from 53.05 to 227.3 t/ha. Other researchers have reported soil loss in Uluguru Mountains under conventional farmers' practice ranging from 91 to 258 t/ha/year (Kimaro, 2003; Kimaro *et al*., 2008). These research results show that cultivated steep slopes of the Uluguru Mountains experience high severity of soil loss. In western Nigeria cowpea and no till resulted into soil loss ranging from 0.1 to 15 t/ha (Lal, 1976). The results in Nigeria were for slopes up to 15 % (Lal, 1976) but at the research site the slope is 56 % and the soil loss results have shown that conservation tillage and the use of cover crops are potentially limited in conserving soil if they are not supported by mechanical methods such as reverse slope bench terraces and "*fanya juu*" terraces.

Results from research conducted by Turkelboom (1999) showed that all of the conservation tillage and cover crops practices on steep slopes also registered severe soil loss. At the Kolero village research site this may be because of the disturbance that occurred during the site clearance and levelling. It is a fact that disturbance of 1 mm of soil has great impact on soil loss amount per hectare about 15.6 t/ha by calculation. Using soil loss results and *in- situ* soil bulk density, the depths of soil loss in the study area were estimated to range from 5.8 mm to 14.6 mm. Furthermore, most of the soil loss occurred in the first weeks after sowing *i.e.* in March when high rainfall intensities coincided with a low percent ground cover of fields. Under the prevailing condition of high rainfall and land slope of about 56%, a very dense ground cover is required to reduce erosion rates which could not be attained by maize monocropping alone. Cowpea as a cover crop gave positive results of reducing the amount of soil loss in the study area. Although the magnitude of soil loss was very high, the trend of soil loss decreased from March to April where erosive storms were almost the same (Tables 3 and 10).

The crop management factor (C) values calculated for different tillage and cropping systems ranged from 0.255 to 0.632 for different treatments (Appendix 2). The topographic factor *LS* derived from Equations 6, 7 and 8 gave the value of 7.105 for slope length of 10 metres and slope gradient of 56 % (29.25°). This implies that at the slope of 56 % the effective slope length is reduced from 10 m to 7.105 m. These RUSLE factors were used in Equation 14 to estimate the seasonal soil loss from the study runoff plots and gave soil loss ranging from 110.21 to 290.09 t/ha (Table 11).

The calculated soil loss is comparable to the actual soil loss measured from the study runoff plots which ranged from 91.0 to 227.3 t/ha (Table 11). Regression analysis results showed $R^2 = 0.135$ and standard error 79.42 of predicted soil loss against the actual soil loss due to the fact that the relationship of measured soil loss to cover and management factor C is poor while the predicted soil loss variation highly depends on the cover and management factor C. In China Xiangxi catchment a C value of 0.46 is related to the soil loss of 120.62 t/ha (Schonbrodt, *et al*., 2010). The overestimation of predicted to actual soil loss was mainly due to C- factor and *LS* factor on steep slopes (Sheng, 1990). The cover and management factor is among the factors which can be controlled in soil reduction under RUSLE equation.

Table 11: Estimated and measured soil losses from the study runoff plots at Kolero village

Treatment	R(MJ-mm/ha-h-yr)	K(t-ha-h/ha-MJ-mm)	LS	C	P	Estimated soil loss(t/ha)	Measured soil loss(t/ha)
T1	4156.55	0.015	7.105	0.632	1	279.96	91.8
T2	4156.55	0.018	7.105	0.461	1	245.06	116.1
T3	4156.55	0.019	7.105	0.517	1	290.09	151.3
T4	4156.55	0.016	7.105	0.317	1	149.79	159.3
T5	4156.55	0.015	7.105	0.255	1	112.96	227.3
T6	4156.55	0.016	7.105	0.259	1	122.38	129.0
T7	4156.55	0.014	7.105	0.364	1	150.49	118.3
T8	4156.55	0.012	7.105	0.311	1	110.21	112.3
T9	4156.55	0.012	7.105	0.326	1	115.53	53.5

4.9 Mechanical Conservation Methods to Support CT on Steep Slopes of Uluguru Mountains

Long term annual rainfall data from the average mean monthly rainfall data of five rain gauge stations in the Uluguru Mountains namely Nyandira, Tchezema, Morning side, Morogoro and Kolero are as shown in Appendix 6. From the long term rainfall volumes, the annual rainfall erosivity calculated is 8006.83MJ.mm/ha.hr.yr with that of Kolero being 8676.63 MJ.mm/ha.hr.yr for year 2013. Such erosivity values show that the Uluguru Mountains are prone to erosive storms hence high soil loss.

High soil losses in the area exceeds the tolerable soil loss for soils in the area which has a maximum rooting depth of 100 cm considered to be renewable is 15 t/ha (Morgan, 2005). Using RUSLE, predicted annual soil losses from the runoff plots are much higher as compared to such tolerable value of 15 t/ha (Table 12 and Appendix 7).

Table 12: Estimated annual soil losses

Treatment	R(MJ-mm/ha-hr-yr	K(t-ha-hr/ha-MJ-mm	LS	C	P	Soil loss(t/ha)
T1	8006.83	0.015	7.1049	0.731	1	623.77
T2	8006.83	0.018	7.1049	0.25	1	255.99
T3	8006.83	0.019	7.1049	0.255	1	275.62
T4	8006.83	0.016	7.1049	0.36	1	327.67
T5	8006.83	0.015	7.1049	0.129	1	110.08
T6	8006.83	0.016	7.1049	0.129	1	117.42
T7	8006.83	0.014	7.1049	0.423	1	336.89
T8	8006.83	0.012	7.1049	0.156	1	106.49
T9	8006.83	0.012	7.1049	0.146	1	99.67

According to Turkelboom (1999), soil erosion severity classes, the soil loss rates represent severe and very severe erosion (Table 13).

Table 13: Soil erosion severerity classes

Class	Description	Soil loss (t/ha/yr)
1	Mild erosion	0 - 10
2	Moderate erosion	10 - 50
3	Moderately severe erosion	50 - 100
4	Severe erosion	100 - 150
5	Very severe erosion	> 150

Source: Turkelboom, 1999

The conventional farmers' practice of shallow tillage with sole maize was predicted to experience extremely high soil loss of 623.77 t/ha-yr (Table 12), suggesting that supportive mechanical conservation methods need to be applied together with the researched conservation tillage methods so as to enable the people of Uluguru Mountains to cultivate their fields on steep slopes with tolerable soil loss *i.e.* < 15 t/ha. Technical suitability of a mechanical soil erosion control techniques is determined by slope steepness of the area and the targeted tolerable soil loss (Mulengera, 2011). For Kolero the rainfall erosivity observed is great as compared to the tolerance of the soils hence it needs to be supported by other means. The suitable mechanical conservation method suggested in the Uluguru Mountains is improved ladder terraces (Reverse slope narrow bench terraces). By calculation the other types of terraces such as the "*Fanya juu*" terraces were found to be less effective as they have a limit of slope of 45 % (Mulengera, 2011).

4.9.1 Improved ladder terraces

In the areas where the slopes are above 50 %, improved ladder terraces can be used to reduce the topographic factor LS, hence reducing soil losses by erosion. The improved ladder terrace design has a reverse slope as shown in Figure 9. The slope changes the direction of run of the runoffs hence reducing erosion effects.

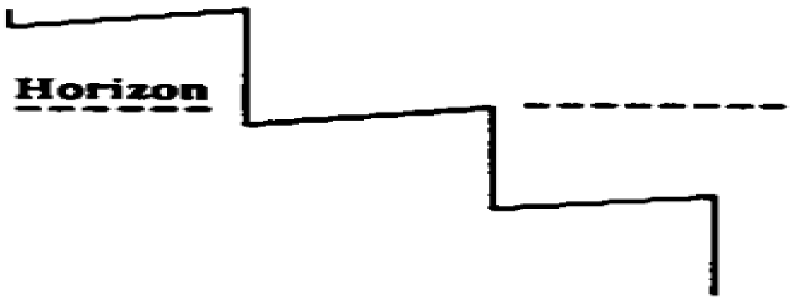


Figure 9: Improved ladder terrace

The topographic factor LS for such a terrace with a width of 1.5 m and a bench slope of 0.4 % ($\theta = 0.23^{\circ}$) across the land slope is obtained by considering an ideal plot of one hectare (100 m x 100 m). The LS factor was determined using Equations 6, 7 and 8 with $\lambda = 100$m and = 0.23^0 (Lal, 1988) and the results are shown in Table 14. The maximum erodibility value of 0.068 t-ha-h/ha-MJ-mm which has been calculated for soils found in the Uluguru Mountains is considered for relating the effectiveness of the ladder terraces. With improved ladder terraces soil loss is greatly reduced where the farmer practice of shallow tillage with sole maize can result in low soil loss of 5.01 t/ha (Table 14). The Conservation Tillage when supported by the improved ladder terraces can result in lower soil loss as low as about 1 t/ha-yr as presented in Table 14. Kingamkono *et al*. (2005) obtained results of soil loss of 0.1 t/ha for normal ladder terraces at Nyandira and Tchezema on the other side of Uluguru Mountains for a period of one and a half month, so the improved ladder terraces are suggested also in the Uluguru Mountains as they can be managed because they are narrow.

The terraces in the slopes of the mountains need to be supported by water ways so as to convey water smoothly down slope. The runoff water within the terrace should be collected to down slope waterways which may be stone pitched or paved with concrete to drain water down slope (Appendix 9) and (Appendix 10). In the area stones can easily be obtained at low cost. Concrete waterways can be used to drain water if the farmers can afford the cost of construction.

Table 14: Estimated soil loss for improved ladder terraced fields with different agronomic practises for the most erodible soils in the Uluguru Mountains

Treatment	R(MJ-mm/ha-h-yr)	K(t-ha-h/ha-MJ-mm)	LS	C	P	Soil loss(t/ha/yr)
T1	8006.83	0.068	0.018	0.731	0.7	5.01
T2	8006.83	0.068	0.018	0.25	0.7	1.72
T3	8006.83	0.068	0.018	0.255	0.7	1.75
T4	8006.83	0.068	0.018	0.36	0.7	2.47
T5	8006.83	0.068	0.018	0.129	0.7	0.88
T6	8006.83	0.068	0.018	0.129	0.7	0.88
T7	8006.83	0.068	0.018	0.423	0.7	2.90
T8	8006.83	0.068	0.018	0.156	0.7	1.07
T9	8006.83	0.068	0.018	0.146	0.7	1.00

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions can be drawn from the study:

Conservation tillage methods studied are vital in controlling soil erosion with time. According to long term predictions zero tillage and strip tillage are good in soil loss reduction in the steep slopes. Cowpea as a cover crop was more effective in controlling soil erosion as it has the least soil loss 53.5 t/ha.

Cover crops are important in controlling soil erosion. Lablab develops slowly in producing cover. Lablab produced maximum biomass of 4.833 t/ha. This biomass will be useful next season for mulching.

5.2 Recommendations

It is therefore recommended that:

i. More research should be conducted in the study to establish the effect of zero tillage and strip tillage in controlling soil erosion.

ii. Farmers should be encouraged to combine cover crops in their fields as they help in controlling erosion.

iii. Supportive mechanical conservation measures are necessary to assist in soil erosion control.

REFERENCES

Angima, A.D, Stott, D.E, O'Nell M.K, Ong C.K. and Weesies, G.A. (2003). Soil erosion prediction using RUSLE for central Kenyan Highland conditions. *Agriculture, Ecosystems and Environment*: 295-308.

Barton, A.P., Fullen, M.A., Mitchell, D.J., Hocking, T.J., Liguang Liu, Zhi Wu Bo, Yi Zheng. and Zheng Y.X. (2004). Effects of soil conservation measures on erosion rates and crop productivity on subtropical Ultisols in Yunnan Province, China. *Agriculture, Ecosystems and Environment* 104: 343-357.

Blake, G.R. and Hartage, K.H. (1986). Bulk density. In: Klute, a(Ed) *Methods of soil analysis.PartI-Physicalandmineralogicalmethods.2nd Ed.Am*.Soc. Agronomy Inc.Madison Wisconsin, USA pp263-275.

Borggaard, O.K., Abdul, G. and Petersen, L. (2003). Sustainability appraisal of shifting cultivation in the Chittagong Hill Tracts of Bangladesh. *Ambio* 32, 118–123.

Brown, L. C. and Foster, G. R. (1987). Storm erosivity using idealized intensity distributions. *Transactions of the American Society of Agricultural Engineers* 30: 379-386.

Buckley, P. and Bhatia, Z. (1998). Uluguru Mountains Biodiversity Conservation Project.TheArcJournal,(7).[online]Availableat:http://www.easternarc.org/pub/uluguru_mountains.html] Site visited on 10 /8/ 2013.

Bueno, A. and Atkins, R. E. (1981). Estimation of individual leaf areas in grain sorghum. Iowa State J. Res. 55:341-349.

Chamshama, S. A. O., Mugasha, A. G., Ngegba, M. S. and Kimaro, A. A. (2006). Agroforestry technologies for semi-arid and sub humid areas of Tanzania: An overview. In Chamshama (eds) Proceedings of the Second National Agroforestry and Environment Workshop: Partnerships and Linkages for Greater Impact in Agroforestry and Environmental Awareness. Held at the Mkapa Hall, Mbeya, Tanzania 14-17 March 2006 (Publisher NASCO Secretariat, 2006).

Chen, Y.Z. and Luk, S.H. (1989). Sediment sources and recent changes in the sediment load of Yellow River, China. In: Proceedings of the 5th International Soil Conservation Conference, Bangkok, Thailand, vol. 1. Department of Land Development, Bangkok, pp. 312–323.

Chuma, E. (1993). Effects of tillage on erosion related soil properties of a sandy soil in semi arid Zimbabwe. In Kaumbutho, P.G. and Simalenga, T. E. (Eds.) (1999). *Conservation tillage with animal traction.* A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA). Harare. Zimbabwe. 173pp.

Coll Besa, M., Ng'habi, S., Mgeta, E., Efraim, M. and Hamad, M.S.(2010). Barriers and emerging success factors towards effective Conservation Agriculture adoption in the Uluguru Mountains, Tanzania. CARE International in Tanzania. 4 pp.

Dick, R. (1982). Garden Way's Joy of Gardening. Troy, N.Y: Garden way Inc. pp178-181.

Dismeyer, G.E. (1982). Developing a USLE cover-management factor (C) procedure for forest conditions. In: *Proceedings of workshop on estimating soil loss and sediment yield on rangelands*, US Dept of Agric., Agric. Res. Service, Washington DC, ARM-W-26:166-187.

Dumanski, J., Peiretti, R., Benetis, J., McGarry, D. and Pieri, C. (2006). The paradigm of conservation tillage. *Proc. World Assoc. Soil and Water Conserv*. 1(2): 58-64.

Enfors, E., Baron, J., Makurira, H., Rockstrom, J. and Tumbo, S. (2010). *Yield and soil system changes from conservation tillage in dryland farming: A case study from North Eastern Tanzania*. [www.elsevier.com/locate/ag wat]. Site visited on 12/08/2012.

Fahlen, A. (1989). A Concise manual in soil conservation techniques and soil erosion processes in the tropics. Uppsala, Sweden. 102pp.

FAO (1978). Yield Response to Water, Irrigation and Drainage Paper No.33, Rome.70pp.

FAO (1998). International Soil Reference and Information Centre (ISRIC) and International Society of Soil Science (ISSS). World Reference Base for Soil Resources, World Soil Resources Report 84. FAO, Rome, Italy. 88 pp.

FAO (2000). Soils Bulletin 68, 'Field Measurement of Soil and Runoff'.Rome.69pp.

FAO (2011). Capacity development guiding report for the MICCA programme in the United Republic of Tanzania. 21pp.

Gachene, C.K.K. and Mwangi, H. (2006). Green Manure / Cover Crops for Soil Erosion Control and Conservation Agriculture in Central and Eastern Highlands of Kenya. Development and Up-scaling Green Manure Legume Technologies in Kenya. Legume Research Network Project KARI P 153.446.

GTZ (1992). "Conservation Tillage for Sustainable Crop Production Systems" is a collaborative programme between the Department of Agricultural Technical and Extension Services (AGRITEX) of Zimbabwe and the Deutsche Gesellschaft fnr Technische Zusammenarbeit (GTZ) GmbH of Germany.22 pp.

Hellin, J. (2006). *Better Land Husbandry From Soil Conservation to Holistic Land Management*. Science Publishers. 315pp.

Hobbs, P. R. (2008). Conservation Agriculture: What Is It and Why Is It Important for Future Sustainable Food Production? Ithala NY, 14853, USA.pp15.

Hsiao, T.C., Heng, L., Steduto, P., Rojas-Lara, B., Raes, D. and Fereres, E. (2009). AquaCrop—The FAO crop model to simulate yield response to water: III. *Parameterization and testing for maize. Agron. J.* 101:448–459. [http//:www.doi.10.2134/agronj2008.0218s] Site visited on 14/07/2013.

Hudson, N.W. (1985). *Field measurement of soil erosion and runoff.* [http://www.fao.org/docrep/T0848E/T0848E00.htm]. Site visited on 22/06/2012.

Hudson, N.W. (1995). *Soil conservation*. BT Batsford, London. 391pp.

Kabanza, A. K., Dondeyne, S., Kimaro, D. N., Kafiriti, E., Poesen, J. and Deckers, J. A. (2013). Effectiveness of soil conservation measuresin two contrasting landscape units of South Eastern Tanzania. Gebr. Borntraeger Verlags buchhandlung, Stuttgart, Germany. [www.borntraeger-cramer.de] Site visited on 20/05/2014.

Kang, S., Zhang, L., Song, X., Zhang, S., Liu, X., Liang, Y. and Zheng, S. (2001). Runoff and sediment loss responses to rainfall and land use in two agricultural catchments on the Loess Plateau of China. Hydrological processes, *Hydrol. Process.* 15 (3): 977–988.

Kaumbuto, P.G., Gebresenbet, G. and Simalenga, T.E. (1999). Overview of conservation tillage practises in East and Southern Africa. In: Kaumbutho P G and Simalenga T E (eds), 1999. *Conservation tillage with animal traction.* A resource book of the Animal Traction Network for Eastern and Southern Africa (ATNESA). Harare. Zimbabwe. 173pp.

Kaumbuto, P., Rockstrom, J., Mwalley, J., Nzabi, A.W., Temesgen, M., Mawenya, L., Barron, J., Mutua, J. and Damgaard-Larsen, S. (2009). *Conservation farming strategies in East and Southern Africa: Yields and rain water productivity from on-farm action research.* Soil & Tillage Research 103 (2009): 23–32.

Kimaro, D. N. (2003). Assessment of major forms of soil erosion in the Morningside catchment, Uluguru Mountains, Tanzania. Unpublished Thesis for Award of PhD at Sokoine University of Agriculture, Morogoro, Tanzania, 264pp.

Kimaro, D. N., Deckers, J.A., Poesen, J., Kilasara, M. and Msanya, B.M. (2005). Short and medium term assessment of tillage erosion in the Uluguru Mountains, Tanzania. *Soil and Tillage Research* 81 (2): 97-108.

Kimaro, D. N., Kilasara, M., Noah, S.G., Donald, G., Kajiru, K. and Deckers, J.A. (1999). Characteristics and management of soils located on specific landform units in the northern slopes of Uluguru Mountains, Tanzania. Agricultural Research Challenges for the 21st Century. Proceedings of the Fourth Annual Research Conference of the Faculty of Agriculture, Sokoine university of Agriculture, Morogoro, Tanzania, November 17th – 19th 1999, pp. 234 – 242.

Kimaro, D. N., Poesen, J., Msanya, B. M. and Deckers, J. (2008). Magnitude of soil erosion on the northern slope of the Uluguru Mountains, Tanzania: Interrill and rill erosion. Catena, 75: 38 – 44.

Kingamkono, M.L., Kahimba, F.C., Tarimo, A.K.P.R. and Tumbo, S. D. (2005). Investigation of Soil Loss and Runoff in Ladder Terraces in the Uluguru Mountains. *Journal of the Institution of Engineers Tanzania*, Volume8 pp18-28.

Kinnel, P.I.A. (1981). Rainfall intensity-kinetic energy relationships for soil loss prediction. *Soil sci. Am* 45(1):153-155.

Lal, R. (1976). *No tillage effects on soil properties under different crops in Western Nigeria*. *Soil Science Society America Journal*48:762-768.

Lal, R. (1988). *Soil erosion research methods*. Soil and water conservation society. 350 pp.

Lal, R. (1990a). *Soil Erosion in the Tropics: Principles and Management*.McGraw-Hill. 580 pp.

Lal, R. (1990b). Low resource agriculture alternatives in sub-Saharan Africa. *Journal of Soil Water Conservation.*45:437-445.

Lal, R. (1993). Role of zero tillage farming in sustainable agriculture in the tropics. *In* "Encontro Latino Americano de Plantio Direto na Pequena Propriedade," November 22-26, 1993, pp. 29-62.

Landon, J.R. (1991). Booker Tropical Soil Manual. A handbook of soil survey and agricultural land evaluation in the tropics and subtropics.Longman Scientific and Technical. 474 pp.

Ley, G. T. (1990). Tiallage and water management in in Southern Highlands of Tanzania. In: Proceedings of the 1st Annual Scientific Conference, SADCC Land and Water Management Research Programme. Saccar, Gaborone. Botswana. M. Kronen (ed) pp. 225-232.

Liu, B.Y., Nearing, M.A., Shi, P.J. and Jia, J.W. (1999). Slope Length Effects on soil loss for steep slopes. In D. E. Scott, R.H. Mohtar and G.C. Steinhardt (Eds) 2001. Sustaining the Global Farm. pp 784-788.

Lovett, J. C. and Pócs, T. (1993). *Assessment of the condition of the Catchment Forest Reserves, a botanical appraisal*. Report prepared for the Catchment Forestry Project (under the Forestry and Beekeeping Division of the Ministry of Tourism, Natural Resources and Environment, Tanzania). pp 120-132.

Madulu, R. and Chalamila, B. (2000). Baseline survey report. Case study of Uluguru and Usambara Mountains. Sokoine university of Agriculture. 10 pp.

MAFC, (2009). Tanzania Variety Catalogue. Ministry of Agriculture Food Security and cooperatives. [*http://www.kilimo.go.tz/publications/publications. htm*]. Site visited on 14/08/2012.

Malhi, S.S., Izaurralde, R. C., Nyborg, M. and Solberg, E.D. (1994). Influence of top soil removal on soil fertility and barley growth. *Journal of soil and Water Conservation49,* pp 96-101.

McKee, G.W. (1964). A coefficient for computing leaf area in hybrid corn. Agron. J. 56: 240-241.

Mgina, C. A. (2000). *Development of crop functions for estimating crop and soil management factors of the Universal Soil Loss Equation for soil erosion prediction under Tanzanian conditions.* Unpublished Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania, pp 97.

Mlengera, N. (2008). *Influence of Lablab purpureus cover crop and crop residues on water productivity under irrigated maize in the Usangu plains, Tanzania*. Unpublished Dissertation for Award of MSc Degree at Sokoine University of Agriculture, Morogoro, Tanzania, 75 pp.

Moore, T.R. (1979). Rainfall erosivity in East Africa. Georg. Ann 61A, 147-156.

Morgan, R.P.C. (1985). Effect of corn and soybean canopy on soil detachment by rainfall. *Transactions of American Society of Agricultural Engineers* 28, 1135-1140.

Morgan, R.P.C. (2005). Soil Erosion and Conservation. Third edition. Blackwell Publishing. 304pp.

Moukam, A. and Ngakanou, D. (1997). The Fertility Status Surface Soils in the Humid Forest Zone of Southern Cameroon. *East African Crop Science Journal.* 5(1): 273-284.

Msaky, J.J.T., Kaaya, A., Kayeke, M., Sibuga, K.P. and Kilima, F.T.M. (2005). Pedological and Soil Fertility Characteristics of Striga Infested Soils Under Maize in Chunya and Iringa Districts of Tanzania. *Tanzania Journal of Agriculture Science*. 23(4): 88-97.

Mulengera, M. K. and Payton, R. W. (1999). Estimating the USLE – soil erodibility factor in developing tropical countries. *Trop. Agric*. (Trinidad) 76 (1):17 – 22.

Mulengera, M.K. (2011). Introduction to Soil and water conservation for the Tropics. Unpublished Lecture Notes. 287pp.

Mulengera, M.K., Lulandala, L.L.L. and Maliondo, S.M.S. (2009). Soil erosion and sediment yield from the degraded Mzinga river catchment in Uluguru Mountains, Tanzania. *Tanzania Journal of Forestry and Nature Conservation* 79 (1): 20-32.

Mureithi, J.G., Gachene, C.K.K. and Wamuongo, J.W. (2003). Legume Cover Crops Research in Kenya KARI Technical Note Series No.12, February, 2003 pp 2-3.

Mvena, Z.S.K. and Kilima, F.T.M. (2009). Hillside conservation agriculture project (HICAP) for improved livelihood in the south Uluguru Mountains, Tanzania. Baseline Survey in Kasanga and Kolero wards, Morogoro, Tanzania. 110pp.

Nkeshimana, G. (2008). The relation between land management practices, soil physical properties and erosion in coffee systems in south Rwanda. Dissertation for Award of MSc. Degree at Wageningen University Netherlands. 102 pp.

Omar, M.M. (2013). Developing Rainfall Erosivity Equations for use in Tanzania with limited Rainfall Intensity data. Unpublished Dissertation for Award of MSc. Degree at Sokoine University of Agriculture, Morogoro, Tanzania. 65 pp.

Owenya, M.Z., Marik, W.L., Kienzle, J., Friedrich, T. and Kassam, A. (2011). Conservation agriculture (CA) in Tanzania: the case of the Mwangaza "B" CA farmer field school (FFS), Rhotia Village, Karatu District, Arusha. *International Journal of Agricultural Sustainability* 9(1): 145-152.

Pierce, F.J., Larson, W. E., Dowdy, R. H. and Graham,W.A.P. (1983). Productivity of soils: Assessing long-term changes due to erosion. *Journal of Soil and Water Conservation* 38(3): 39-44. [http://www.jswconline.org/ search?] Site visited on 22/03/2014.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L., Saffouri, R. and Blair, R. (1995). Environmental and economic costs of soil erosion and conservation benefits. Science 267: 1117-1123.

Rapp, A., Axelson,V., Berry, L. and Murray-Rust, D. H. (1972). Soil Erosion and Sediment Transport in the Morogoro river catchment, Tanzania. . *Geografiska Annalar*., 54A (3-4): 1125-155.

Renard, K.G. and Freimund, J. R. (1994). Using monthly precipitation data to estimate the R factor in the revised USLE. *Journal of hydrology* 157(3): 287-306.

Rose, C, W., Coughan, K. J., Ciesiolka, C.A.A. and Fentie, B. (1997). The Role of Cover in Soil Conservation in Coughlan, K.J. and Rose, C.W. (Eds) (1997). A new soil conservation methodology and application to cropping systems in tropical steep lands. ACIAR Technical Reports No. 40, 147 pp.

Sarrantonio, M. and Gallandt, E. (2003). The role of Cover Crops in North American cropping Systems. *Journal of Crop Production*.8(4): 53-74.

Scherr, J. (1999). The State of World Population. [http://www.unfpa.org/swp/1999/intro/preview.htm]. Site visited on 16/06/2013.

Schobrodt, S., Saumer, P., Behrens, T., Seeber, C. and Scholten, T. (2010). Assessing the USLE crop and management factor *C* for soil erosion modeling in a large mountainous watershed in Central China. *Journal of Earth Science*. 21(6): 835-845.

Sheng, T. C. (1990). Runoff plots and erosion phenomena on tropical steeplands. Research Needs and Applications to Reduce Erosion and Sedimentation in Tropical Steeplands (Proceedings of the Fiji Symposium, June 1990): IAHS-ISSS Publ. No.192.

Shetto, R. and Owenya, M. (2007). *Conservation agriculture as practiced in Tanzania: Three case studies.* African Conservation Tillage Network, Centre of Development, Food and Agriculture Organization of the United Nations, Nairobi. 147pp.

Shrestha, D. P. (1997). Assessment of Soil Erosion in the Nepalese Himalaya, A Case Study in Likhu Khola Valley, Middle Mountain Region. Land husbandry, volume 2, no. 1. Oxford and IBH Publishing Co. Pvt. Ltd, pp.59-80.

Stocking, M. A. (1988). Assessing vegetative cover and management effects In Lal, R. (Ed) (1988) *Soil erosion research methods.* Soil and water conservation society. 200 pp.

Sullivan, P. (2003). Overview of Cover Crops and Green Manures, 16pp. [http://attra.ncat.org/attra-pub/PDF/covercrop.pdf] Site visited on 16/10/2013.

Tangtham, N. (1991). Erosion study and control in Thailand. In: Soil Erosion and Debris Flow Control. The Indonesian Institute of Science, Yogyakarta. 32 pp.

Temple, P. H. and Murray-Rust, D. H. (1972). Sheet wash measurements on erosion plots at Mfumbwe, Eastern Uluguru Mountains, Tanzania. *Geografiska Annalar.*, 54A (3-4): 195-202.

Temu, A. E. M. and Bisanda, S. (1996). Pit Cultivation in the Matengo Highlands of Tanzania. In Reij, C., Scoones, I. and Toulimn, C. (1996). Sustaining the Soil- Indigenous Soil and Water Conservation in Africa. London, UK. Earthscan Publications. 24pp.

Turkelboom, F. (1999). On-farm diagnosis of steepland erosion in northern Thailand: Integrating spatial scales with household strategies. PhD Thesis, Catholic University of Leuven, Belgium. 309pp.

URT (2005). Uluguru Component Biodiversity Survey 2005. Ministry of Natural Resources and Tourism. Conservation and Management of the Eastern Arc Mountain Forests, Tanzania. Dar es Salaam, Tanzania. 90pp.

Valenzuela, H. and Smith, J. (2002). Sustainable Agriculture Green Manure Crops Aug. 2002, SA-GM-7. University of Hawaii. http://hdl.net/10125/12737 site visited on 10/11/2013.

Van Hulst, F. (2011). Soil erosion prediction using RUSLE for rainfed crops under Conservation Agriculture practices in the Lake Alaotra region in Madagascar. Dissertation for Award of Msc. Degree Wageningen University 55pp.

Wischmeir, W.H. and Smith, D.D. (1978). *Predictingrainfall erosion losses- A guide to conservation planning.*US dept. of Agric., Agricultural Handbook no.537, 58pp.

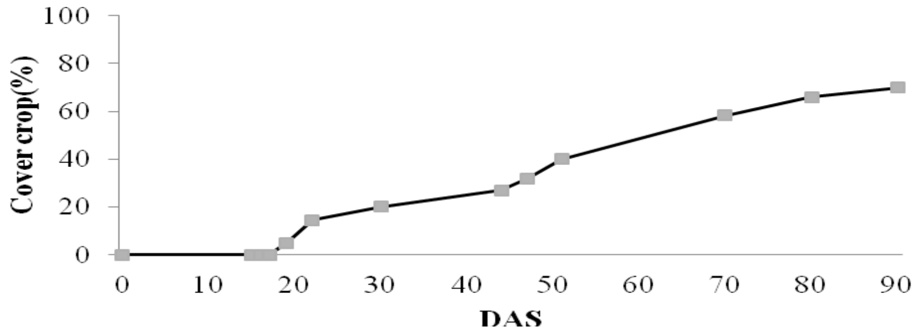
Woltering, L. (2005). Estimating the influence of on farm Conservation Practices on the Water Balance: Case of the Mzinyatthini Catchment in Zimbabwe. Msc. thesis Delft University of Technology. 103 pp.

Wu, C. (1997). Effective conservation practises for the cultivation of slope lands. National Pingtung University of Science and Technology, Taiwan. *Journal of Chinese Soil and Water Conservation*. 26 (2): 121-133.

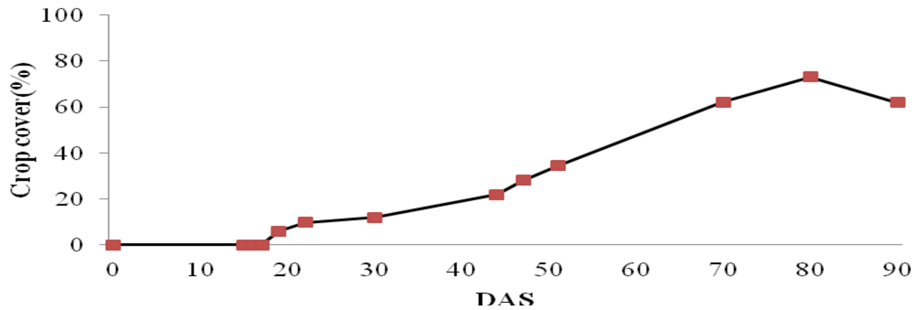
Zegeye, A.D., Steenhuis, T.S., Blake, R.W., Kidnau, S., Collick, A.S. and Dadgari F., (2009). Assessment of Upland Erosion Processes and Farmer Perception of Land Conservation in Debre-Mewi Watershed, near Lake Tana, Ethiopia. International Symposium: “Ecohydrology for water ecosystems and society in Ethiopia” Addis Ababa, Ethiopia: pp. 18-20.

APPENDICES

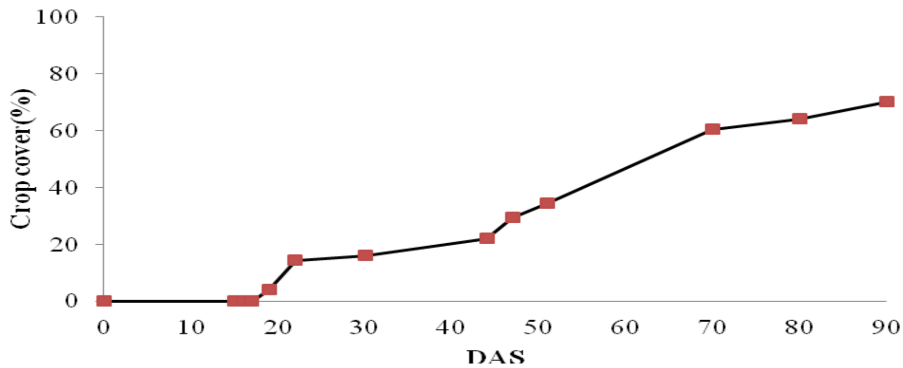
Appendix 1: Ground surface covers



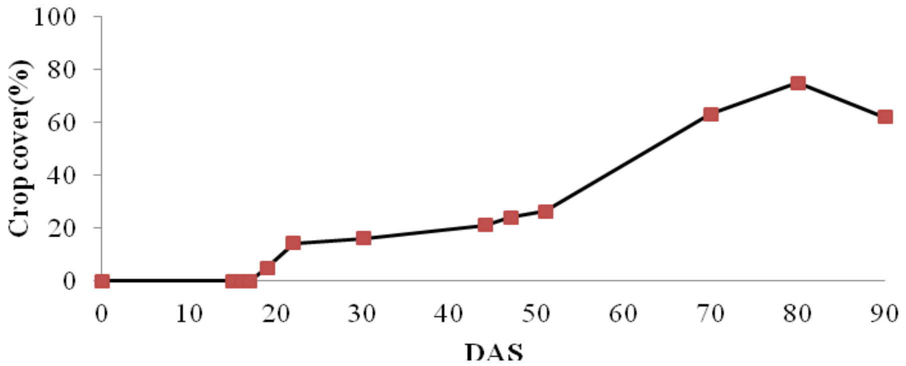
(a) Lablab ground surface cover (T2)



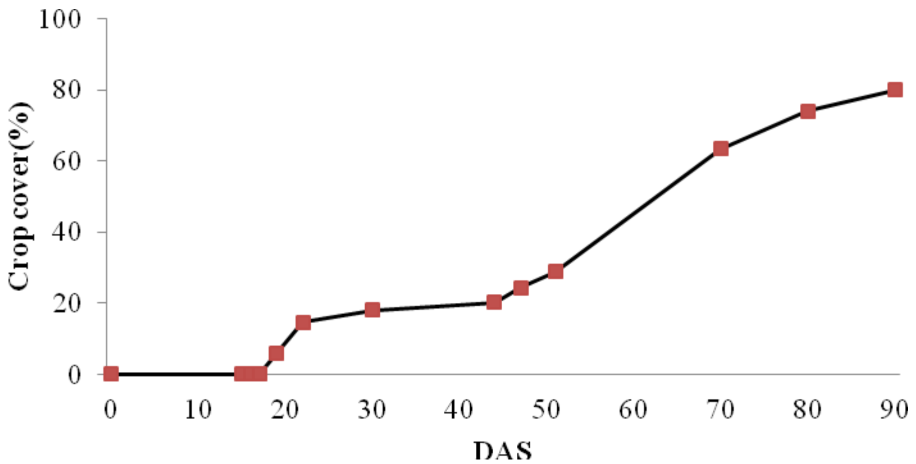
(b) Cowpea ground surface cover (T3)



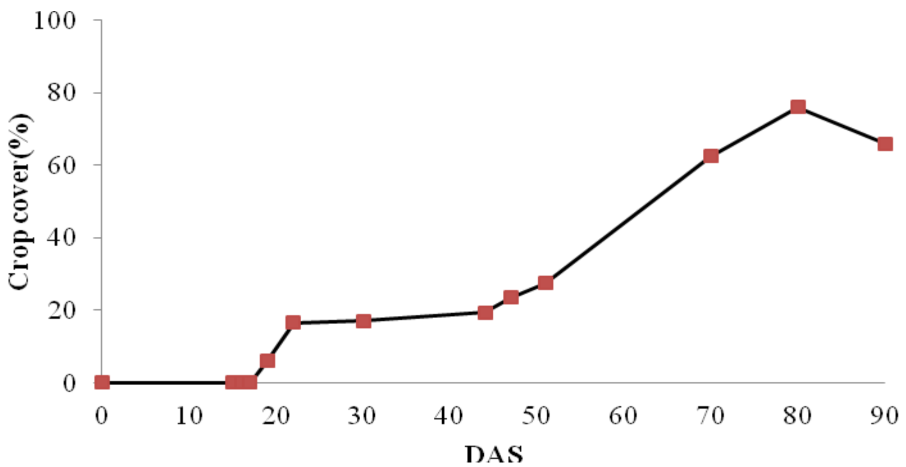
(c) Lablab ground surface cover (T5)



(d) Cowpea ground cover (T6)



(e) Lablab ground surface cover (T8)



(f) Cowpea ground surface cover (T9)

Appendix 2: Seasonal crop management factors determination

(a) Treatment 1: Shallow tillage + Maize

DAS	CCi	GSCi	SRi	PLUi	Reconi	EI/sumEI	Ci
5	1	1	0.9	0.9	1	0.0061	0.0049
6	1	1	0.9	0.9	1	0.0167	0.0135
7	1	1	0.9	0.9	1	0.0508	0.0412
8	1	1	0.9	0.9	1	0.0008	0.0006
15	0.97	1	0.9	0.9	1	0.0589	0.0463
17	0.85	1	0.9	0.9	1	0.1174	0.0808
18	0.85	1	0.9	0.9	1	0.0559	0.0385
19	0.82	1	0.9	0.9	1	0.0278	0.0185
22	0.8	1	0.9	0.9	1	0.0379	0.0246
24	0.81	1	0.9	0.9	1	0.0149	0.0098
26	0.8	1	0.9	0.9	1	0.0559	0.0362
30	0.86	1	0.9	0.9	1	0.0559	0.0389
32	0.82	1	0.9	0.9	1	0.1518	0.1008
33	0.82	1	0.9	0.9	1	0.0152	0.0101
40	0.78	1	0.9	0.9	1	0.0529	0.0334
44	0.77	1	0.9	0.9	1	0.0266	0.0166
47	0.7	1	0.9	0.9	1	0.0304	0.0172
51	0.72	1	0.9	0.9	1	0.0149	0.0087
55	0.71	1	0.9	0.9	1	0.0154	0.0089
56	0.71	1	0.9	0.9	1	0.0916	0.0527
57	0.65	1	0.9	0.9	1	0.0154	0.0081
62	0.68	1	0.9	0.9	1	0.0248	0.0137
66	0.73	1	0.9	0.9	1	0.0020	0.0012
68	0.82	1	0.9	0.9	1	0.0015	0.0010
70	0.82	1	0.9	0.9	1	0.0091	0.0060
							0.632

(b) Treatment 2: Shallow tillage + Maize + Lablab

DAS	CCi	GSCi	SRi	PLUi	Reconi	EI/sumEI	Ci
5	1	1	0.9	0.9	1	0.0061	0.0049
6	1	1	0.9	0.9	1	0.0167	0.0135
7	1	1	0.9	0.9	1	0.0508	0.0412
8	1	1	0.9	0.9	1	0.0008	0.0006
15	0.94	1	0.9	0.9	1	0.0589	0.0449
17	0.93	1	0.9	0.9	1	0.1174	0.0884
18	0.9	1	0.9	0.9	1	0.0559	0.0408
19	0.93	0.68	0.9	0.9	1	0.0278	0.0143
22	0.88	0.62	0.9	0.9	1	0.0379	0.0168
24	0.84	0.6	0.9	0.9	1	0.0149	0.0061
26	0.84	0.59	0.9	0.9	1	0.0559	0.0224
30	0.82	0.59	0.9	0.9	1	0.0559	0.0219
32	0.83	0.56	0.9	0.9	1	0.1518	0.0571
33	0.82	0.55	0.9	0.9	1	0.0152	0.0055
40	0.95	0.55	0.9	0.9	1	0.0529	0.0224
44	0.9	0.52	0.9	0.9	1	0.0266	0.0101
47	0.86	0.5	0.9	0.9	1	0.0304	0.0106
51	0.83	0.45	0.9	0.9	1	0.0149	0.0045
55	0.81	0.36	0.9	0.9	1	0.0154	0.0036
56	0.8	0.35	0.9	0.9	1	0.0916	0.0208
57	0.82	0.3	0.9	0.9	1	0.0154	0.0031
62	0.79	0.28	0.9	0.9	1	0.0248	0.0044
66	0.79	0.25	0.9	0.9	1	0.0020	0.0003
68	0.8	0.23	0.9	0.9	1	0.0015	0.0002
70	0.8	0.22	0.9	0.9	1	0.0091	0.0013
	0.82	0.22	0.9	0.9	1	0.0053	0.0008
							0.461

(c) Treatment 3: Shallow tillage + Maize + Cowpea

DAS	CCi	GSCi	SRi	PLUi	Reconi	EI/sumEI	Ci
5	1	1	0.9	0.9	1	0.0061	0.0049
6	1	1	0.9	0.9	1	0.0167	0.0135
7	1	1	0.9	0.9	1	0.0508	0.0412
8	1	1	0.9	0.9	1	0.0008	0.0006
15	0.98	1	0.9	0.9	1	0.0589	0.0468
17	0.98	1	0.9	0.9	1	0.1174	0.0932
18	0.84	1	0.9	0.9	1	0.0559	0.0380
19	0.83	0.95	0.9	0.9	1	0.0278	0.0178
22	0.83	0.89	0.9	0.9	1	0.0379	0.0227
24	0.82	0.74	0.9	0.9	1	0.0149	0.0073
26	0.8	0.7	0.9	0.9	1	0.0559	0.0254
30	0.94	0.68	0.9	0.9	1	0.0559	0.0289
32	0.93	0.67	0.9	0.9	1	0.1518	0.0766
33	0.91	0.64	0.9	0.9	1	0.0152	0.0072
40	0.91	0.62	0.9	0.9	1	0.0529	0.0242
44	0.9	0.58	0.9	0.9	1	0.0266	0.0112
47	0.88	0.54	0.9	0.9	1	0.0304	0.0117
51	0.87	0.46	0.9	0.9	1	0.0149	0.0048
55	0.87	0.4	0.9	0.9	1	0.0154	0.0043
56	0.86	0.39	0.9	0.9	1	0.0916	0.0249
57	0.86	0.37	0.9	0.9	1	0.0154	0.0040
62	0.84	0.32	0.9	0.9	1	0.0248	0.0054
66	0.82	0.28	0.9	0.9	1	0.0020	0.0004
68	0.82	0.27	0.9	0.9	1	0.0015	0.0003
70	0.83	0.25	0.9	0.9	1	0.0091	0.0015
	0.59	0.14	0.9	0.9	1	0.0053	0.0004
							0.517

(d) Treatment 4: Zero tillage + Maize

DAS	CCi	GSCi	SRi	PLUi	Reconi	EI/sumEI	Ci
5	1	1	0.9	0.9	0.5	0.0061	0.0025
6	1	1	0.9	0.9	0.5	0.0167	0.0068
7	1	1	0.9	0.9	0.5	0.0508	0.0206
8	1	1	0.9	0.9	0.5	0.0008	0.0003
15	0.97	1	0.9	0.9	0.5	0.0589	0.0232
17	0.93	1	0.9	0.9	0.5	0.1174	0.0442
18	0.93	1	0.9	0.9	0.5	0.0559	0.0211
19	0.89	1	0.9	0.9	0.5	0.0278	0.0100
22	0.88	1	0.9	0.9	0.5	0.0379	0.0135
24	0.85	1	0.9	0.9	0.5	0.0149	0.0051
26	0.82	1	0.9	0.9	0.5	0.0559	0.0186
30	0.8	1	0.9	0.9	0.5	0.0559	0.0181
32	0.78	1	0.9	0.9	0.5	0.1518	0.0479
33	0.77	1	0.9	0.9	0.5	0.0152	0.0047
40	0.75	1	0.9	0.9	0.5	0.0529	0.0161
44	0.76	1	0.9	0.9	0.5	0.0266	0.0082
47	0.75	1	0.9	0.9	0.5	0.0304	0.0092
51	0.7	1	0.9	0.9	0.5	0.0149	0.0042
55	0.65	1	0.9	0.9	0.5	0.0154	0.0041
56	0.64	1	0.9	0.9	0.5	0.0916	0.0237
57	0.62	1	0.9	0.9	0.5	0.0154	0.0039
62	0.6	1	0.9	0.9	0.5	0.0248	0.0060
66	0.62	1	0.9	0.9	0.5	0.0020	0.0005
68	0.63	1	0.9	0.9	0.5	0.0015	0.0004
70	0.65	1	0.9	0.9	0.5	0.0091	0.0024
							0.317

(e) Treatment 5: Zero tillage + maize + Lablab

DAS	CCi	GSCi	SRi	PLUi	Reconi	EI/sumEI	Ci
5	1	1	0.9	0.9	0.5	0.0061	0.0025
6	1	1	0.9	0.9	0.5	0.0167	0.0068
7	1	1	0.9	0.9	0.5	0.0508	0.0206
8	1	1	0.9	0.9	0.5	0.0008	0.0003
15	0.9	1	0.9	0.9	0.5	0.0589	0.0215
17	0.89	1	0.9	0.9	0.5	0.1174	0.0423
18	0.89	1	0.9	0.9	0.5	0.0559	0.0202
19	0.87	0.9	0.9	0.9	0.5	0.0278	0.0088
22	0.94	0.72	0.9	0.9	0.5	0.0379	0.0104
24	0.94	0.7	0.9	0.9	0.5	0.0149	0.0040
26	0.95	0.64	0.9	0.9	0.5	0.0559	0.0138
30	0.96	0.69	0.9	0.9	0.5	0.0559	0.0150
32	0.96	0.68	0.9	0.9	0.5	0.1518	0.0401
33	0.94	0.63	0.9	0.9	0.5	0.0152	0.0036
40	0.92	0.59	0.9	0.9	0.5	0.0529	0.0116
44	0.91	0.58	0.9	0.9	0.5	0.0266	0.0057
47	0.9	0.53	0.9	0.9	0.5	0.0304	0.0059
51	0.87	0.44	0.9	0.9	0.5	0.0149	0.0023
55	0.87	0.4	0.9	0.9	0.5	0.0154	0.0022
56	0.84	0.38	0.9	0.9	0.5	0.0916	0.0118
57	0.84	0.35	0.9	0.9	0.5	0.0154	0.0018
62	0.8	0.32	0.9	0.9	0.5	0.0248	0.0026
66	0.77	0.29	0.9	0.9	0.5	0.0020	0.0002
68	0.76	0.27	0.9	0.9	0.5	0.0015	0.0001
70	0.76	0.25	0.9	0.9	0.5	0.0091	0.0007
	0.6	0.24	0.9	0.9	0.5	0.0053	0.0003
							0.255

(f) Treatment 6: Zero tillage + Maize + Cowpea

DAS	CCi	GSCi	SRi	PLUi	Reconi	EI/sumEI	Ci
5	1	1	0.9	0.9	0.5	0.0061	0.0025
6	1	1	0.9	0.9	0.5	0.0167	0.0068
7	1	1	0.9	0.9	0.5	0.0508	0.0206
8	1	1	0.9	0.9	0.5	0.0008	0.0003
15	0.95	1	0.9	0.9	0.5	0.0589	0.0227
17	0.95	1	0.9	0.9	0.5	0.1174	0.0452
18	0.93	1	0.9	0.9	0.5	0.0559	0.0211
19	0.92	0.98	0.9	0.9	0.5	0.0278	0.0102
22	0.98	0.68	0.9	0.9	0.5	0.0379	0.0102
24	0.98	0.68	0.9	0.9	0.5	0.0149	0.0040
26	0.97	0.67	0.9	0.9	0.5	0.0559	0.0147
30	0.96	0.67	0.9	0.9	0.5	0.0559	0.0146
32	0.95	0.64	0.9	0.9	0.5	0.1518	0.0374
33	0.95	0.6	0.9	0.9	0.5	0.0152	0.0035
40	0.94	0.58	0.9	0.9	0.5	0.0529	0.0117
44	0.94	0.5	0.9	0.9	0.5	0.0266	0.0051
47	0.93	0.49	0.9	0.9	0.5	0.0304	0.0056
51	0.91	0.46	0.9	0.9	0.5	0.0149	0.0025
55	0.88	0.4	0.9	0.9	0.5	0.0154	0.0022
56	0.87	0.39	0.9	0.9	0.5	0.0916	0.0126
57	0.85	0.39	0.9	0.9	0.5	0.0154	0.0021
62	0.82	0.31	0.9	0.9	0.5	0.0248	0.0026
66	0.8	0.26	0.9	0.9	0.5	0.0020	0.0002
68	0.78	0.25	0.9	0.9	0.5	0.0015	0.0001
70	0.78	0.22	0.9	0.9	0.5	0.0091	0.0006
	0.61	0.19	0.9	0.9	0.5	0.0053	0.0002
							0.259

(g) Treatment 7: Strip tillage + maize

DAS	CCi	GSCi	SRi	PLUi	Reconi	EI/sumEI	Ci
5	1	1	0.9	0.9	0.6	0.0061	0.0030
6	1	1	0.9	0.9	0.6	0.0167	0.0081
7	1	1	0.9	0.9	0.6	0.0508	0.0247
8	1	1	0.9	0.9	0.6	0.0008	0.0004
15	0.95	1	0.9	0.9	0.6	0.0589	0.0272
17	0.95	1	0.9	0.9	0.6	0.1174	0.0542
18	0.94	1	0.9	0.9	0.6	0.0559	0.0255
19	0.94	1	0.9	0.9	0.6	0.0278	0.0127
22	0.93	1	0.9	0.9	0.6	0.0379	0.0171
24	0.81	1	0.9	0.9	0.6	0.0149	0.0059
26	0.81	1	0.9	0.9	0.6	0.0559	0.0220
30	0.76	1	0.9	0.9	0.6	0.0559	0.0206
32	0.72	1	0.9	0.9	0.6	0.1518	0.0531
33	0.71	1	0.9	0.9	0.6	0.0152	0.0052
40	0.63	1	0.9	0.9	0.6	0.0529	0.0162
44	0.6	1	0.9	0.9	0.6	0.0266	0.0077
47	0.58	1	0.9	0.9	0.6	0.0304	0.0086
51	0.57	1	0.9	0.9	0.6	0.0149	0.0041
55	0.57	1	0.9	0.9	0.6	0.0154	0.0043
56	0.56	1	0.9	0.9	0.6	0.0916	0.0249
57	0.62	1	0.9	0.9	0.6	0.0154	0.0046
62	0.65	1	0.9	0.9	0.6	0.0248	0.0078
66	0.65	1	0.9	0.9	0.6	0.0020	0.0006
68	0.65	1	0.9	0.9	0.6	0.0015	0.0005
70	0.66	1	0.9	0.9	0.6	0.0091	0.0029
							0.364

(h) Treatment 8: Strip tillage + maize + Lablab

DAS	CCi	GSCi	SRi	PLUi	Reconi	EI/sumEI	Ci
5	1	1	0.9	0.9	0.6	0.0061	0.0030
6	0.98	1	0.9	0.9	0.6	0.0167	0.0080
7	0.98	1	0.9	0.9	0.6	0.0508	0.0242
8	0.97	1	0.9	0.9	0.6	0.0008	0.0004
15	0.96	1	0.9	0.9	0.6	0.0589	0.0275
17	0.94	1	0.9	0.9	0.6	0.1174	0.0536
18	0.94	1	0.9	0.9	0.6	0.0559	0.0255
19	0.92	0.85	0.9	0.9	0.6	0.0278	0.0106
22	0.98	0.9	0.9	0.9	0.6	0.0379	0.0163
24	0.98	0.85	0.9	0.9	0.6	0.0149	0.0060
26	0.97	0.74	0.9	0.9	0.6	0.0559	0.0195
30	0.96	0.68	0.9	0.9	0.6	0.0559	0.0177
32	0.96	0.61	0.9	0.9	0.6	0.1518	0.0432
33	0.96	0.6	0.9	0.9	0.6	0.0152	0.0042
40	0.95	0.53	0.9	0.9	0.6	0.0529	0.0129
44	0.93	0.5	0.9	0.9	0.6	0.0266	0.0060
47	0.92	0.48	0.9	0.9	0.6	0.0304	0.0065
51	0.88	0.44	0.9	0.9	0.6	0.0149	0.0028
55	0.86	0.38	0.9	0.9	0.6	0.0154	0.0025
56	0.86	0.37	0.9	0.9	0.6	0.0916	0.0142
57	0.85	0.35	0.9	0.9	0.6	0.0154	0.0022
62	0.84	0.3	0.9	0.9	0.6	0.0248	0.0030
66	0.82	0.28	0.9	0.9	0.6	0.0020	0.0002
68	0.8	0.25	0.9	0.9	0.6	0.0015	0.0001
70	0.78	0.22	0.9	0.9	0.6	0.0091	0.0008
	0.62	0.12	0.9	0.9	0.6	0.0053	0.0002
							0.311

(i) Treatment 9: Strip tillage + Maize + Cowpea

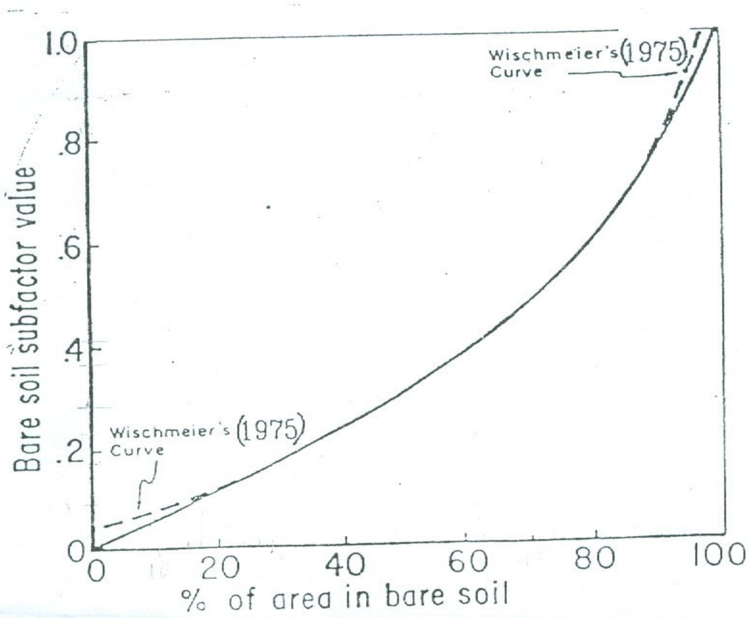
DAS	CCi	GSCi	SRi	PLUi	Reconi	EI/sumEI	Ci
5	1	1	0.9	0.9	0.6	0.0061	0.0030
6	1	1	0.9	0.9	0.6	0.0167	0.0081
7	1	1	0.9	0.9	0.6	0.0508	0.0247
8	1	1	0.9	0.9	0.6	0.0008	0.0004
15	0.98	1	0.9	0.9	0.6	0.0589	0.0281
17	0.97	1	0.9	0.9	0.6	0.1174	0.0553
18	0.97	1	0.9	0.9	0.6	0.0559	0.0264
19	0.92	0.9	0.9	0.9	0.6	0.0278	0.0112
22	0.98	0.9	0.9	0.9	0.6	0.0379	0.0163
24	0.97	0.84	0.9	0.9	0.6	0.0149	0.0059
26	0.97	0.73	0.9	0.9	0.6	0.0559	0.0192
30	0.96	0.71	0.9	0.9	0.6	0.0559	0.0185
32	0.95	0.71	0.9	0.9	0.6	0.1518	0.0498
33	0.95	0.7	0.9	0.9	0.6	0.0152	0.0049
40	0.94	0.62	0.9	0.9	0.6	0.0529	0.0150
44	0.93	0.58	0.9	0.9	0.6	0.0266	0.0070
47	0.91	0.54	0.9	0.9	0.6	0.0304	0.0072
51	0.88	0.5	0.9	0.9	0.6	0.0149	0.0032
55	0.86	0.38	0.9	0.9	0.6	0.0154	0.0025
56	0.83	0.37	0.9	0.9	0.6	0.0916	0.0137
57	0.83	0.34	0.9	0.9	0.6	0.0154	0.0021
62	0.82	0.28	0.9	0.9	0.6	0.0248	0.0028
66	0.8	0.25	0.9	0.9	0.6	0.0020	0.0002
68	0.79	0.22	0.9	0.9	0.6	0.0015	0.0001
70	0.77	0.2	0.9	0.9	0.6	0.0091	0.0007
	0.58	0.21	0.9	0.9	0.6	0.0053	0.0003
							0.326

Appendix 3: Soil particle size distribution (soil texture) at a depth of 0-15 cm at Kolero research site

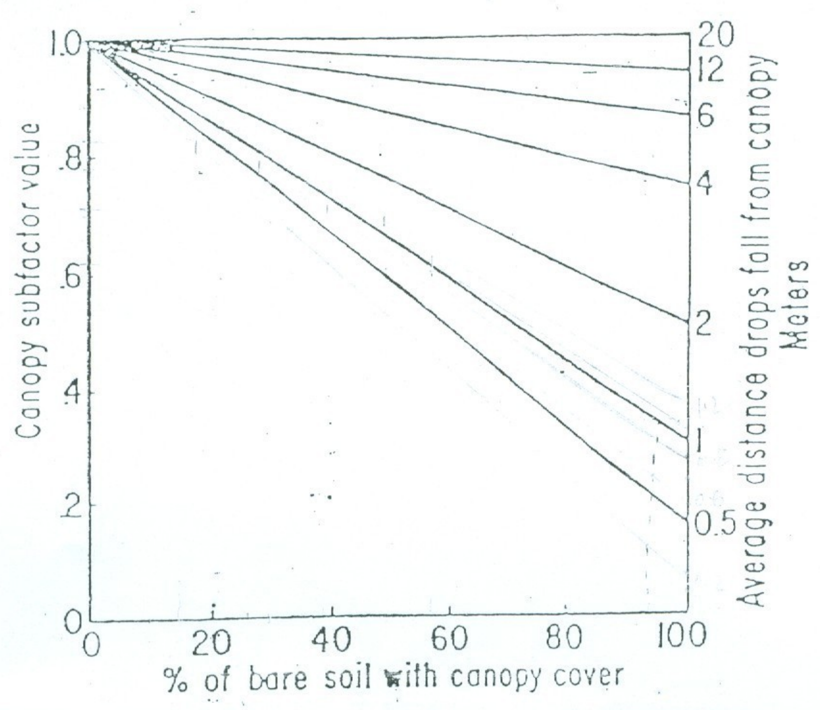
Treatment	Tillage system	Cover	Sand%	Clay%	Silt%	Textural class	Erodibility K
T1	Shallow tillage		33.51	53.33	13.16	Clay	0.015
T2	Shallow tillage	Lablab	40.84	46	13.16	Sand Clay	0.018
T3	Shallow tillage	Cowpea	43.84	43	13.16	Sand Clay	0.019
T4	Zero tillage		36.51	50.33	13.16	Sand Clay	0.016
T5	Zero tillage	Lablab	34.51	53	12.49	Sand Clay	0.015
T6	Zero tillage	Cowpea	31.17	55.67	13.16	Sand Clay	0.014
T7	Strip tillage		29.17	57.67	13.16	Sand Clay	0.014
T8	Strip tillage	Lablab	28.29	60.00	11.71	Sand Clay	0.012
T9	Strip tillage	Cowpea	24.96	62.00	13.16	Sand Clay	0.012

SI unit for K is t-ha-hr/ha-MJ-mm

Appendix 4: Estimation of ground cover sub-factor



Appendix 5: Estimation of canopy cover sub-factor



Appendix 6: Mean monthly rainfall of five locations within Uluguru Mountains

Month	Nyandira	Tchezema	Morogoro	Morning side	Kolero
January	75	165	94	148	152.59
February	160	120	104	135	103.19
March	260	135	167	255	452.1
April	260	355	208	506	421.7
May	105	105	96	310	53.97
June	0	40	27	101	89.3
July	10	20	15	81	37.2
August	20	15	10	78	0
September	10	25	17	93	36.3
October	50	20	27	143	354.4
November	60	120	54	199	188.8
December	75	135	73	186	47.1
Annual	1085	1255	892	2235	1936.65

Appendix 7: Crop management factors, C, for all treatments

(a) Treatment 1: Shallow tillage + Maize

Months	CC_i	GSC_i	SR_i	PLU_i	$RECONS_i$	EI_{30mo}/EI_{30an}	C_i
January	1	1	0.9	0.9	1	0.086	0.070
February	1	1	0.9	0.9	1	0.084	0.068
March	0.9	1	0.9	0.9	1	0.171	0.125
April	0.76	1	0.9	0.9	1	0.236	0.145
May	0.74	1	0.9	0.9	1	0.09	0.054
June	1	1	0.9	0.9	1	0.035	0.028
July	1	1	0.9	0.9	1	0.022	0.018
August	1	1	0.9	0.9	1	0.017	0.014
September	1	1	0.9	0.9	1	0.024	0.019
October	1	1	0.9	0.9	1	0.08	0.065
November	1	1	0.9	0.9	1	0.084	0.068
December	1	1	0.9	0.9	1	0.07	0.057
							0.731

(b) Treatment 2: Shallow tillage + Lablab

Months	CC_i	GSC_i	SR_i	PLU_i	$RECONS_i$	EI_{30mo}/EI_{30an}	C_i
January	1	0.135	0.9	0.9	1	0.086	0.009
February	1	0.135	0.9	0.9	1	0.084	0.009
March	0.93	0.71	0.9	0.9	1	0.171	0.091
April	0.74	0.59	0.9	0.9	1	0.236	0.083
May	0.72	0.38	0.9	0.9	1	0.09	0.020
June	1	0.135	0.9	0.9	1	0.035	0.004
July	1	0.135	0.9	0.9	1	0.022	0.002
August	1	0.135	0.9	0.9	1	0.017	0.002
September	1	0.135	0.9	0.9	1	0.024	0.003
October	1	0.135	0.9	0.9	1	0.08	0.009
November	1	0.135	0.9	0.9	1	0.084	0.009
December	1	0.135	0.9	0.9	1	0.07	0.008
							0.250

(c) Treatment 3: Shallow tillage + Cowpea

Months	CC_i	GSC_i	SR_i	PLU_i	$RECONS_i$	EI_{30mo}/EI_{30an}	C_i
January	1	0.139	0.9	0.9	1	0.086	0.010
February	1	0.139	0.9	0.9	1	0.084	0.009
March	0.92	0.81	0.9	0.9	1	0.171	0.103
April	0.69	0.58	0.9	0.9	1	0.236	0.077
May	0.57	0.45	0.9	0.9	1	0.09	0.019
June	1	0.139	0.9	0.9	1	0.035	0.004
July	1	0.139	0.9	0.9	1	0.022	0.002
August	1	0.139	0.9	0.9	1	0.017	0.002
September	1	0.139	0.9	0.9	1	0.024	0.003
October	1	0.139	0.9	0.9	1	0.08	0.009
November	1	0.139	0.9	0.9	1	0.084	0.009
December	1	0.139	0.9	0.9	1	0.07	0.008
							0.255

(d) Treatment 4: Zero tillage

Months	CC_i	GSC_i	SR_i	PLU_i	$RECONS_i$	EI_{30mo}/EI_{30an}	C_i
January	1	1	0.9	0.9	0.5	0.086	0.035
February	1	1	0.9	0.9	0.5	0.084	0.034
March	0.93	1	0.9	0.9	0.5	0.171	0.064
April	0.73	1	0.9	0.9	0.5	0.236	0.070
May	0.62	1	0.9	0.9	0.5	0.09	0.023
June	1	1	0.9	0.9	0.5	0.035	0.014
July	1	1	0.9	0.9	0.5	0.022	0.009
August	1	1	0.9	0.9	0.5	0.017	0.007
September	1	1	0.9	0.9	0.5	0.024	0.010
October	1	1	0.9	0.9	0.5	0.08	0.032
November	1	1	0.9	0.9	0.5	0.084	0.034
December	1	1	0.9	0.9	0.5	0.07	0.028
							0.360

(e) Treatment 5: Zero tillage + Lablab

Months	CC_i	GSC_i	SR_i	PLU_i	$RECONS_i$	EI_{30mo}/EI_{30an}	C_i
January	1	0.141	0.9	0.9	0.5	0.086	0.005
February	1	0.141	0.9	0.9	0.5	0.084	0.005
March	0.92	0.81	0.9	0.9	0.5	0.171	0.052
April	0.68	0.6	0.9	0.9	0.5	0.236	0.039
May	0.59	0.46	0.9	0.9	0.5	0.09	0.010
June	1	0.141	0.9	0.9	0.5	0.035	0.002
July	1	0.141	0.9	0.9	0.5	0.022	0.001
August	1	0.141	0.9	0.9	0.5	0.017	0.001
September	1	0.141	0.9	0.9	0.5	0.024	0.001
October	1	0.141	0.9	0.9	0.5	0.08	0.005
November	1	0.141	0.9	0.9	0.5	0.084	0.005
December	1	0.141	0.9	0.9	0.5	0.07	0.004
							0.129

(f) Treatment 6: Zero tillage + Cowpea

Months	CC_i	GSC_i	SR_i	PLU_i	$RECONS_i$	EI_{30mo}/EI_{30an}	C_i
January	1	0.149	0.9	0.9	0.5	0.086	0.005
February	1	0.149	0.9	0.9	0.5	0.084	0.005
March	0.93	0.74	0.9	0.9	0.5	0.171	0.048
April	0.71	0.59	0.9	0.9	0.5	0.236	0.040
May	0.61	0.5	0.9	0.9	0.5	0.09	0.011
June	1	0.149	0.9	0.9	0.5	0.035	0.002
July	1	0.149	0.9	0.9	0.5	0.022	0.001
August	1	0.149	0.9	0.9	0.5	0.017	0.001
September	1	0.149	0.9	0.9	0.5	0.024	0.001
October	1	0.149	0.9	0.9	0.5	0.08	0.005
November	1	0.149	0.9	0.9	0.5	0.084	0.005
December	1	0.149	0.9	0.9	0.5	0.07	0.004
							0.129

(g) Treatment 7: Strip tillage

Months	CC_i	GSC_i	SR_i	PLU_i	$RECONS_i$	EI_{30mo}/EI_{30an}	C_i
January	1	1	0.9	0.9	0.6	0.086	0.042
February	1	1	0.9	0.9	0.6	0.084	0.041
March	0.94	1	0.9	0.9	0.6	0.171	0.078
April	0.63	1	0.9	0.9	0.6	0.236	0.072
May	0.65	1	0.9	0.9	0.6	0.09	0.028
June	1	1	0.9	0.9	0.6	0.035	0.017
July	1	1	0.9	0.9	0.6	0.022	0.011
August	1	1	0.9	0.9	0.6	0.017	0.008
September	1	1	0.9	0.9	0.6	0.024	0.012
October	1	1	0.9	0.9	0.6	0.08	0.039
November	1	1	0.9	0.9	0.6	0.084	0.041
December	1	1	0.9	0.9	0.6	0.07	0.034
							0.423

(h) Treatment 8: Strip tillage + Lablab

Months	CC_i	GSC_i	SR_i	PLU_i	$RECONS_i$	EI_{30mo}/EI_{30an}	C_i
January	1	0.141	0.9	0.9	0.6	0.086	0.006
February	1	0.141	0.9	0.9	0.6	0.084	0.006
March	0.95	0.76	0.9	0.9	0.6	0.171	0.060
April	0.7	0.6	0.9	0.9	0.6	0.236	0.048
May	0.61	0.49	0.9	0.9	0.6	0.09	0.013
June	1	0.141	0.9	0.9	0.6	0.035	0.002
July	1	0.141	0.9	0.9	0.6	0.022	0.002
August	1	0.141	0.9	0.9	0.6	0.017	0.001
September	1	0.141	0.9	0.9	0.6	0.024	0.002
October	1	0.141	0.9	0.9	0.6	0.08	0.005
November	1	0.141	0.9	0.9	0.6	0.084	0.006
December	1	0.141	0.9	0.9	0.6	0.07	0.005
							0.156

(i) Treatment 9: Strip tillage + Cowpea

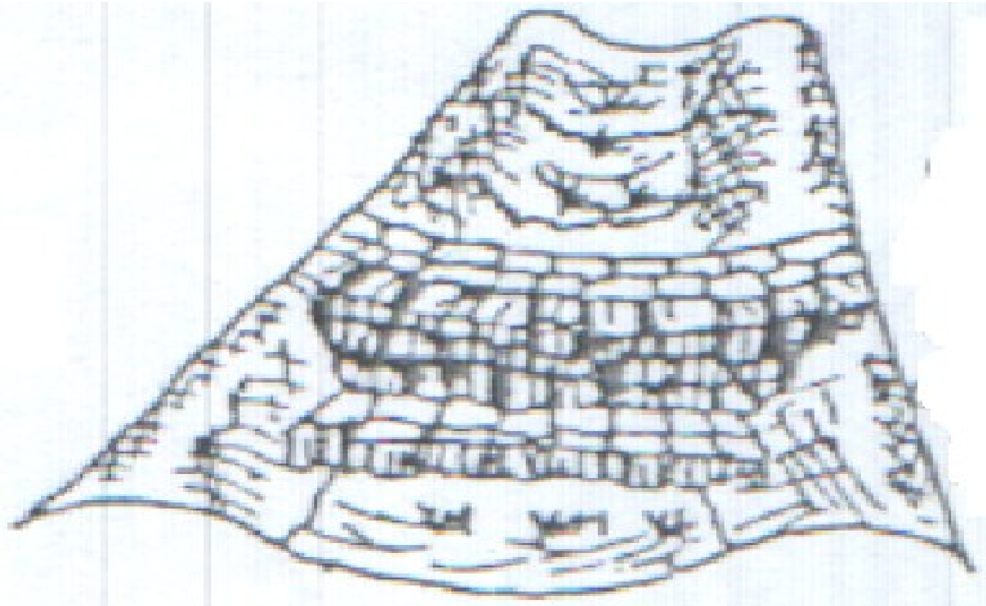
Months	CC_i	GSC_i	SR_i	PLU_i	$RECONS_i$	EI_{30mo}/EI_{30an}	C_i
January	1	0.146	0.9	0.9	0.6	0.086	0.0061
February	1	0.146	0.9	0.9	0.6	0.084	0.0060
March	0.89	0.71	0.9	0.9	0.6	0.171	0.0525
April	0.65	0.61	0.9	0.9	0.6	0.236	0.0455
May	0.55	0.5	0.9	0.9	0.6	0.09	0.0120
June	1	0.146	0.9	0.9	0.6	0.035	0.0025
July	1	0.146	0.9	0.9	0.6	0.022	0.0016
August	1	0.146	0.9	0.9	0.6	0.017	0.0012
September	1	0.146	0.9	0.9	0.6	0.024	0.0017
October	1	0.146	0.9	0.9	0.6	0.08	0.0057
November	1	0.146	0.9	0.9	0.6	0.084	0.0060
December	1	0.146	0.9	0.9	0.6	0.07	0.0050
							0.146

Appendix 8: Yield potential of some crops (tha^{-1})

Land Capability	Input	Millet	Sorghum	Maize	Soybean	Bean	Sweet Potato	Cassava
Very suitable	Low	0.9	1.1	1.6	0.7	0.7	2.2	2
	High	3.5	4.6	6.4	3	3	9.1	12.2
Suitable	Low	0.6	0.8	1	0.4	0.4	1.5	1
	High	1.8	3	4.2	2	2	6	8.1
Marginal	Low	0.3	0.4	0.5	0.2	0.2	0.7	0.3
	High	1.2	1.5	2.1	1	1	3	4

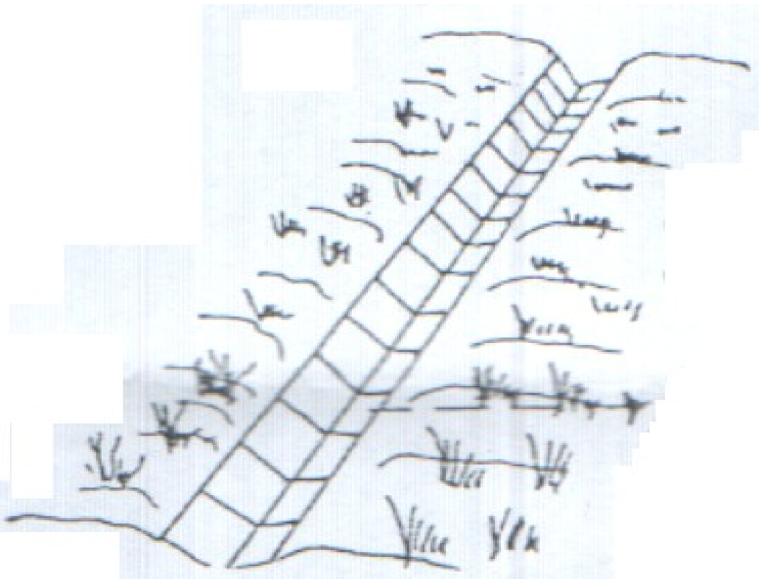
Source: FAO,1978

Appendix 9: Grass waterway stone pitched



Source: Fahlen, 1989

Appendix 10: Concrete waterway



Source: Fahlen, 1989