EFFECTIVENESS AND PERFORMANCE OF INDIGENOUS SOIL AND WATER CONSERVATION MEASURES IN THE WEST USAMBARA MOUNTAINS, TANZANIA

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EXTENDED ABSTRACT

The West Usambara Mountains in Tanzania are severely affected by soil degradation caused by water erosion that includes rill, interill, gully and landslides. To a large extent the area is also affected by soil degradation that is caused by declining soil fertility and harvesting of tuber, bulb and root crops. The problem of soil degradation in the area has triggered adverse effect on crop productivity and is a serious threat to livelihood. Many scientific *'Soil and Water Conservation'* (SWC) measures such as bench terraces, *Fanya Juu* terraces, cut off drains, contour strips and agroforestry have been promoted in the area to combat the escalating problem of soil degradation. However, these technologies were rejected or minimally adopted because most of them were laborious and expensive. In the West Usambara Mountains, farmers have their own local SWC measures such as *miraba* (rectangular grass bound strips that do not necessarily follow contour lines), micro ridges and stone bunds, technologies which unfortunately have received very little considerations. *Miraba* is the most preferred and widely practised indigenous SWC measure in the West Usambara Mountains because it is cheaper in implementation and provides fodder for livestock.

Despite all the efforts in combating soil degradation, little success has been achieved as the process has been active even in places where SWC measures are practised. The general objective of the current study was to enhance knowledge on indigenous SWC measures under smallholder farming conditions for preventing soil degradation and improving crop yields in the West Usambara Mountains. Specifically the study aimed to i) evaluate potentials and constraints of indigenous SWC technologies for minimizing soil degradation and enhancing crop yields in various landscape types in farmers' fields ii) determine the effectiveness and performance of selected indigenous SWC measures for improved crop yields and iii) investigate the mass of soil and nutrient losses due to crop harvesting under different indigenous SWC measures. The study was conducted in Majulai and Migambo villages in Lushoto District, Tanzania. The studied villages belong to two major contrasting agro-ecological zones of the West Usambara Mountains. The former village belongs to dry warm and the latter to the humid cold agro-ecological zone.

Participatory Rural Appraisal (PRA) coupled with soil fertility and crop yield surveys under various SWC technologies in farmers' fields were conducted. Low soil fertility and spatial variability of soil fertility were revealed as major constraints to high crop yields under *miraba*. Thus, *miraba* were integrated with mulching and spacing of grass strips adjusted to rectify the observed constraints such that i) the spacing of grass strips that form *miraba* across the slope was reduced from traditionally very wide (10 m - 30 m apart depending on the size of the farm plots) to 5 m apart to mimic the recommended maximum width of hand made bench terraces; and ii) mulching applications using leaves of readily available plants namely Tithonia (*Tithonia diversifolia*) and *Tughutu* (*Vernonia myriantha*). These plants are also reported to have appreciable contents of N, P and K.

The effectiveness and performance of *miraba* that were adjusted to 5 m and with above-mentioned mulching materials were tested in runoff experiments that were set in Majulai and Migambo villages, in which climatic data were also collected using standard rain gauges and tipping bucket rain gauges. Furthermore, root properties of Guatemala grass (*Tripsacum andersonii*), Napier grass (*Pennisetum purpureum*) and Tithonia shrub (*Tithonia diversifolia*) were investigated in farmers' fields and their

erosion-reducing effects predicted. Since these plants are used for establishing *miraba* and stabilizing the edge of bench terraces, it was deemed rational to investigate the erosion-reducing potential of their roots since during drought or fire outbreak, the above biomass disappears but roots remain and these could significantly contribute to reduction of soil runoff. A survey was also conducted in farmers' fields to investigate the magnitude of soil and nutrient losses resulting from harvesting of root, tuber and bulb crops under *miraba*. The aim was to determine the magnitude and effect of this process on soil degradation and extent to which it may contribute to frustrate soil conservation efforts in the area.

The results of the current study showed that: at 5 m spacing of *miraba* grass strips, there was formation of progressive bench terraces which significantly demonstrated their effectiveness in controlling soil erosion in the West Usambara Mountains. Formation of progressive bench terraces as a result of *miraba* implementation is by far cheaper than mechanical construction of bench terraces which is not favoured by farmers due to the labour costs that are involved. The roots of Guatemala grass had higher ($p < 0.05$) potential to reduce soil erosion rates by concentrated flow than Napier grass and Tithonia shrub in the 0-40 cm soil depth. These findings have implications on the selection and use of appropriate plants for soil erosion control. Soil loss was significantly ($p < 0.05$) higher in cropland with no SWC measure than under *miraba* with mulching (*e.g.* 184 Mg ha^{-1} yr^{-1} vs. 8 Mg ha^{-1} yr^{-1}). The annual nutrient losses (kg $ha^{-1}yr^{-1}$) were higher ($p < 0.001$) in croplands with no SWC measures (*e.g.* 307, 0.8, 14 NPK) than under *miraba* with mulching (37, 0.1, 4.0 NPK respectively). Soil fertility was higher ($p < 0.05$) under *miraba* with *Tughutu* than under *miraba* with Tithonia and *miraba* sole. Similarly, maize and bean yields

(Mg ha^{-1}) followed the same trend *e.g.* 3.8 vs. 1.6 for maize and 1.0 vs. 0.6 for beans under *miraba* with *Tughutu* mulching vs. cropland with no SWC measures respectively. The crop yields did not vary between segments under *miraba* or *miraba* with mulching, whereas, under cropland with no SWC measures, maize yields differed significantly ($p < 0.05$) with lower position segments having higher yields than the upper position segments. Climatic conditions had an influence on the effectiveness and performance of *miraba* such that *miraba* were found more effective in Migambo village which is humid than in Majulai village which has drier climate. During dry spells, Napier grasses forming *miraba* were found to die out and rejuvenate during the rainy seasons, hence the formed Napier grass strips become weaker and less effective. On the other hand, soil loss due to crop harvesting (SLCH) under *miraba* was significantly ($p < 0.05$) higher for carrot 7.1 than 3.8 for onion and 0.7 Mg ha^{-1} $harvest^{-1}$ in the case of potato harvesting. Soil nutrient losses in kg ha^{-1} $harvest^{-1}$ were higher ($p < 0.05$) for carrot than for onion and potato harvesting. Soil water content at harvest time played a significant role at 5 % level in inducing SLCH for onion crop. Bulk density and soil texture played only a minor role to SLCH of the studied crops. These observations imply that soil degradation due to crop harvesting under *miraba* is substantial and poses a challenge that calls for immediate attention on the harvesting practices.

Based on the findings, it is concluded that i) low soil fertility and spatial variability of soil fertility and crop performance under traditional *miraba* and micro ridges are the major constraints to high crop yields in smallholder farmlands of the West Usambara Mountains. ii) soils of the West Usambara Mountains are susceptible to erosion as indicated by their very low values of *K* factors and very high rates of soil

degradation by water erosion. iii) roots of Guatemala grass are more effective in reducing concentrated flow erosion rates in the 0 - 40 cm soil depth than the roots of Napier grass while the roots of Tithonia shrub are the least effective. Thus selection of plants with effective rooting characteristics for controlling concentrated flow erosion is important. iv) improved *miraba* are effective in reducing runoff, soil and nutrient losses, but, improved *miraba* with either Tithonia or *Tughutu* mulching were more effective. v) *Tughutu* mulches had higher potential in soil fertility restoration than Tithonia mulches; and thus improved *miraba* with *Tughutu* mulching was the best SWC measure for improving crop yields. vi) although *miraba* and *miraba* with mulching were effective in reducing soil and nutrient losses, significant rates of soil and nutrient losses under *miraba* that were revealed due to harvesting of root, tuber and bulb crops could frustrate the success of soil conservation efforts that have been achieved.

The following recommendations are made: i) due to the vulnerability of the West Usambara Mountains to soil degradation, it is recommended not to cultivate in these areas without the use of appropriate SWC measures. ii) in dry areas such as Majulai village drought resistant grasses such as Guatemala should be used for establishing *miraba* because Napier grasses mostly preferred are sensitive to drought, thus leading to reduced effectiveness of *miraba*. iii) the spacing of *miraba* grass strips across the slope is recommended at 5 m apart for effectively controlling spatial variability of soil fertility and crop yields and for allowing *miraba* to form progressive bench terraces that are effective in controlling soil erosion in the West Usambara Mountains. iv) the use of *Tughutu* shrub should be strongly promoted for use as mulching materials under *miraba* as the shrub has demonstrated its

effectiveness in controlling soil erosion and at the same time improving soil fertility and crop yields. v) furthermore, *Tughutu* shrubs should be planted along the borders of farm plots so that the plants can easily be available for use as mulching materials. vi) farmers should remove as much as possible soil stuck on the harvested crops at their farm plots to avoid losses of soil and nutrients from farm lands. vii) further studies should be carried out on the scaling up of the application of improved *miraba* in other areas not only in the West Usambara Mountains but also in other areas of the country with similar socio-economic and environmental conditions for reduced soil degradation and improved crop productivity. viii) the potentials of the studied mulching materials should be tested for the productivity of vegetables such as cabbage, tomatoes, onions and carrots which are widely cultivated in the West Usambara Mountains. ix) further research should be carried out to investigate the effectiveness of the studied soil conservation practices on watershed protection to mitigate river stream sedimentation. x) more studies should be carried out to investigate SLCH for other crops in different climatic conditions and soil types to validate further this process under low input farming.

DECLARATION

I, Sibaway Bakari Mwango, hereby declare to the Senate of Sokoine University of Agriculture that this thesis is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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LIST OF ABBREVIATIONS AND SYMBOLS

AHI	African Highland Initiative
AMC	Available Moisture Content
ANOVA	Analysis of Variance
ARI	Agricultural Research Institute
BA	Bare land
BD	Bulk Density
Ca	Calcium
CEC	Cation Exchange Capacity
CO	Control plots
CRD	Complete Randomized Design
COSTECH	Commission for Science and Technology of Tanzania
Cu	Copper
DALDO	District Agricultural and Livestock Development Officer
DSM	Dar es Salaam, Tanzania
DSS	Department of Soil Science of Sokoine University of Agriculture
ETo	Reference evapo-transpiration
FAO	Food and Agriculture Organization of the United Nations
Fe	Iron
GDP	Gross Domestic Product
GIS	Geographic Information System
GTZ	Gesellschaft für Technische Zusammenarbeit
ICRAF	International Centre for Research in Agroforestry

K	Potassium
KU Leuven	Katholieke Universiteit Leuven
MI	*Miraba* an indigenous SWC measure established by grass barriers
TG	*Tughutu* an indigenous shrub in Usambara Mountains
TH	Tithonia an indigenous shrub in Usambara Mountains
Mg	Magnesium
Mn	Manganese
N	Nitrogen
Na	Sodium
NSS	National Soil Service of Tanzania
OC	Organic Carbon
P	Phosphorus
pH	Potential Hydrogen (measure of acidity)
RAR	Root Area Ratio
RIP	Research Initiative Project
RD	Root Density
RLD	Root Length Density
RSD	Relative Soil Detachment
RUSLE	Revised Universal Soil Loss Equation
SECAP	Soil Erosion Control and Agro-forestry Project in Lushoto, Tanzania
SIDA	Swedish International Development Agency
SLCH	Soil Loss due to Crop Harvesting
SLCHcrop	Soil Loss due to Crop Harvesting per area-unit basis

SLCHspec	Soil loss due to crop harvesting per unit of net fresh crop mass
SSA	Sub-Saharan Africa
STDEV	Standard Deviation
SUA	Sokoine University of Agriculture
SWC	Soil and Water Conservation
TIP	Traditional Irrigation Program
UK	United Kingdom
UN	United Nations
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
URT	United Republic of Tanzania
USA	United States of America
VLIR-UOS	Flemish Interuniversity Council, Belgium
vs.	versus
WRB	World Reference Base for soil resources
Zn	Zinc

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Global Soil Degradation and Crop Productivity

1.1.1 Soil degradation

Soil degradation problems are a preoccupation of countries all over the world (Ligonja and Shrestha, 2013; Mandal and Sharda, 2013). Consequently, the protection of the soil resources for the future generations is their main challenge (Zhao *et al*., 2013; Lieskovsky and Kenderessy, 2014). It is also reported that during the last 40 years nearly one-third of the world‘s arable land has been lost through erosion and continues to be lost at a rate of more than ten million hectares per year (Pimentel *et al*., 1995). A study by Wilkinson and McElroy (2007) estimates that soil loss from global farmlands is currently running at a rate of more than 6 Mg ha^{-1} yr^{-1}, which is more than 15 times the estimated average rate of erosion (0.42 Mg ha^{-1} yr^{-1}) during the whole Phanerozoic Era, a period of 542 million years spanning the Lower Cambrian to the Tertiary Pliocene (Bakker *et al*., 2007).

Erosion is widely considered to be the most serious form of soil degradation, undermining the long-term viability of agriculture in many parts of the world (Kimaro, 2003; Kimaro *et al.,* 2008; Liu *et al*., 2012). Oldeman *et al*. (1991) estimated that erosion by water accounts for 84 % of the total global area of degraded soils. In South Asia, the annual economic loss is estimated at US$ 600 million for nutrient loss by erosion, and US$ 1200 million due to soil fertility depletion (Stocking, 1986; UNEP/FAO/UNDP, 1994). According to FAO’s Global Land Degradation Assessment (GLADA), almost a quarter of the global land area was degraded between 1981 and 2003, with one of the most severely affected areas being

Africa south of the equator (Bai *et al*., 2010; FAO, 2014). The countries in Sub-Saharan Africa (SSA) depend largely on agriculture (Heerink, 2005; Wall, 2008; Giller *et al*., 2009). However, soil degradation that is caused by soil and fertility losses is a major biophysical limitation to agricultural productivity (Liu *et al*., 2012; Wickama *et al*., 2014). Studies have shown high rates of soil degradation in the area for example, Vigiak *et al*. (2005) estimated an alarming soil loss of about 135 Mg ha^{-1} yr^{-1} by water erosion in East African Highlands. In Uganda, it is reported that fertile topsoil is lost at a rate of about one billion cubic meters per year, resulting in massive environmental degradation and constituting a serious threat to sustainable agriculture and forestry (FAO, 2013). Depletion of soil fertility is increasingly recognised as a major biophysical driver of stagnant per capita food production in SSA (Sanchez, 2002; Koning and Smaling, 2004). Muniafu and Kinyamario (2007) reported that soil erosion is responsible for the depletion of 130 kg N, 5 kg P and 25 kg K ha^{-1} yr^{-1} in East African Highlands. Stoorvogel *et al*. (1993) in Zimbabwe, claim that soil erosion results in an annual loss of N and P alone totalling US$ 1.5 billion.

Nutrient (N, P, and K) balances for 13 countries in SSA showed negative trends with about 200 million ha of cropland having lost 660 kg N ha^{-1}, 75 kg P ha^{-1} and 450 kg K ha^{-1} in the last 30 years, with high to very high depletion rates in East and Central Africa (Stoorvogel *et al*., 1997; Cobo *et al*., 2010). As a result, soil fertility has continued to decline to levels that are currently prohibitive to profitable agriculture, whereby the originally fertile lands that yielded 2 - 4 Mg ha^{-1} of cereal grains have been degraded with cereal crop yields of < 1 Mg ha^{-1} which is becoming common in many areas of SSA (Sanchez, 2002; Salako *et al*., 2007). Some researchers have argued that a significant area of land now being cultivated may be rendered biologically and/or economically unproductive if erosion continues unabated (den Biggelaar *et al*., 2004; Kimaro *et al*., 2008, Kaswamila, 2013; Wickama *et al*., 2014).

Among the various soil degradation processes threatening sustainable agriculture, soil losses due to root, tuber and bulb harvesting are poorly documented in tropical environments (Isabirye *et al*., 2007). In developed countries high rates of soil degradation due to harvesting of root, tuber and bulb crops especially under mechanised agriculture have been reported (Poesen *et al*., 2001; Ruysschaert *et al*., 2006). Yet, under low input agriculture especially in SSA, this type of soil degradation is overlooked. The only study by Isabirye *et al*. (2007) in Uganda, reported soil loss of 3.4 Mg ha^{-1} $harvest^{-1}$ for cassava and 0.1 Mg ha^{-1} $harvest^{-1}$ for sweet potato and nutrient loss of 1.71 kg N ha^{-1} $harvest^{-1}$, 0.16 kg P ha^{-1} $harvest^{-1}$ and 1.08 kg K ha^{-1} $harvest^{-1}$ for cassava and 0.14 kg N ha^{-1} $harvest^{-1}$, 0.01 kg P ha^{-1} $harvest^{-1}$ and 0.15 kg K ha^{-1} $harvest^{-1}$ for sweet potato. The soil loss under cassava harvesting was considered alarming for the efforts to be taken to mitigate the observed losses.

1.1.2 Crop productivity

Soil degradation poses a significant threat to the world's food production capacity to ensure food security in the context of an increasing global population (den Biggelaar *et al*., 2004; Bakker *et al*., 2007). The crop yield reduction due to soil erosion by the year 2020 is estimated to reach 16.5 % for the African continent and about 14.5 % for sub-Saharan Africa (FAO, 2013). These yield reduction rates are very high when compared with the situation in Europe where according to Bakker *et al*. (2007) the decrease in crop yield due to soil erosion is predicted to vary from close to 0 in the

Netherlands to 3.8 % in Greece for the next 100 years. Studies including that of Ngwu *et al*. (2005) observed high maize yield reduction of 50 % and 95 % following 3 cm and 6 cm topsoil loss by water erosion respectively in an *Ultisol* under a sub humid climate in Nigeria. High crop yield reduction was also reported by Oyedele and Aina (2006) where maize yields were reduced by 56 %, 82.5 %, 90 % and 95.5 % resulting from 5 cm, 10 cm, 15 cm and 20 cm topsoil loss respectively, in an *Oxisol* in a sub humid climate in Nigeria.

Likewise, Salako *et al*. (2007) reported high maize yield reduction of 17 % and 67 % on upper slope and 65 % and 76 % on lower slope at 15 cm and 25 cm of topsoil loss, respectively, in a gravelly *Alfisol* in a sub humid climate in Nigeria. Reports in Malawi indicated that due to soil erosion by water, maize yields have declined from over 2 Mg ha^{-1} in the 1970s to 0.85 Mg ha^{-1} in 2005 (FAO, 2013). There are also serious 20 % productivity losses caused by erosion in Asia, especially in India, China, Iran, Israel, Jordan, Lebanon, Nepal, and Pakistan (Dregne, 1992). In South Asia, annual loss in productivity is estimated at 36 million Mg of cereal equivalent valued at US$ 5400 million by water erosion, and US$ 1800 million due to wind erosion (UNEP/FAO/UNDP, 1994). Generally, it is estimated that about 11.9 - 13.4 % of the global agricultural supply has been lost in the past five decades due to soil degradation (FAO, 2009). The situation in SSA calls for more sustainable farming systems as a means of restoring the productivity of eroded soils in the region. For some time now, the challenge has been on how to accommodate better conservation practices to reduce the problem of soil erosion in SSA for improved productivity and people's livelihood. This study was conducted as an attempt to address this challenge.

1.1.3 Extent of soil degradation and crop productivity in Tanzania

According to URT (2012), the population of Tanzania is estimated at 45 million people of whom about 77 % depend solely on agriculture for their livelihood. Agriculture in Tanzania is currently accounting for 60 % of export earnings (URT, 2010) and 24.1 % of Gross Domestic Product (GDP), a decline from 29 % in 2001 (URT-PHDR, 2008; URT, 2009; World Development Indicators, 2013). Despite the importance of agriculture in Tanzania, soil degradation in the form of soil erosion by water in agricultural land is rampant, and there is lack of appropriate technology that can solve the problem (Mwango, 2000; Tenge *et al*., 2005; Kimaro *et al*., 2008; Msita, 2013; Wickama *et al*., 2014). It is estimated that about 61 % of the total area of Tanzania is degraded by soil erosion caused by water (URT, 2004).

Studies in mountainous areas that constitute potential agricultural land of Tanzania showed high rates of soil erosion by water which posed a severe negative impact on crop productivity (Kimaro *et al*., 2005; Vigiak *et al*., 2005). High rates of soil erosion were reported by Buch (1983) who estimated topsoil losses ranging from 1 to 4 mm ha^{-1} yr^{-1} for protected fields and 6 to 10 mm ha^{-1} yr^{-1} for unprotected fields in the West Usambara Mountains. Tenge (2005) also observed high soil loss in the West Usambara Mountains ranging from 48 to 128 Mg ha^{-1} yr^{-1} on *Acrisol* with slope gradients of 32 % to 59 %.

Ndakidemi and Semoka (2006) reported low soil fertility in West Usambara Mountains with P deficiency in 90 % and N in 73 % of the area, whereas Mg^{2+}, K^{+} and Ca^{2+} were limiting at critical levels in 67 %, 53 % and 50 % of the area respectively. In this study soil degradation by water erosion was spotted as the main reasons for the depleted soil fertility. Kimaro *et al*. (2008) observed high soil erosion rates of 69 - 163 Mg ha^{-1} yr^{-1} on slope gradients ranging from 30 % to 70 % in the Uluguru Mountains. Likewise, high losses of soil and nutrients were observed by Msita (2013) in the West Usambara Mountains on *Acrisols* at 45 % slope where 132 Mg ha^{-1} yr^{-1} of soil loss due to erosion by water was also responsible for nutrient loss of about 248 kg, 31 kg and 3 kg ha^{-1} yr^{-1} of N, P and K^+ respectively.

In South Eastern Tanzania, Kabanza *et al*. (2013) reported high soil losses due to rill and interill erosion of up to 127 Mg ha^{-1} season^{-1}. High losses of soil and nutrients were also reported by Kaswamila (2013) in the West Usambara Mountains with an estimated average topsoil losses ranging from 0.6 - 1 cm per year, which is about 100 Mg ha^{-1} yr^{-1}, and nitrogen loss of about 370 kg ha^{-1} yr^{-1}. A study by Wickama *et al*. (2014) estimated average losses of topsoil depth ranging from 3.25 mm ha^{-1} yr^{-1} to 4.45 mm ha^{-1} yr^{-1} in the West Usambara Mountains. The reported soil losses are very high beyond the tolerable limit of 7.2 Mg ha^{-1} yr^{-1} for very deep soils (120 - 180 cm deep) and 4.8 Mg ha^{-1} yr^{-1} for deep soils (80 - 120 cm deep) (FAO, 2009). Likewise, the observed nutrient losses were high, and yet most local farmers do not apply fertiliser to replenish their farms and those who do, the application rate is always low and less than 50 kg ha^{-1} with 18:46:0 or 46:0:0 NPK ratio which is less than the lost nutrients.

Soil degradation by water erosion seems to be the greatest factor limiting soil productivity and impeding agricultural production in Tanzania. It was reported by Lal (2003) that reductions in maize yield in Tanzania due to severe past erosion of soils ranged from 15 % to 48 %. Msita (2013) reported low crop yield of 0.7 Mg ha^{-1}

for maize and 0.2 Mg ha^{-1} for beans in eroded cropped land as compared with 2.6 Mg ha^{-1} for maize and 1.3 Mg ha^{-1} for beans in well managed cropped land. Wickama *et al*. (2014) also reported low crop yields in eroded cropped land of 612 kg ha^{-1} yr^{-1} for maize and 199 kg ha^{-1} yr^{-1} for beans as compared with 2263 kg ha^{-1} yr^{-1} for maize and 1360 kg ha^{-1} yr^{-1} for beans in well managed cropped land. In most potential agricultural areas of Tanzania, soil degradation undermines efforts towards sustainable agricultural production and so poses a major threat to the future of agriculture.

Regrettably, there has been limited investment in soil improving technologies, lack of appropriate information and low adoption of available soil and water conservation technologies coupled with inadequate incentives to reverse the trend (Vigiak *et al*., 2005; Msita, 2013). Yet, restoration of degraded soils is crucial for bringing about drastic increase in agricultural productivity to feed the ever increasing population in the country (Tenge, 2005; Ligonja and Shrestha, 2013).

1.2 Efforts in Addressing Soil Degradation by Water Erosion in the West Usambara Mountains

1.2.1 Introduced SWC measures in the West Usambara Mountains

Introduced soil and water conservation (SWC) measures in the West Usambara Mountains have a long history since the British Colonial era and post-independence Governments (Watson, 1972). The strategies of SWC measures by both pre- and post-independence Governments included the prohibition to cultivate on steep slopes, contour ridging and protection of stream banks and planting of grass leys for fodder (Semgalawe, 1998; Conte, 2005). However, these efforts were negatively perceived by the local community due to the top - down approaches that were used by both pre- and post-independence Governments (Temple, 1972). In these approaches farmers were considered recipients of technologies rather than equal partners in their development (Conte, 2005). Worse still these technologies were not site-specific and therefore could not cater for the great biophysical and socio-economic heterogeneity of mountain ecosystems and people.

The recent initiatives in the last 20 years on SWC projects have used participatory approaches in technology development and dissemination. In these approaches all stakeholders were involved and the local communities were considered important partners as well as owners of the process. These projects included the Soil Erosion Control and Agro-forestry Project (SECAP) from 1981-2000. Implementation of SECAP involved planting of about 10 000 000 trees on hilltops and farmlands, which is about 20 % of the required number of trees to meet the growing demand for fuel wood and reduce harvesting pressure on existing natural forests (Johansson, 2001). Furthermore SECAP introduced macro contour strips for soil and water conservation consisting of upper-storey trees, shrubs and fodder grasses (Johansson, 2001). However, the macro contour strips were not popular with the farmers because the components were competitive to agricultural crops, harboured rodent pests and were believed to be potential carriers of plague (Johansson, 2001). They were also not very effective in promoting water infiltration. Consequently they were modified to bench terraces with trees on the embankments (Shelukindo, 1995; Tenge *et al.,* 2005).

The African Highland Initiative (AHI) implemented from 1997-2004 was a collaborative eco-regional research programme focusing on Integrated Natural Resource Management in the highlands of East and Central Africa. AHI introduced multipurpose trees and shrubs, bench terraces, *Fanya Juu* terraces, infiltration ditches and cut-off drains for soil and water conservation, use of improved fallow and use of organic-inorganic nutrient resources for soil fertility improvement. Improved crop varieties, high value crops and better livestock management practices were also introduced as a strategy for diversification and intensification. The use of traditional dances as well as exchange visits was the tool employed for disseminations. Efforts were also directed towards facilitation of formation of credit association to enable farmers acquire the necessary inputs for agricultural production (Shelukindo, 1995; Tenge, 2005).

Other initiatives included the Traditional Irrigation and Environmental Development Project (TIPDO) which started in 1989 as Traditional Irrigation Project (TIP). The main activities of TIPDO included conservation of water sources and irrigation areas, rehabilitation and improvement of the traditional irrigation systems and organisation of irrigation water users to water user associations. Other activities were introduction of bench terraces and tree planting on farmland to reduce overdependence on the natural forest reserves (Shelukindo, 1995). In the past 12 years a total of 80 irrigation water users groups have been covered in three irrigation zones namely Umba, Soni and Baga River, the availability of irrigation water promoted the cultivation of high values crops (vegetables) which increased income.

Although the current initiatives in the area have shown that participatory approaches had some success, yet the promoted soil and water conservation measures such as bench terraces, *Fanya Juu* terraces and cut-off drains were rejected or minimally adopted because their construction is labour intensive and expensive (Conte, 2005; Tenge, 2005), aspects that were feared by many farmers. Moreover, farmers had their own criteria of selecting specific soil conservation measures such as provision of fodder, soil fertility improvement and low costs of implementation (Tenge, 2005; Msita, 2013). Furthermore, indigenous soil and water conservation measures such as *miraba* which are mostly preferred and widely practised in the area were not taken into consideration.

1.2.2 Indigenous SWC measures practised in the West Usambara Mountains

Indigenous SWC measures practised in the West Usambara Mountains evolved before colonial era (Msita *et al*., 2010). *Miraba* is a unique indigenous SWC technology widely practised by communities in the West Usambara Mountains where a field crop is bounded by a rectangular grass strip that does not necessarily follow contour lines (Msita, 2013). *Miraba* are traditionally characterized by a wide spacing of grass strips across the slope and usually the spacing depends on the size of farm plots (Msita *et al*., 2010). According to Msita *et al*. (2010), *miraba* were earlier been used to control floods and conserve fertile soils in valley bottoms where vegetables were mostly cultivated. But due to population pressure and increased intensity of land uses, *miraba* were then implemented on the slopes as an integral part of their farming systems (Msita *et al*., 2010; Msita, 2013).

Although *miraba* are used as soil and water conservation measure, grasses that are used for establishing *miraba* are also preferred for stall feeding of cattle. Despite the importance of *miraba* in the West Usambara Mountains it was never a subject of scientific research until recently Msita (2013) initiated a study to investigate the effectiveness of *miraba* in reducing runoff, soil loss, and nutrient loss. The purpose was to establish the insights to support soil and water conservation planning in the area. Results from this study have demonstrated that the annual soil loss is significantly different ($p < 0.05$) among the bare plot, cropped plot, and *miraba* treatments. In this study it was also reported that *miraba* with farm yard manure and Tithonia mulching were effective in controlling soil loss by 99 % and nutrient losses by > 83 % when compared with bare plots. Also they were found to increase maize grain yield by 270 % and beans grain yield by 550 % as compared with cropped land without soil conservation measures. However, this study was carried out only in one season and in a humid and cold climate part of the West Usambara Mountains, thus the results could not confidently be applied in other areas with different soils and agro-climatic conditions. In addition, the erosion-reducing potentials of roots of plants such as Napier grass (*Pennisetum purpureum* Schumach) and Guatemala grass (*Tripsacum andersonii* J.R. Gray) that are used for establishing *miraba* were overlooked. Studying the effectiveness and contribution of plant roots on soil erosion control could provide an insight on the selection of plant species that are most effective and appropriate in controlling soil erosion especially during drought and fire outbreaks where the above ground biomass disappears.

Other indigenous SWC technologies identified in the area include micro-ridges and stone bunds. Micro-ridges are small ridges about 10 cm high and 10 cm wide spaced very close to each other perpendicular to slope. Their length depends on the size of farm plots. Stone bunds are practised in the West Usambara Mountains, in areas where stones are available. The technology involves collection of stones in lines that make bunds perpendicular to slope. The spacing between bunds varies depending on farmers' will. Although micro-ridges and stone bunds are practised in the West Usambara Mountains, but not a single study has attempted to investigate the contribution of these SWC technologies in soil erosion control. Even though indigenous SWC measures are widely practised in the West Usambara Mountains, soil degradation has been active in places even where these measures are used because farmers could not adjust and improve these technologies to the increasing intensity of land uses (Tenge, 2005; Vigiak *et al*., 2005; Kyaruzi, 2013; Msita, 2013).

1.2.3 Studies on the effectiveness of SWC measures in East African Mountains

Several studies on the effectiveness of SWC technologies on soil erosion control have been carried out in the Usambara Mountains, Tanzania (Tenge, 2005; Msita, 2013; Wickama *et al*., 2014). Most of these studies tested the physical effectiveness of bench terraces, grass strips and *Fanya Juu* terraces (Tenge, 2005; Wickama *et al*., 2014). In Gikuuri, Embu district in the central highlands of Kenya *Fanya Juu* terraces are reported to effectively control soil loss by 57 % and bench terraces by 44 % as compared with cropped land without soil conservation measures (Tenge, 2005).

Likewise, in the West Usambara Mountains, Tanzania, Tenge (2005) reported *Fanya Juu* terraces to reduce soil loss by 94 %, bench terraces by 77 % and grass strips by 44 % as compared with cropped land without soil conservation measures. In Tenge's study, bench terraces were spotted as the most effective soil conservation measure for improving maize grain yields by 70 % and bean grain yields by 45 % as compared with a situation without conservation measures. However, this study could not integrate indigenous soil conservation practices which are mostly preferred by the farmers in the area. Besides, the extent of soil nutrient losses which are an important attribute for planning of fertility management programs were overlooked.

It is further observed here that, none of the previous studies in combination or in isolation has explained the linkages that exist between soil properties associated with the tested SWC technologies and agricultural productivity that could be useful in monitoring crop yields. The current study therefore attempted to bring on board the worth of available local technologies with scientific knowledge for effective control of soil degradation and improved crop yield in the West Usambara Mountains and other areas with similar ecological conditions.

1.3 Justification of the Current Study

The West Usambara Mountains are part of the East African Arc Mountains which are a biodiversity hotspot. The area has also a great potential for the production of maize, beans, vegetables, fruits and Irish potatoes which feed important urban areas in East Africa. Maize (*Zea mays*) and beans (*Phaseolus vulgaris*) are also the main food crops in the area (Tenge, 2005). Moreover, the area is an important catchment of many rivers and streams which supply water for domestic and industrial uses in the downstream towns and cities and for hydropower generation. However, there has been continued degradation of the natural resource base leading to decline in land productivity and reduced river flows (Vigiak *et al.,* 2005). On the other hand, efforts to combat soil degradation by water erosion were not satisfactory to conserve the area. Despite the fact that soil degradation due to harvesting of root, tuber and bulb crops have been alerted to cause considerable losses of soil and nutrients. It is worth to note that no single study had considered this process of soil degradation which suggestions show that it could upset the success of soil conservation efforts.

The Usambara highlands serve as the home and income source of about 492 441 people with a population density greater than 120.4 persons per km^2 (National Bureau of Statistics, 2012). The high population density of the West Usambara Mountains has caused high rates of land fragmentation manifested by widespread cultivation of marginal areas and encroachment of forest reserves (Vigiak *et al.,* 2005). This has resulted in severe land degradation (Kaswamila, 2013; Wickama *et al*., 2014) as reflected by many soil erosion features namely rills, interills, gullies and landslides. This poses a danger to sustainable agriculture, stability and quality of the environment and has an adverse impact on economic and social development (Tenge, 2005).

The severe degradation of the land resources has necessitated several soil and water conservation intervention programmes to reverse the trend (Msita *et al*., 2010). However, the impact of these efforts has not yielded to satisfaction with respect to conservation of the area (Wall, 2008; Msita *et al*., 2010). This has been partly attributed to deterioration of some soil qualities that have been active in places even where SWC technologies are practised (Vigiak *et al*., 2005; Kyaruzi, 2013; Msita, 2013). This observation is associated with the fact that a knowledge gap exists on how the implementations of SWC technologies affect soil properties (Tenge, 2005; Kyaruzi, 2013).

Currently there is a growing recognition of the role of indigenous SWC technologies that can play a big role in soil erosion control and improve farmers' livelihoods. However, the extent of their contribution to sustained crop productivity has not been fully exploited (Vigiak *et al.,* 2005; Nyssen *et al*., 2007; Msita, 2013). There is still a paucity of knowledge between the recognition of indigenous SWC practices and their effective use. Moreover, indigenous technologies have remained traditional for decades with limited scientific interventions for improvements to sustain crop production. In the West Usambara Mountains, for example, *miraba* are an indigenous SWC technology most preferred and widely practised by the smallholder farming community. They are usually established by Napier (*Pennisetum purpureum*) or Guatemala (*Tripsacum andersonii*) grasses. These grasses are preferred because they are also used as fodder. Scientific studies and interventions that link indigenous SWC technologies such as *miraba* would significantly contribute to reduced soil degradation and improved crop productivity.

Bench terraces have been highly recommended for use to protect the arable land of Usambara Mountains (Tenge, 2005; Wickama *et al*., 2014). However, construction of bench terraces is very expensive in terms of labour and money the costs which are feared by farmers and hence their minimal adoption or outright rejection. It has been documented that soil conservation measures such as *Fanya Juu* and stone bunds have a tendency of forming progressive bench terraces when constructed at a closer spacing (Sheng, 2002). Progressive bench terraces formation could also be possible under *miraba* when adjusted to appropriate spacing of grass strips. Formation of natural bench terraces as a result of *miraba* implementation is much less expensive compared to mechanical bench terrace construction. Therefore it was appropriate to explore and demonstrate this important information to farmers.

Mulching has frequently been reported to play a big role in controlling soil erosion and improving crop productivity (Lal, 1997; Sasa, 2009). Despite its importance, it is rarely applied in the study area because little has been done to demonstrate its potential to farmers. In the West Usambara Mountains, the leaves of local plants such as *Tithonia diversifolia* (Hemsl.) A. Gray (*Alizeti Pori*) and *Vernonia myriantha* Hook f. (*Tughutu*) have been documented by ICRAF (Palm *et al*., 1997) and Wickama and Mowo (2001) to contain appreciable amounts of NPK and have been strongly recommended for use as green manure. Farmers in the area believe that when *Tughutu* (*Vernonia myriantha*) shrub grow in their farms, the area around these plants becomes more fertile and will have high crop productivity (Mowo *et al.,* 2006). Msita (2013) reported *Tithonia diversifolia* mulching to be effective in reducing runoff, soil and nutrient losses at the same time is a good green manure. Therefore, it was important in the study reported here to investigate the effectiveness of *Tughutu* and Tithonia as mulching materials for use as both green manure and supportive SWC measure under *miraba* for controlling soil degradation by water and improving crop yield in different soils and climatic conditions.

In view of the above, a study was conducted to provide an account on the potentials of indigenous SWC practices in controlling soil erosion and improving crop yield in the West Usambara Mountains and other areas with similar agro- ecological conditions. Such studies are needed to generate information and tools that can be used for appropriate implementation of SWC programs in mountainous areas under smallholder farming for enhanced agricultural productivity and protection of water sources.

1.4 Objectives

1.4.1 Overall objective

The overall objective of this study was to enhance knowledge on indigenous SWC measures under smallholder farming conditions for reduced soil degradation and improved crop yields in the West Usambara Mountains, Lushoto, Tanzania.

1.4.2 Specific objectives

The specific objectives were to:

i. Evaluate potentials and constraints of indigenous soil and water conservation technologies for minimizing soil degradation and enhancing crop yields at various landscape types in farmers' fields.
ii. Determine the effectiveness and performance of selected indigenous soil and water conservation measures for improved crop yields.
iii. Investigate the mass of soil and nutrient losses due to crop harvesting under indigenous soil and water conservation measures.

1.5 Conceptual Framework Adopted in the Current Study

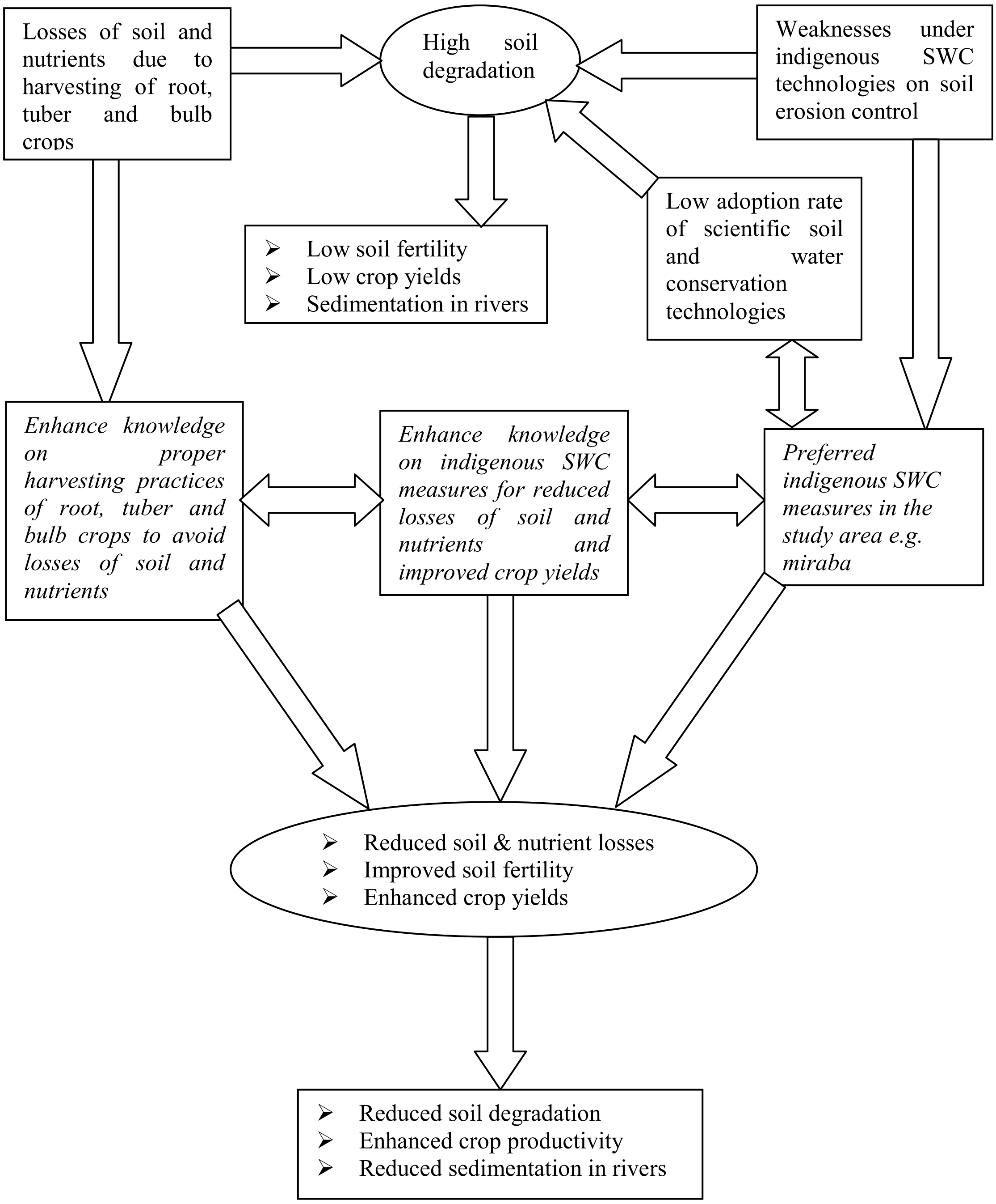

Figure 1.1: Conceptual framework

1.6 Type, Stracture and Organisation of the Thesis

The current thesis was developed in a publishable manuscripts format and organized in eight chapters as summarized in Fig. 1.2.

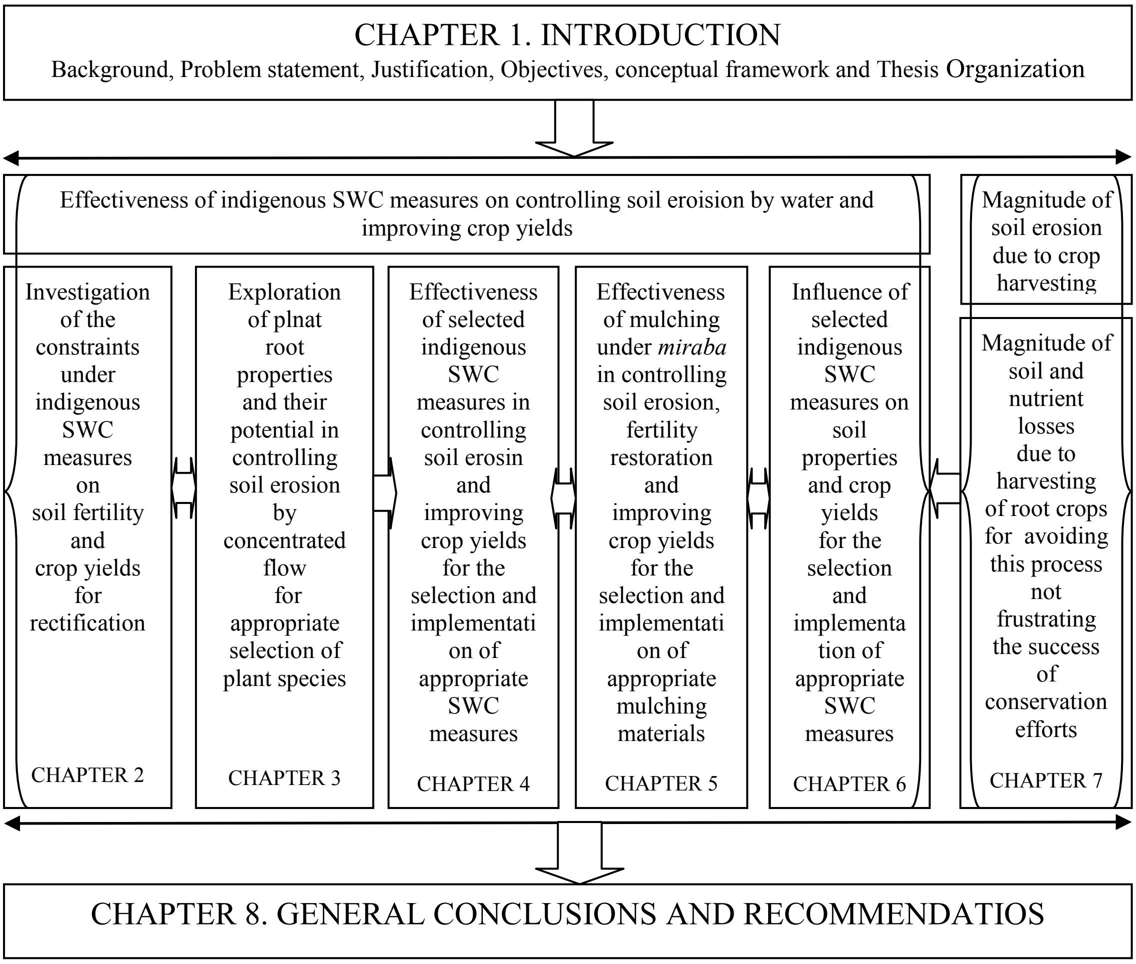

Figure 1.2: Thesis outline

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CHAPTER TWO

2.0 SOIL FERTILITY AND CROP YIELD VARIABILITY UNDER INDIGENOUS SOIL AND WATER CONSERVATION TECHNOLOGIES IN THE WEST USAMBARA MOUNTAINS, TANZANIA

ABSTRACT

Indigenous soil and water conservation (SWC) technologies such as *miraba* (rectangular grass bound strips that do not necessarily follow the contour lines) and micro ridges have been used widely in the West Usambara Mountains, Tanzania. However, their strengths and limitations to crop production have not been investigated. This study aimed to determine soil fertility and crop yield variability under *miraba*, micro ridges and bench terraces as a way to explore and compare these SWC technologies. A survey was carried out in Majulai watershed (with *Acrisols* as dominant soils*)* which is highly affected by soil degradation due to water erosion. Composite soil samples were collected from 0 - 30 cm depth in upper, middle and lower segments within bench terraces, micro ridges and *miraba* at the upper, mid and lower slopes of the watershed. Soil nutrients (*e.g.* available P, K^+, Ca^{2+} and Mg^{2+}) and maize grain yields varied significantly ($p < 0.05$) between SWC technologies, with the trend: bench terraces > micro ridges > *miraba* > control (fields with no SWC measures). Similarly under all the three SWC technologies soil fertility and maize grain yields varied significantly ($p < 0.05$) with slope position, showing the trend: lower slopes > mid slopes > upper slopes. On the other hand soil fertility and maize grain yields varied significantly ($p < 0.05$) between segments of the studied SWC technologies except for bench terraces. The trends for both soil fertility and maize grain yields were as follows: lower segments > middle segments > upper segments under micro ridges; lower segments > upper segments > middle segments under *miraba*. These observations call for management strategies (*e.g.* mulching) and technological adjustments (*e.g.* reducing the spacing of grass strip barriers that form *miraba*) that would reduce pattern and magnitude of spatial variations of soil nutrients and crop yields under *miraba* and micro ridges for improved crop production in the West Usambara Mountains.

Key words: Soil erosion, soil nutrients, bench terraces, micro ridges, *miraba*

2.1 INTRODUCTION

The Usambara Mountains which are located in north eastern Tanzania cover an area of about 2625 sq. km and have an altitude ranging from 1000 to 2270 m a.s.l. These Mountains are highly dissected with moderately steep to very steep slopes, and are highly affected by land degradation (Vigiak *et al.*, 2005; Wickama *et al.*, 2014). Majulai village in the West Usambara Mountains is typical of villages most affected by different forms of soil erosion in the area (Plate 2.1) and is experiencing a decline in soil fertility, deterioration of soil quality and reduced soil productivity (Wickama and Mwihomeke, 2006). These have adverse impacts on people's economic and social development (Tenge, 2005).

Local farmers have developed indigenous soil and water conservation (SWC) measures such as '*miraba'* (rectangular grass bound strips that do not necessarily follow contour lines), micro ridges and stone bunds (Plate 2.2) as an integral part of their farming systems, while rejecting or minimally adopting introduced SWC technologies (Msita *et al.,* 2010). According to Msita (2013) *miraba* are uniquely preferred and are widely practised in the West Usambara Mountains. They are characterized by a wide spacing of grass strips across the slope. Usually the spacing depends on the size of farm plots. Micro-ridges are small ridges of about 10 cm high

Plate 2.1: Majulai watershed severely degraded by water erosion and land clearing for agriculture resulting in accelerated soil erosion. Plate by: Mwango, S.B. 25/03/2011

and 10 cm wide constructed across the slope with narrow furrows between them. Their lengths depend on the size of farm plots. Despite their wide application in the study area, the potential of their contribution to conservation agriculture i.e. "a concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment" (FAO, 2007), has not been fully exploited. Although grass strips and stone bunds have been documented to develop progressive

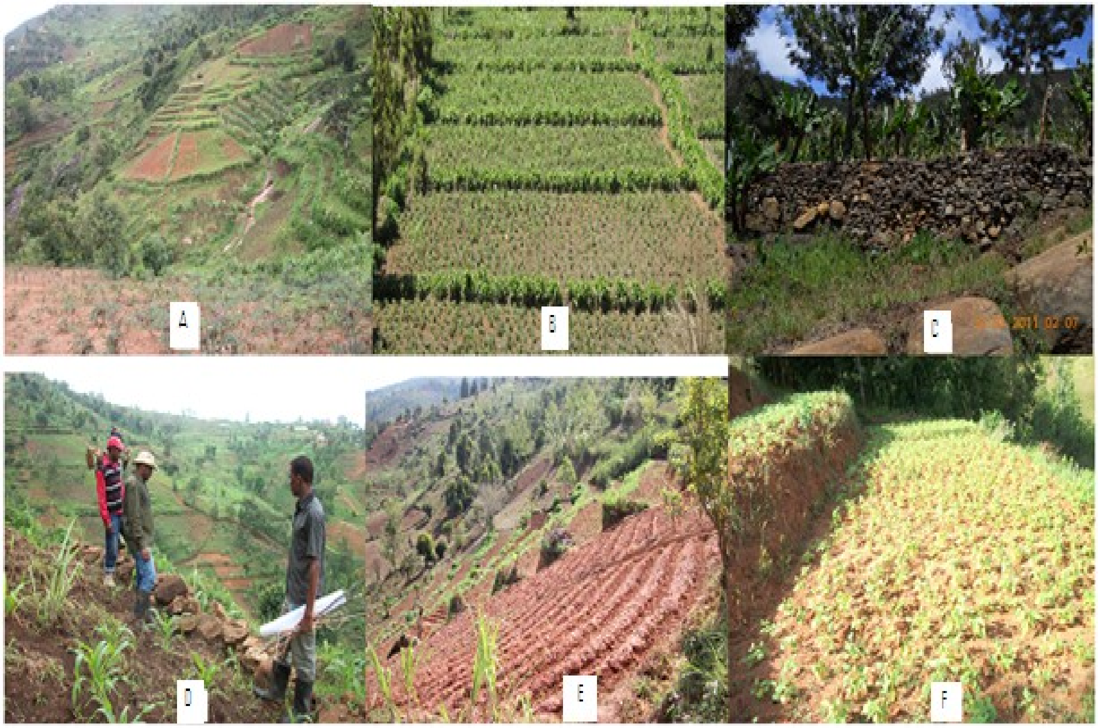

Plate 2.2: Major SWC technologies in the West Usambara Mountains, Tanzania i) A&B=*miraba* ii) C&D=stone bunds iii) E=micro ridges and bench terraces iv) F=bench terraces. Plates by: Mwango, S.B. 13/04/2011 and 11/01/2013 for D

terraces by accumulating sediment behind these structures (Stark *et al*., 1999; Dercon *et al*., 2003), still some of these technologies have been criticized in some countries (*e.g*. Uganda and Ethiopia) for triggering soil fertility variability which causes spatial and temporal variability of crop response to applied fertilizers (Stark *et al*., 1999, Vanlauwe *et al*., 2007). Furthermore, famers in the study area register low crop yields under their fields where the studied indigenous SWC technologies are practised. The current study aimed to evaluate the variability of soil fertility and crop yields under bench terraces, micro-ridges and *miraba* in order to explore and compare their strengths and limitations in small holder farming conditions. The specific objectives were: i) to investigate the strengths and limitations of the studied SWC technologies according to farmers' knowledge ii) to determine the magnitude of soil fertility variability between and within the studied SWC technologies iii) to evaluate the influence of slope positions on soil fertility variability under the studied SWC technologies iv) to investigate crop yield variability between segments under the studied SWC technologies.

2.2 MATERIALS AND METHODS

2.2.1 Description of the study sites

This study was conducted in Majulai village located between latitudes 4^0 36′ 9" and 4^0 38′ 4" and longitudes 38^0 19′ 46" and 38^0 20′ 40" in the West Usambara Mountains, Lushoto District, Tanzania (Fig. 2.1). The altitude ranges from 1360 to 1 800 m above sea level. Daily temperature ranges from 16 to 21 ^{0}C. The area has a bimodal rainfall pattern with long rains from late February to May and short rains from October to December. The annual rainfall ranges from 500 to 1700 mm. Soils of the study area are mainly *Acrisols* formed from in situ weathering of gneissic rocks or their derived colluvium and alluvium parent materials. Majulai watershed (about 360 ha) is characterized by cropland on slopes and valley bottoms; and settlements on ridge summits and upper slopes. The average farm size is about 1.4 ha per household for rain-fed agriculture (Tenge, 2005) with low input traditional farming where tillage is by hand hoes. Crops include vegetables such as carrots, onions, tomatoes and cabbages usually grown as sole crops under rain-fed or under traditional irrigated schemes where groups of farmers construct local storage dams and canals to irrigate their crops. Beans, maize and Irish potatoes are usually cultivated under rain-fed mixed cropping systems. Maize is usually grown during short rains and beans during long rains. The main fertilizers used include urea, diammonium phosphate (DAP) and farmyard manure; however urea and (DAP) are mainly used in vegetable production usually under bench terraces and/or micro ridges.

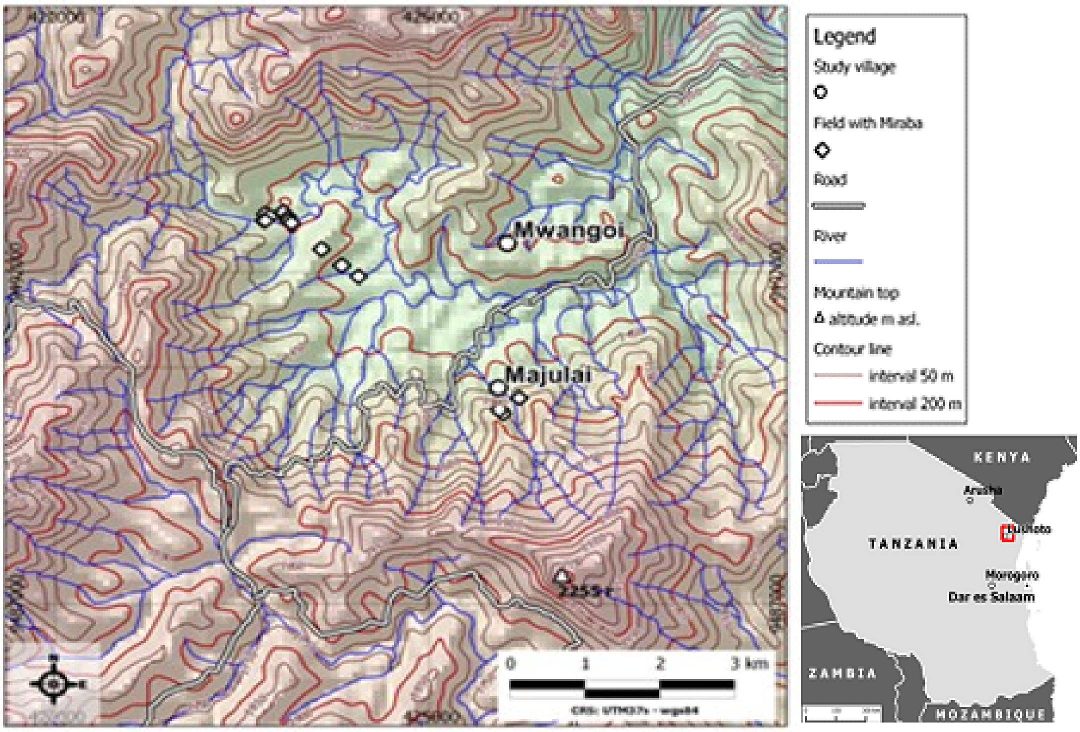

Figure 2.1: Location map of Majulai village, Lushoto District, Tanzania. Source: Adapted from Msita (2013)

2.2.2 Identification of major SWC technologies in the study area

Participatory Rural Appraisal (PRA) was conducted in Majulai village to identify major SWC technologies and investigate their strengths and limitations with respect to soil fertility and crop yields. Several indigenous SWC technologies (*miraba*, micro ridges, stone bunds and mulching) and introduced SWC technologies (bench terraces, *Fanya Juu* terraces, cut-off drains and afforestation) were identified. The most preferred and widely practised SWC technologies were identified by ranking the scores against SWC technologies that were allocated by the members of the PRA meeting. From members of the village meeting, a focused group of 24 representatives was selected for in-depth discussions (Plate 2.3). Transect walks were conducted to verify different SWC technologies that were identified during the PRA meeting.

Plate 2.3: Focused group discussion at the village office in Majulai, Lushoto, Tanzania. Plates by: Mwango, S.B. 26/03/2011

2.2.3 Soil survey and soil sampling under the studied SWC technologies

Nine fields from each SWC technology and control (fields with no SWC measures) that were planted with maize (*Zea mays*) PAN 67 variety the main food crop in the area were selected for soil fertility and crop yield variability investigation. The fields were selected with respect to landforms i.e. at the upper, mid and lower slope positions with three fields from each SWC technology and at each slope position (Appendix 2). A survey was conducted to map the soils of Majulai watershed after a base map was prepared at a scale of 1:20 000 (Appendix 3) using ArcView 3.2 GIS software. Seven soil profiles representing soil units based on landforms were excavated and described using guidelines for soil description (FAO, 2006) and soils were classified according to the World Reference Base for Soil Resources (FAO, 2014).

In each SWC technology and a control, composite soil samples each consisting of 10 sub samples (0 - 30 cm depth) was collected systematically using an auger. In each SWC technology sampling was done in three segments i.e. at the lower, middle and upper segments. In each segment, soil fertility was determined and maize was harvested and dry maize grains weighed at 13 % moisture content and the results converted to kg ha^{-1}. A total of 108 composite soil samples were collected i.e. 3 (slope positions) x 4 (SWC technologies + control) x 3 segments of (SWC technologies + control) x 3 (replications) = 108. Most of the bench terraces were introduced by the Soil Erosion Control and Agro-forestry Programme (SECAP) since 1980s (Shelukindo, 1995; Tenge, 2005) whereas well established *miraba* of more than 10 years old were selected by asking farmers. However, as micro-ridges are temporary structures we could only get two years old structures.

2.2.4 Soil analyses

Soil analysis was done following the Moberg's (2001) laboratory manual. Organic carbon (OC) was measured using the dichromate oxidation method, total nitrogen (TN) by Kjeldahl method, available phosphorus (Bray-I), exchangeable bases (Ca^{2+} and Mg^{2+}) by atomic absorption spectrophotometer, exchangeable Na^{+} and K^{+} by flame photometer and pH in water by normal laboratory pH meter.

2.2.5 Data analysis

Bartlett's test for homogeneity of variances was conducted to test data normality using GenStat software (GenStat, 2011), skewed data were log-normally transformed. All data were subjected to Analysis of Variance (ANOVA). GenStat statistical analysis software (GenStat, 2011) was used for the analysis and significant differences were tested by the Least Significant Difference ($LSD_{0.05}$).

2.3 RESULTS AND DISCUSSION

2.3.1 Strengths and limitations of major SWC technologies according to farmers' knowledge in the study area

According to farmers, *miraba* were ranked the most preferred and widely practised indigenous SWC technology followed by far micro-ridges. On the other hand bench terraces were spotted as the most preferred and widely practised introduced SWC technology. According to farmers, bench terraces were introduced and implemented by SECAP during 1980s without which they could not be in place today.

Although bench terraces were ranked higher in crop yield, farmers feared them because their construction is expensive and laborious and may decrease crop yield in the initial stage unless they are highly fertilised. *Miraba* were ranked the most preferred due to their easy establishment and provision of fodder to livestock. However, farmers criticised *miraba* for the relatively lower crop yields and uneven response of crops i.e. higher crop yields at the lower segments than the upper segments. Micro-ridges are preferred because their construction is easy and simple but also provide high yields when constructed on gentle slopes.

2.3.2 Soils and topographic setting

The soils of the study area are presented in Appendix 2. The soils of the ridge summits, upper, mid and lower slopes are moderately deep to very deep, well drained dark red to red sandy clay to clays, with thin dark red sandy clay topsoils. Soils of the ridge summits are mainly *Haplic Acrisols* (*Profondic*), those of upper and mid slopes are *Chromic Acrisols* (*Profondic, Cutanic*), while those of lower slopes the soils are *Chromic Acrisols* (*Profondic, Clayic, Cutanic, Colluvic*). *Stagnic Acrisols* (*Hyperdystric, Profondic, Colluvic*) and *Haplic and Gleyic Fluvisols* (*Humic, Eutric*) occupy respectively the toe slopes and the valley bottoms (Appendix 3).

2.3.3 Soil fertility variability between the studied SWC technologies

Soil fertility levels in the studied SWC technologies are presented in Table 2.1. The soil fertility levels were significantly ($p < 0.05$) different between the studied SWC technologies. Higher pH was observed under bench terraces and micro ridges than under *miraba* and control; organic carbon was higher under *miraba* than under bench terraces, micro ridges and control; and total N content was higher under micro ridges than under control. The higher OC content under *miraba* can be explained by the presence of grass strips that form *miraba* which on decomposition contribute substantially to the OC content in the soil. P content was higher under bench terraces and micro ridges than under *miraba* and control while Ca^{2+} content was higher under bench terraces than under *miraba* and control and was higher under micro ridges than under the control. Mg^{2+} content was higher under bench terraces and *miraba* than under micro ridges and control.

Generally, the soil fertility status in the studied SWC technologies followed the trend: bench terraces > micro ridges > *miraba* > control. This observation is strongly supported by Appendix 2 where the studied SWC technologies in each slope position were on the same soil type (*Chromic Acrisol (Profondic, Cutanic*)). Thus the observed differences in soil properties in Table 2.1 have developed as a result of the studied SWC technologies' intervention.

Table 2.1: Soil fertility variability under the studied SWC technologies in Majulai village, Lushoto, Tanzania

SWC technologies	MEAN								
	N	pH	%TN	%OC	P mg kg^{-1}	Ca^{2+} cmol kg^{-1}	Mg^{2+} cmol kg^{-1}	K^{+} cmol kg^{-1}	Na^{+} cmol kg^{-1}
Bench terraces	27	5.5	0.14	1.62	9.56	8.18	2.89	0.42	0.48
Micro ridges	27	5.0	0.16	1.83	7.35	7.46	2.27	0.40	0.42
Miraba	27	5.0	0.13	1.87	3.48	6.60	2.29	0.31	0.41
Control	27	4.8	0.13	1.58	3.03	6.43	1.68	0.27	0.42
LSD ($p \leq 0.05$)		0.4	0.02	0.27	1.61	0.70	0.31	0.11	0.04
SE		0.1	0.01	0.10	0.17	0.25	0.11	0.04	0.01

LSD: least significant difference; SE: standard error of means

The higher contents of most of nutrients under bench terraces are probably due to the fact that bench terraces (Plate. 2.1F) are nearly level surfaces and supported by grass barrier that prevent soil nutrients from being washed away by runoff. Kyaruzi (2013) observed that bench terraces influenced soil chemical properties such as pH, total N, OC, CEC, Ca^{2+} and Mg^{2+} when compared with sites without any conservation measures. Micro-ridges (Plate 2.1E) are spaced closely together, and are too small to resist heavy runoff in areas with very steep slopes like the study area. However, the furrow associated with micro ridges act as reservoirs which prevent soil nutrients from being washed out by runoff. Kabanza *et al*. (2013) also reported ridge furrows to effectively prevent runoff and soil losses.

The higher soil fertility status under bench terraces and micro ridges when compared with *miraba* and control can partly be explained by land use and management practices where bench terraces and micro ridges are usually used for vegetables cultivation where fertilizers such as Urea and DAP are frequently applied as compared with *miraba* and control. The low soil fertility status under *miraba* can be explained by the fact that the surfaces under *miraba* are not levelled while also the wide spacing of grass strips (Plate 2.1B) provide a running track that accelerate runoff velocity thereby washing away soil nutrients. This is strongly supported by Kaswamila (2013) who hypothesised that grass strip spacing is an important aspect in soil conservation planning i.e. the closer the strips are, the more effective they become and vice versa.

2.3.4 Effects of topographic slope positions on soil fertility variability under the studied SWC technologies

The mean soil nutrient values are presented in Table 2.2. Slope positions of the terrain had significant ($p < 0.05$) influence on soil fertility variability under the studied SWC technologies. Under all SWC technologies, most of the studied soil nutrients were significantly ($p < 0.05$) higher in lower slopes than in the mid slopes. Reza *et al*. (2011) reported the depletion of soil nutrients in the upper slopes to be associated with the movement of nutrients down the slope. Although soil nutrients under all SWC technologies were higher in lower slopes than in upper slopes but the differences were not significant except for P, OC and total N; the higher P and total N contents in the lower slopes can be explained by the tendency of phosphorus to strongly adhere to soil particles (because the available form of phosphorus i.e. the phosphate is negatively charged thereby always adhering on active sites on surfaces of soil particles) and therefore is subject to be transported down slope by tillage and water erosion.

In the case of N, this nutrient is transported during erosion both in soluble form and adsorbed on soil particles (Brady and Weil, 1999). pH was significantly correlated to

Table 2.2: The effect of slope positions on soil fertility variability under the studied SWC technologies in Majulai village, Lushoto, Tanzania

			Mean							
SWC technologies	N	Slope position	pH	% TN	% OC	P mg kg^{-1}	Ca^{2+} cmol kg^{-1}	Mg^{2+} cmol kg^{-1}	K^{+} cmol kg^{-1}	Na^{+} cmol kg^{-1}
Bench terraces	9	Upper slope	5.3	0.1	1.5	4.0	8.0	2.7	0.5	0.5
	9	Mid slope	5.2	0.1	1.7	11.0	8.0	2.7	0.4	0.5
	9	Lower slope	6.1	0.2	1.7	21.0	9.0	3.3	0.4	0.4
	27	**Mean**	5.5	0.1	1.6	12.0	8.3	2.9	0.4	0.5
Micro ridges	9	Upper slope	5.1	0.2	1.9	5.0	8.0	2.1	0.4	0.5
	9	Mid slope	4.9	0.1	1.8	6.0	7.0	2.1	0.4	0.4
	9	Lower slope	4.9	0.2	1.9	13.0	8.0	2.6	0.4	0.4
	27	**Mean**	5.0	0.2	1.9	8.0	7.7	2.3	0.4	0.4
Miraba	9	Upper slope	5.5	0.1	1.7	3.0	7.0	2.9	0.3	0.4
	9	Mid slope	4.8	0.1	1.8	3.0	6.0	1.9	0.3	0.4
	9	Lower slope	4.8	0.1	2.0	5.0	7.0	2.1	0.4	0.4
	27	**Mean**	5.0	0.1	1.8	3.7	6.7	2.3	0.3	0.4
Control	9	Upper slope	4.9	0.1	1.6	2.0	7.0	1.6	0.3	0.5
	9	Mid slope	4.5	0.1	1.4	3.0	6.0	1.5	0.3	0.4
	9	Lower slope	5.1	0.2	1.8	5.0	7.0	2.0	0.3	0.4
	27	**Mean**	4.8	0.1	1.6	3.3	6.7	1.7	0.3	0.4
	LSD ($p \le 0.05$)		0.6	0.03	0.5	2.3	1.2	0.5	0.2	0.1
	SE		0.2	0.01	0.2	0.3	0.4	0.2	0.1	0.02

LSD: least significant difference; SE: standard error of means

Ca^{2+}, Mg^{2+} and K^{+} at ($p < 0.001$) level (Spearman's rho correlation), indicating that pH is largely dependent on the Ca^{2+}, Mg^{2+} and K^{+} contents of the weathered gneissic rocks parent material. This could partly be a reason why pH was relatively higher in upper slopes than in the mid slopes as the bases also followed that trend. Phosphorus was significantly correlated with pH ($p < 0.02$), Ca^{2+} ($p < 0.003$), Mg^{2+} ($p < 0.001$) and K^{+} ($p < 0.001$). Total N was significantly correlated with OC, Ca^{2+} and P ($p < 0.001$) and Mg^{2+} ($p < 0.002$). These observations can be explained by the influence of slope positions of the terrain where most of the soil nutrients were transported down the slope. Generally, under all SWC technologies soil nutrients were higher in lower than in the mid and upper slopes. A similar observation was reported by Reza *et al*. (2011), where slope positions were found to control the translocation of soil nutrients in a hill slope and contribute to the spatial variation of soil nutrients.

2.3.5 Variability of soil fertility within SWC technologies

The mean soil nutrient values are presented in (Table 2.3) respectively. It is clear that lower, middle and upper segments within bench terraces, micro ridges and *miraba* had significant ($p < 0.05$) influence on soil fertility variability (Table 2.3).

Table 2.3: Soil fertility variability within SWC technologies in Majulai village, Lushoto, Tanzania

SWC technologies	N	Segments within SWC technologies	Mean pH	% TN	% OC	P mg kg^{-1}	Ca^{2+} cmol kg^{-1}	Mg^{2+} cmol kg^{-1}	K^{+} cmol kg^{-1}	Na^{+} cmol kg^{-1}
Bench terraces	9	Upper Seg*.	5.5	0.1	1.7	7.0	7.5	2.6	0.4	0.4
	9	Middle Seg.	5.6	0.1	1.6	10.0	8.2	3.0	0.4	0.5
	9	Lower Seg.	5.5	0.2	1.7	12.0	8.9	3.1	0.5	0.6
	27	**Mean**	5.5	0.1	1.7	9.7	8.2	2.9	0.4	0.5
Micro ridges	9	Upper Seg.	5.0	0.1	1.9	5.0	6.7	2.0	0.3	0.4
	9	Middle Seg.	4.9	0.2	1.8	7.0	7.5	2.4	0.4	0.4
	9	Lower Seg.	4.9	0.2	1.9	11.0	8.2	2.4	0.5	0.5
	27	**Mean**	4.9	0.2	1.9	7.7	7.5	2.3	0.4	0.4
Miraba	9	Upper Seg.	5.1	0.1	1.9	4.0	6.6	2.3	0.3	0.4
	9	Middle Seg.	5.0	0.1	1.5	3.0	5.9	2.1	0.3	0.4
	9	Lower Seg.	5.0	0.1	2.1	4.0	7.3	2.5	0.4	0.5
	27	**Mean**	5.0	0.1	1.8	3.7	6.6	2.3	0.3	0.4
Control	9	Upper Seg.	4.8	0.1	1.6	3.0	6.3	1.6	0.3	0.4
	9	Middle Seg.	4.8	0.1	1.5	3.0	6.5	1.8	0.3	0.4
	9	Lower Seg.	4.8	0.1	1.6	3.0	6.5	1.7	0.3	0.4
	27	**Mean**	4.8	0.1	1.6	3.0	6.4	1.7	0.3	0.4
	LSD ($p \leq 0.05$)		0.6	0.03	0.5	2.3	1.2	0.5	0.2	0.1
	SE		0.2	0.01	0.2	0.3	0.4	0.2	0.1	0.02

Seg*. = Segment; LSD: least significant difference; SE: standard error of means

Most of the studied soil nutrients varied significantly ($p < 0.05$) between segments under bench terraces and micro ridges except for pH which did not differ significantly between their segments. Soil fertility followed the trend that lower segments > middle segments > upper segments. Similarly under *miraba* most soil nutrients varied significantly ($p < 0.05$) between segments except for pH which did not differ significantly between its segments. Soil fertility followed the trend that lower segments > upper segments > middle segments. Soil fertility in cropland with no SWC measures did not differ significantly between its segments.

Observations by Damene *et al*. (2011) reported that soil fertility variability under terracing were not significantly different, however lower segments had relatively higher soil fertility than the upper segments. Previous studies in Ethiopia (Vancampenhout *et al*., 2005), Ecuador (Dercon *et al*., 2003) and Ethiopia (Esser *et al.,* 2002) observed P and total N variability. The presence of P variability was associated with the tendency of phosphorus to strongly adhering to soil particles and therefore easily transported down slope by tillage and water erosion, whereas Nitrogen is transported during erosion both in soluble form and adsorbed on soil particles.

The higher soil fertility in lower segments under bench terraces can probably be due to the fact that bench terraces are constructed by cutting the upper soil and filling at the lower segments thus exposing the infertile subsoil at the upper segment. Stark *et al*. (1999) reported a similar trend under terraces developed from natural vegetation strips where the upper segments revealed depleted plant nutrient levels and attributed this to the redistribution of sediments from upper to lower terrace zones that lead to soil fertility variability between zones and significantly lowered crop yields. The higher soil fertility in lower segments under micro ridges can be explained by the presence of furrows which prevent soil nutrients from being washed out by runoff. However, micro-ridges are very small and weak structures that they are easily destroyed by heavy runoff at the upper segments thus allowing soil nutrients to move down the slope at the lower segments.

On the other hand the trend of soil fertility under *miraba* can be explained by the fact that grass strips forming *miraba* are traditionally spaced very widely apart (between 10 cm to 30 cm) thereby facilitating an increased runoff velocity that washes away more soil nutrients in the middle segments than at the upper segments; and finally the nutrients are captured behind the grass barriers down the slope at the lower segments. Lee *et al*. (2003) observed the same trend where the grass strip retained 80 % of total N and 78 % of total P, by capturing sediments from runoff.

2.3.6 Variability of maize grain yield between segments of SWC technologies with respect to slope positions

The yields of maize in different slope positions and segments of the studied SWC technologies are presented in (Table 2.4). The results show that maize grain yields were significantly ($p < 0.001$) different between SWC practices. Maize yield followed the trend: Bench terraces > Micro ridge > *miraba* > control (Table 2.4). The crop yield differences can partly be associated with the influences of the studied SWC practices. Similar observations were reported by Tenge (2005), Msita (2013) and Wickama *et al*. (2014) where SWC practices namely *Fanya Juu* terraces, bench terraces, grass strips and *miraba* were found to influence the yields of maize and beans. Under all the studied SWC technologies, maize yields differed significantly ($p < 0.001$) between slope positions. The trend was lower slopes > upper slopes > mid slopes. The low maize yield in mid slopes can partly be explained by the fact that Majulai watershed has steep slopes thus runoff becomes more intense and destructive in mid slopes than in upper and lower slopes.

Table 2.4: Maize grain yield variability within segments of SWC technologies in Majulai village, Lushoto, Tanzania

SWC technologies	N	Slope position	Segments within SWC technologies	Maize grain yield Mg ha^{-1}	Slope position	Segments within SWC technologies	Maize grain yield Mg ha^{-1}	Slope position	Segments within SWC technologies	Maize grain yield Mg ha^{-1}
Bench terraces	3	Upper	Upper Seg*.	2.63	Mid	Upper Seg.	2.55	Lower	Upper Seg.	3.00
	3	Upper	Middle Seg.	2.65	Mid	Middle Seg.	2.55	Lower	Middle Seg.	3.01
	3	Upper	Lower Seg.	2.65	Mid	Lower Seg.	2.56	Lower	Lower Seg.	3.03
	9	Upper	**Mean**	2.64	Mid	**Mean**	2.55	Lower	**Mean**	3.01
Micro ridges	3	Upper	Upper Seg.	1.96	Mid	Upper Seg.	1.90	Lower	Upper Seg.	2.25
	3	Upper	Middle Seg.	2.07	Mid	Middle Seg.	2.00	Lower	Middle Seg.	2.52
	3	Upper	Lower Seg.	2.23	Mid	Lower Seg.	2.03	Lower	Lower Seg.	2.55
	9	Upper	**Mean**	2.09	Mid	**Mean**	1.98	Lower	**Mean**	2.44
Miraba	3	Upper	Upper Seg.	1.86	Mid	Upper Seg.	1.71	Lower	Upper Seg.	2.17
	3	Upper	Middle Seg.	1.74	Mid	Middle Seg.	1.60	Lower	Middle Seg.	2.12
	3	Upper	Lower Seg.	1.93	Mid	Lower Seg.	1.81	Lower	Lower Seg.	2.80
	9	Upper	**Mean**	1.84	Mid	**Mean**	1.71	Lower	**Mean**	2.36
Control	3	Upper	Upper Seg.	1.51	Mid	Upper Seg.	1.50	Lower	Upper Seg.	1.74
	3	Upper	Middle Seg.	1.53	Mid	Middle Seg.	1.51	Lower	Middle Seg.	1.85
	3	Upper	Lower Seg.	1.54	Mid	Lower Seg.	1.52	Lower	Lower Seg.	1.90
	9	Upper	**Mean**	1.53	Mid	**Mean**	1.51	Lower	**Mean**	1.83
			LSD ($p \leq 0.05$)	**0.06**		**LSD ($p \leq 0.05$)**	**0.06**		**LSD ($p \leq 0.05$)**	**0.06**
			SE	**0 .02**		**SE**	**0.02**		**SE**	**0.02**

Seg.*= Segment; LSD: least significant difference; SE: standard error of means

Similarly, maize grains yields varied significantly ($p < 0.001$) between segments of the studied SWC technologies except for bench terraces where maize grain yields did not differ significantly between its segments. The trend was: lower segments > upper segments > middle segments under *miraba*; lower segments > middle segments > upper segments under micro ridges. Maize grain yields did not vary significantly within its segments under control (Table 2.4). The low maize grain yields in middle segments of *miraba* can be explained by the fact that *miraba* are characterised by very wide spacing of grass strips. The wide spacing of grass strips facilitates an increased runoff velocity that carries with it soil nutrients down the slope and become more intense at the middle segments before being reduced by grass barriers at the lower segments where soil nutrients are captured and retained behind grass barriers.

2.4 CONCLUSIONS AND RECOMMENDATIONS

Low soil fertility and spatial variability of soil fertility and crop yields were revealed as major constraints to high crop yields in smallholder farmlands under *miraba* and micro ridges. Soil fertility varied significantly between SWC technologies with the trend: bench terraces > micro ridges > *miraba* > control. A similar trend was observed for maize grain yields. Soil fertility varied significantly between slope positions under all the studied SWC technologies with the trend: lower slopes > upper slopes > mid slopes. Again a similar trend was observed for maize grain yields. On the other hand soil fertility varied significantly between segments of the studied SWC technologies. Maize grain yields varied significantly between segments of the studied SWC technologies, except under bench terraces. Both soil fertility and maize yields followed the trend: lower segments > upper segments > middle segments under *miraba*, while under micro ridges the trend was lower segments > middle segments > upper segments.

It is recommended that supportive SWC measures such as mulching should be tested and accompanied under *miraba* and micro ridges as an effort to reduce the magnitude of soil fertility and crop yield variability under the studied SWC technologies. It is further recommended that spacing of grass bound strips that form *miraba* should be reduced to minimise the speed and intensity of runoff which in turn will also minimise magnitude of soil fertility and crop yield variability between segments under *miraba*.

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CHAPTER THREE

3.0 ROOT PROPERTIES OF PLANTS AND THEIR POTENTIAL FOR SOIL EROSION CONTROL IN THE WEST USAMBARA MOUNTAINS, TANZANIA

ABSTRACT

Plant roots may have a strong erosion-reducing effect. However, little is known about root characteristics of tropical plants used for erosion control. A study was thus conducted in the West Usambara Mountains, Tanzania to investigate rooting characteristics of Guatemala grass (*Tripsacum andersonii*), Napier grass (*Pennisetum purpureum*) and Tithonia shrub (*Tithonia diversifolia*), also referred to as wild sunflower, and to evaluate their potential for erosion control. For each plant species, mean root diameter (D), root density (RD), root length density (RLD) and root area ratio (RAR) were assessed for six plants in each species and relative soil detachment rate (RSD) predicted. Mean RD values in the 0 - 0.4 m soil depth for Majulai village and Migambo village, respectively, were 50.9 and 58.6 kg m^{-3} for Guatemala grass, 30.4 and 31.3 kg m^{-3} for Napier grass and 22.1 and 23.0 kg m^{-3} for *Tithonia* shrub. RLD values were 35.9 and 45.0 kg m^{-3} for Guatemala grass, 31.3 and 150.0 kg m^{-3} for Napier grass and 10.5 and 6.4 kg m^{-3} for *Tithonia* shrub. Predicted RSD values were $4.43*10^{-12}$ and $1.20*10^{-14}$ for Guatemala grass, $6.10*10^{-5}$ and $2.74*10^{-4}$ for Napier grass and $4.43*10^{-3}$ and $2.24*10^{-4}$ for *Tithonia* shrub. The results indicate that Guatemala grass has a higher potential to reduce soil erosion rates by concentrated flow as compared to Napier grass or *Tithonia* shrub in the 0 - 0.4 m soil depth. These findings have implications on the selection and use of appropriate plants for soil

erosion control.

Keywords: Root density, root length density, Napier grass, Guatemala grass, Tithonia shrub, Soil conservation

3.1 INTRODUCTION

In the highlands of the West Usambara Mountains in Northern Tanzania farm lands are located on steep slopes and are highly susceptible to soil degradation by rill and gully erosion. Soil erosion is a major problem impacting agricultural productivity and river discharge (Vigiak *et al*., 2005). In view of the cool tropical climate, the West Usambara Mountains are suitable to many crops such as vegetables, fruits, potatoes, beans and maize many of which cannot be grown in the lowlands. They are sold in major cities *e.g*. Dar es Salaam, Tanga, Mombasa and Arusha. There is a lot of pressure in land resource in the area which results in significant water and tillage erosion (Tenge *et al*., 2005). Local farmers and development organizations including the Soil Erosion Control and Agro forest Program (SECAP) and the African Highland Initiative Program (AHI) promoted soil conservation measures at farm level using various measures. Examples of measures were bench terraces, *miraba*, agro-forestry, *Fanya Juu* terraces and ridges.

Miraba are indigenous practices widely adopted by farmers in the West Usambara Mountains. They comprise rectangular grass strips (ca. 0.5 m) that run parallel and perpendicular to the contour lines (Msita, 2013) using Guatemala or Napier grass. Other soil erosion control measures such as bench terraces and *Fanya Juu* terraces are usually stabilized by Guatemala grass, Napier grass or wild sunflower (*Tithonia* shrubs) and in a few occasion sugarcane and /or banana are used. Napier grass is mostly preferred as it is also used for forage, whereas, Guatemala grass is known for its drought resistance.

The studied plants particularly Napier and Guatemala grasses have been documented (Cook *et al*., 2005; Tenge, 2005; Msita, 2013) to be used as fodder in many tropical countries including Tanzania and in the West Usambara Mountains. Their popularity relates to their wide ecological range (from the coast to over 2000 meters above sea level), high yield and ease of propagation and management (Cook *et al*., 2005). Furthermore, when above ground biomass disappear due to drought or fire outbreak roots play an important role in controlling concentrated flow erosion. Surprisingly, little in-depth research has been focusing on these grasses, in the West Usambaras. This study aims to contribute by exploring their rooting characteristics and their effectiveness to control concentrated flow erosion.

Roots bind particles in the topsoil, which offer protection to soil that is under pressure of detachment by sheet flow or concentrated flow (De Baets *et al*., 2006; Poesen and De Baets, 2006). The presence of roots also increases the soil's roughness, thereby providing a greater capacity for infiltration and for reducing surface runoff velocity (De Baets *et al*., 2007a). In Sub-Saharan Africa, including Tanzania, most soil erosion studies focused on the effects of the above-ground vegetation, whereas much less attention has been paid to the effects of plant roots on water erosion rates (Gyssels *et al.*, 2005; Wanyama *et al.,* 2012). Research on the effects of root characteristics on soil erosion rates is scanty in Sub-Saharan Africa (*e.g*. Wanyama *et al*. 2012) and particularly in Tanzania and in the Usambara

Mountains where it has never been done before. Some experimental studies by De Baets *et al*. (2006) and De Baets *et al*. (2007a, 2007b) on the effects of roots on reducing soil erosion rates have been conducted in Belgium and Spain and have reported that root systems of some plants have a large potential to reduce soil erosion rates during concentrated flow. In these studies relative soil detachment rates compared to bare soil ranged between 0.3×10^{-12} and 0.7 for the 0.1 m thick topsoil.

Therefore, the current study aimed to investigate rooting characteristics of some plants frequently used for soil erosion control in the West Usambara Mountains in order to explore why they are used for soil erosion control and identify the most effective plants. The studied plants included Guatemala (*Tripsacum andersonii*), Napier (*Pennisetum purpureum*) and wild sunflower (*Tithonia diversifolia*). The objectives are (i) to determine root characteristics of the selected plants, (ii) to compare root characteristics of the selected plants, and (iii) to identify the most effective plants for controlling soil erosion by concentrated flow.

3.2 MATERIALS AND METHODS

3.2.1 Study area

This study was conducted in Migambo and Majulai villages, in the West Usambara Mountains, Lushoto District, Tanzania (Fig. 3.1) located between 38^0 15' E to 38^0 24' E and 4^0 34' S to 4^0 48' S. Migambo has a humid, cold climate with a mean daily air temperature of 12 −17 ^{0}C, maximum in March and minimum in July and annual precipitation ranging between 800 and 2300 mm usually occurring from October to December (short rains) and late February to May (long rains). Majulai has a dry, warm climate with a mean daily air temperature ranging between 16 ^{0}C and 21 ^{0}C,

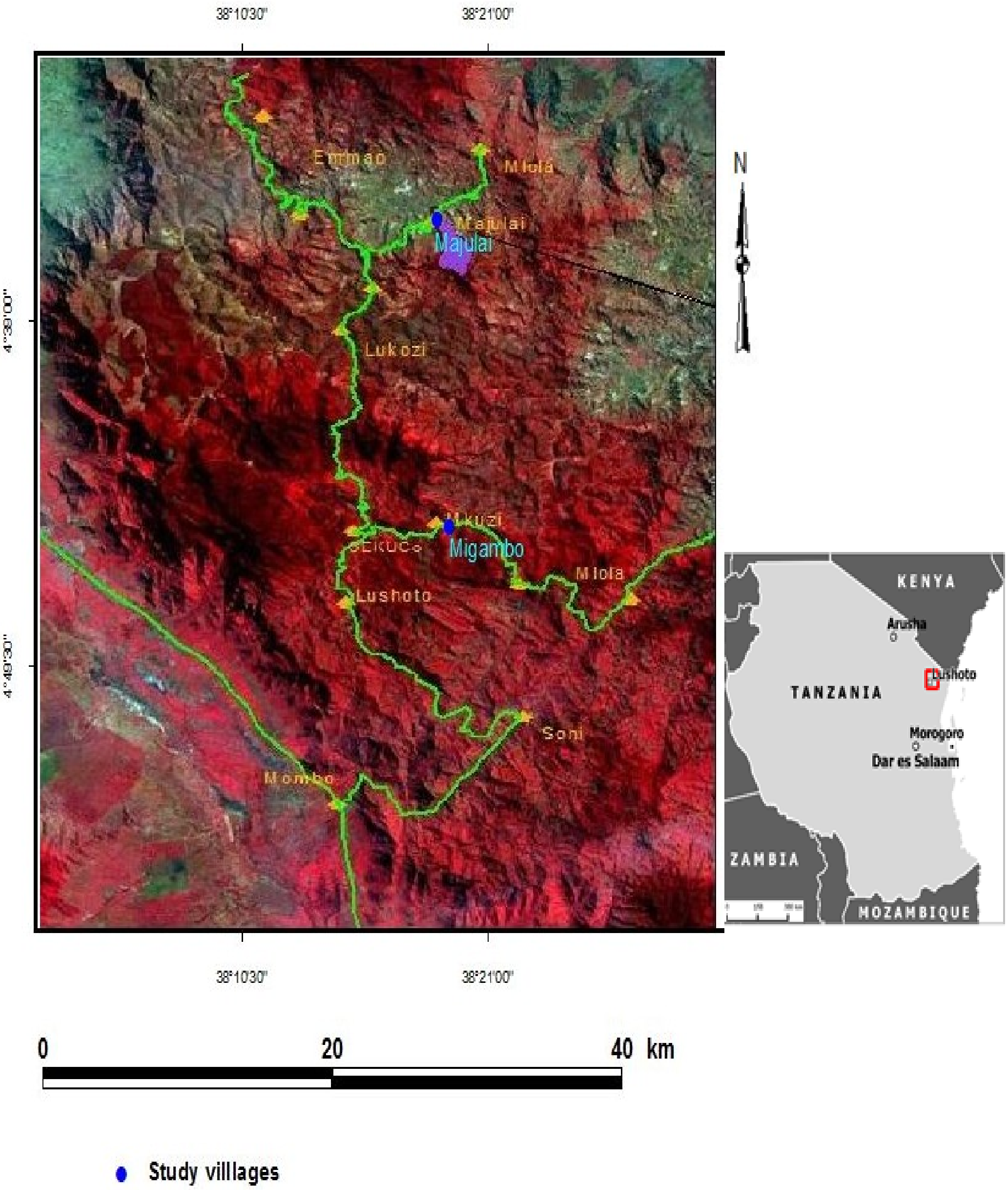

Figure 3.1: Location of Majulai and Migambo villages, Lushoto District, Tanzania. Source: Terrain image derived from SRTM data available at http://srtm.csi.cgiair.org/

maximum in March and minimum in July, and annual precipitation of 500 to 1700 mm mainly occurring from mid-October to December (short rains) and late February to May (Long rains). The soils of Migambo village (according to Kyaruzi, 2013) and that of Majulai village and topographical properties of the study area are presented in Table 3.1.

Table 3.1: Soil and topographical properties of the study area

Plant	AEZ	Altitude (m a.s.l.)	Slope (%)	Landform	Soil texture	Soil type
Majulai village	Dry warm zone					
Guatemala		1 334-1 633	45-55	Lower and mid slopes	Sand clay loam - Clay	*Chromic Acrisols*
Napier		1 356-1 660	40-56	Lower and mid slopes	Sand clay loam	*Chromic Acrisols*
Tithonia		1 339-1 567	30-40	Lower and upper slopes	Sandy loam – Sand clay loam	*Chromic Acrisols*
Migambo village	Humid cold zone					
Guatemala		1 542-1 607	15-45	Lower and mid slopes	Sand clay loam - Clay	*Haplic Acrisols*
Napier		1 603-1 654	10 -45	Lower and mid slopes	Sandy loam – Sand clay loam	*Haplic Acrisols*
Tithonia		1 598-1 644	22-35	Lower and mid slopes	Sandy loam - Sand clay loam	*Haplic Acrisols*

AEZ = Agro-ecological zone, m a.s.l. = above sea level

The study area is characterized by cropland on slopes and valley bottoms; and settlements on depressions, ridge summits and slopes. The average farm size is about 1.4 ha per household for rain-fed agriculture (Tenge, 2005) with low input traditional farming where cultivation is by hand hoes. Vegetables such as carrots, onions, tomatoes, cabbages, and peas are grown as sole crops in valleys under rain-fed or under traditional irrigated schemes where groups of farmers construct local storage dams and canals to irrigate their crops. Beans, maize, round potatoes and fruits namely peaches, plums, pears, avocado and banana are grown on ridge slopes under rain- fed mixed cropping systems with either of the fruits cropped with beans, maize and round potatoes. Round potatoes are also grown in valleys as sole crop or intercropped with maize. Maize is usually grown during short rains and beans during long rains.

3.2.2 Data collection

Medium-size mature plants 2 to 2.5 years old (for comparison purposes) were selected for root sampling in croplands of the study area. The age of the plants were obtained by asking farmers. Plant root characteristics such as root density (RD) and root length density (RLD) have direct relations with age and size of the plant (De Baets *et al*., 2009), thus it was necessary to collect root samples from plants of the same age and size for a reliable comparison. Plants were sampled randomly in 18 sites and six plants from each species were excavated and analysed for rooting characteristics. Root sampling was done by excavating six individual plants per species at their natural conditions as described by De Baets *et al*. (2008). The excavation method provided a clear picture of the rooting system of the plant under natural conditions. Around the plant a contour was delineated at a distance from the plant stem equalling the orthogonal projected radius of the above-ground biomass; a soil column was then dug around this orthogonal projection as deep as possible. The soil material was carefully removed from the excavated soil column starting from the top to the bottom. After excavation, digital photos were taken to record the rooting systems. Height and diameter of the orthogonal projection of the above-ground biomass were measured with a ruler. The roots were cut into soil depth classes of 0.1 m for the upper 0.4 m soil depth, collected in plastic bags for each soil depth class and per plant species for laboratory analysis. Composite top soil samples around the studied plant species were collected at a soil depth 0 – 30 cm for soil texture determination by hydrometer method according to the laboratory manual of Moberg (2001). In the laboratory, roots from each soil depth class were divided over 4 diameter classes: i.e. < 2 mm, 2 - 5 mm, 5 - 10 mm and >10 mm (De Baets *et al*., 2007b) using a 200 mm digital calliper. The roots were oven dried for 24 hours at 60- 65 ^{0}C to obtain dry mass (Smit *et al.,* 2000).

Digital photos of roots from each depth class were taken and total root length was determined using image analysis (MapInfo Professional 11.5).

The rooting characteristics determined included: root diameter (D) in mm, root density (RD) mass of dry root biomass per unit volume of root-permeated soil (kg/m^3), root length density (RLD) in km/m^3. The root area ratio (RAR) was also determined as a root parameter in this study. Relative soil detachment rate (RSD) was estimated using an empirical relationship established by De Baets *et al.* (2007a) for the determination of the most effective plant for soil erosion control:

Root density (RD) $kg/m^3 = M_D/V$……………………………………………….…. (1)

Where M_D (kg) = dry living root mass, V (m^3) = volume of the corresponding soil cylinder (De Baets *et al.*, 2006)

Root length density (RLD) $km/m^3 = L_R/V$……………………………………………. (2)

Where L_R is the total length of the roots (km), V is the volume of root permeated soil sample (m^3) (De Baets *et al.*, 2006)

Root area ratio (RAR) = RLD x RCSA……………………………………………….. (3)

Where RCSA is mean cross-sectional area of a single root (m^2) (De Baets *et al.*, 2006)

Relative soil detachment rate (RSD) = $e^{-1.45RD_{1<D<5mm}} e^{-0.47RD_{D>5mm}}$…….………. (4)

Where D is the root diameter (mm) (De Baets *et al.*, 2007a).

3.2.3 Data analysis

The data on RD, RLD, RAR and RSD were subjected to Analysis of Variance (ANOVA) using GenStat 14 statistical software (GenStat, 2011). Least Significance Difference ($LSD_{0.05}$) was used to detect mean differences between plants.

3.3 RESULTS AND DISCUSSION

3.3.1 General characteristics of the studied plant species

The characteristics above and below ground of the studied plant are presented in Table 3.2.

Table 3.2: Characteristics of the studied plant species

Plant	Type	n	H (m)	d max (m)	D_{SV} (m)	% of total root mass D < 2 (mm)	2 < D < 5 (mm)	5 < D < 10 (mm)	D > 10 (mm)	RD (kg/m^3)
Majulai										
Guatemala	Grass	3	1.4	0.5	0.4	57	43	0	0	50.9
Napier	Grass	3	1.6	0.5	0.4	95	5	0	0	30.4
Tithonia	Shrub	3	1.3	0.5	0.5	36	37	21	6	22.1
Migambo										
Guatemala	Grass	3	1.2	0.5	0.5	78	22	0	0	58.6
Napier	Grass	3	1.6	0.6	0.4	100	0	0	0	31.3
Tithonia	Shrub	3	1.3	0.6	0.5	31	33	34	2	23.0

n is number of sampled plants per species, H (m) is mean plant height, d max (m) is the maximum sampled root depth, D_{SV} (m) is mean horizontal diameter of the rooted soil volume, D is root diameter, RD is root density for 0 – 0.4 m soil depth.

Most root distribution occurred within 0 - 0.4 m soil depth and thus only roots within this soil depth were considered for further analysis. The mean height (H) of the measured Guatemala grasses was 1.2 m in Majulai and 1.4 m in Migambo village and mean diameter of the rooted soil volume (D_{SV}) was 0.43 m in Majulai and 0.48 m in Migambo village; the mean height of Napier grasses was 1.62 m in Majulai and 1.63 m in Migambo village and mean D_{SV} was 0.38 m in Majulai and 0.38 m in Migambo village, whereas the mean height of *Tithonia* shrub was 1.27 m in Majulai and 1.26 m in Migambo village and mean D_{SV} was 0.45 m in Majulai and 0.53 m in Migambo village. The slight variability in D_{SV} may be due to differences in climatic conditions between the studied villages where Migambo is humid while Majulai has a dry climate.

The mean root distribution values over different root diameter classes for Guatemala grass were 57 % for D < 2 mm and 43 % for 2 < D < 5 mm in Majulai; and 78 % for D < 2 mm and 22 % for 2 < D < 5 mm in Migambo village. The mean root distribution values for Napier grass were 95 % for D < 2 mm and 5 % for 2 < D < 5 mm in Majulai; and in Migambo village 100 % of the below ground biomass consisted of roots smaller than 2 mm in diameter. In the case of *Tithonia* shrub, the mean root distribution values were 36 % for D < 2 mm, 37 % for 2 < D < 5 mm, 21 % for 5 < D < 10 mm and 6 % for D > 10 mm in Majulai, and 31 % for D < 2 mm, 33 % for 2 < D < 5 mm, 34 % for 5 < D < 10 mm and 2 % for D > 10 mm in Migambo village. The distribution of roots over different root diameter classes was highly variable for the studied plant species. Moreover, the root architecture (Plate 3.1) also showed a large variability among the plant species.

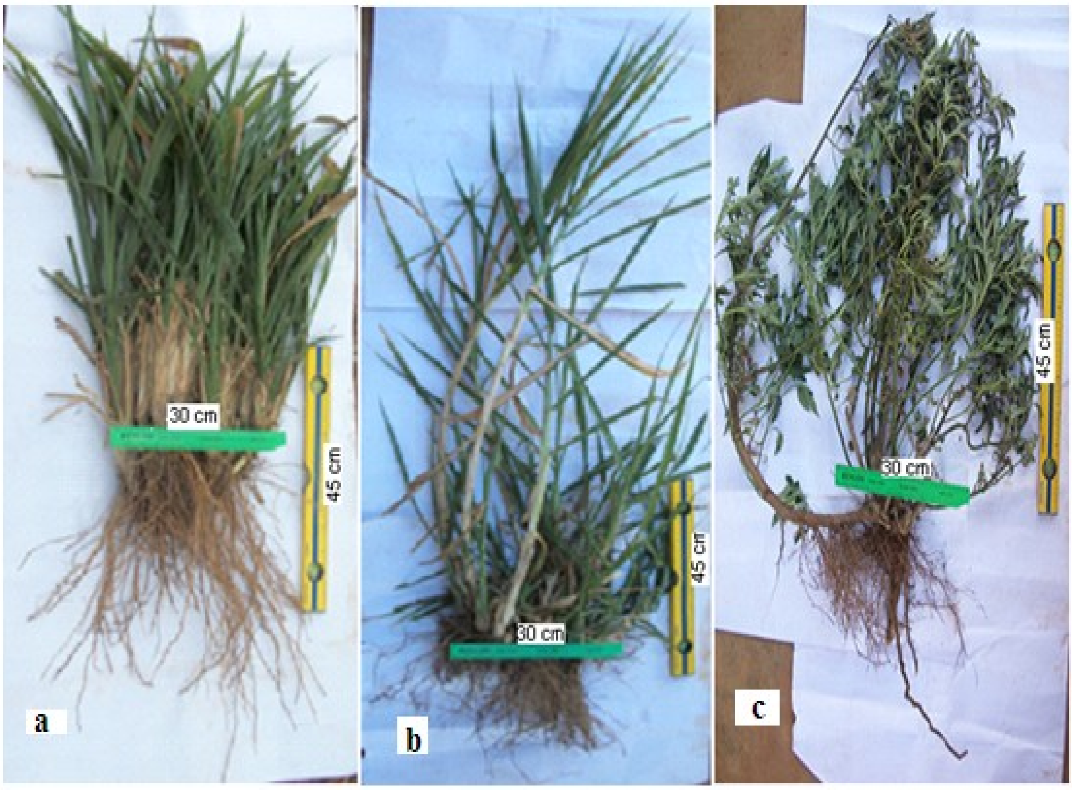

Plate 3.1: Illustration of root architecture of Guatemala grass (a), Napier grass (b) and *Tithonia* shrub (c). Plates by: Mwango, S.B. 20/12/2012

Root architecture is used to describe the spatial arrangement of the root system components (geometry), its structure and topology (Smit *et al.*, 2000). Root topology refers to how individual root axes are connected to each other through branching (Lynch, 1995), while geometry includes the shape, the size, the orientation and the spatial location of the components (Godin, 2000). Guatemala and Napier grasses have only fine-branched fibrous roots, Tithonia shrub has thicker tap root system.

3.3.2 Rooting characteristics of the studied plant species

In this study, rooting characteristics of the studied plant species are expressed by Root Density (RD), Root Length Density (RLD) and Root Diameter (D) as presented in Table 3.2 & Fig. 3.2. Root density (RD) values of the studied plants in Majulai village for the 0 - 0.4 m soil depth were 50.9 kg m^{-3} (stdev = 7.9 kg m^{-3}) for Guatemala grass, 30.4 kg m^{-3} (stdev = 8.4 kg m^{-3}) for Napier grass and 22.1 kg m^{-3} stdev = 12 kg m^{-3}) for Tithonia shrub. In Migambo village, RD values for 0 - 0.4 m soil depth were 58.6 kg m^{-3} (stdev = 8.9 kg m^{-3}) for Guatemala grass, 31.3 kg m^{-3} (stdev = 9.1 kg m^{-3}) for Napier grass, and 23.0 kg m^{-3} (stdev = 8.9 kg m^{-3}) for *Tithonia* shrub.

Under similar tropical environment a study by Wanyama *et al*. (2012) near Lake Victoria in Uganda reported that RD for 0 - 0.4 m soil depth were 20.6 kg m^{-3} for Paspalum, 7.6 kg m^{-3} for Lemon grass, 3.8 kg m^{-3} for Elephant grass and 5.1 kg m^{-3} for Sugarcane. Root density values of pasture grasses located in the loess belt of Belgium, range between 4 and 38 kg m^{-3} (n =32, mean =14 kg m^{-3}, stdev =7 kg m^{-3}). This indicates that RD of the studied plants are higher than those of Paspalum, Lemon grass and Elephant grass in Uganda and pasture grasses in Belgium. The

RLD values for the 0 - 0.4 m soil depth were 35.9 kg m^{-3} (stdev = 7.2 kg m^{-3}) for Guatemala grass, 31.3 kg m^{-3} (stdev = 0.3 km/m^3) for Napier grass and 10.5 kg m^{-3} (stdev = 3.4 km m^{-3}) for Tithonia shrub in Majulai whereas in Migambo village the values were 45.0 kg m^{-3} (stdev = 13.1 kg m^{-3}) for Guatemala grass, 150.0 kg m^{-3} (stdev = 8.1 kg m^{-3}) for Napier grass and 6.4 kg m^{-3} (stdev = 2.1 kg m^{-3}) for *Tithonia* shrub. In Majulai village mean RD at 0 - 0.4 m for Guatemala grass was significantly higher at 5 % level ($p < 0.003$) than for Napier grass or Tithonia shrub whereas RLD values for Guatemala grass and Napier grass were significantly higher at 5 % level ($p < 0.001$) than Tithonia shrub. In Migambo village, mean RLD for Napier grass at 0 - 0.4 m soil depth was higher at 5 % level ($p < 0.009$) than Guatemala grass or Tithonia shrub whereas RD for Guatemala grass was higher at 5 % level ($p < 0.002$) when compared with Napier grass and Tithonia shrub. Plants sampled in Migambo village have higher RD and RLD values when compared with plants in Majulai village. This can be explained by the different agro-ecological conditions, Migambo has more favourable climatic conditions (larger and well distributed rainfall and lower air temperature) for plant growth as compared to Majulai village which is drier and warm.

De Baets *et al*. (2007b) reported higher root densities in some habitats to be linked with the availability of soil moisture content and therefore, species growing in channels and on steep bad land slopes had more roots at greater depths compared to species growing on flat, gently sloping abandoned fields. According to De Baets *et al*. (2006) measurements of grass RLD, in pastures located in the loess belt of Belgium, range between 740 and 6190 km m^{-3} (n = 32, mean = 2310 km m^{-3}, stdev =1200 km m^{-3}), indicating that the RLD values for the studied plants are lower than pasture grass in Belgium. This can be due to the fact that pasture grass has finer roots than the studied plants.

3.3.3 Root distribution with soil depth for the studied plants

The distribution of roots with soil depth is presented in Fig. 3.2. In both villages, RD of the studied plant species decreased with soil depth, however mean RSD increased with soil depth.

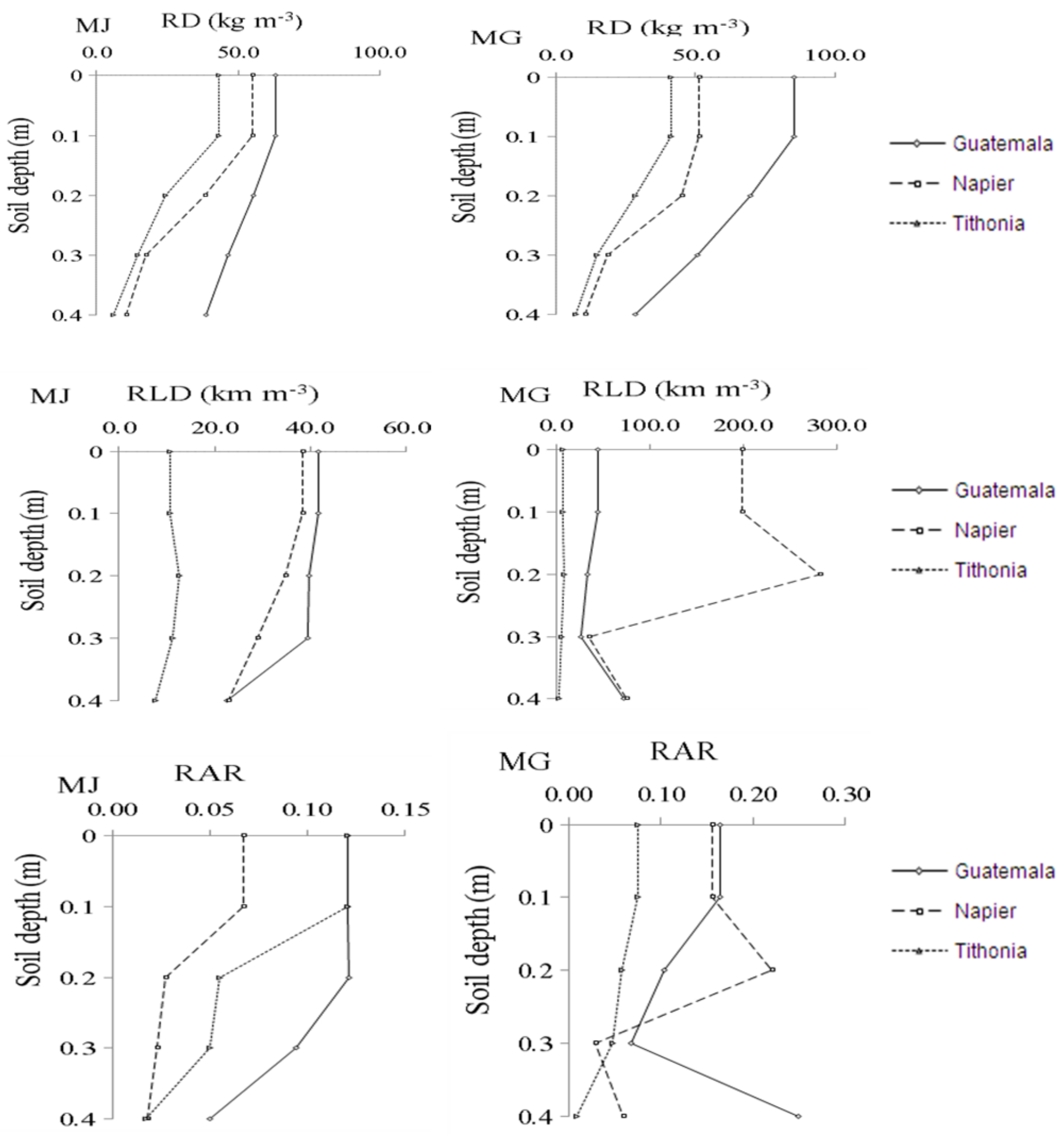

Figure 3.2: Variation of root properties with soil depth and their erosion-reducing potentials for the studied plants in Majulai (MJ) and Migambo (MG) villages. RD is root density; RLD is root length density; RAR is root area ratio; RSD is relative soil detachment rate

This observation was also made by De Baets *et al*. (2007b) whereby RD of 26 plant species studied decreased with soil depth. Root length density decreased with soil depth in Majulai, while in Migambo RLD for Guatemala grass and *Tithonia* shrub tended to increase at deeper soil depths; which is probably due to reliable and well distributed rainfall favourable for plant growth through promoting finer roots at deeper soil depths in Migambo than in Majulai village. Root area ratio followed the same trend as that observed for RLD.

3.3.4 Selection of the most effective plant for soil erosion control

The relationships established by De Baets *et al*. (2007a) to predict the erosion-reducing effect of root systems were applied in this study. The idea was to apply these tropical grasses which have comparable root systems but are growing in different soil types. We therefore aimed at obtaining a first indication of the relative effectiveness of the studied plants species for controlling concentrated flow erosion. It was observed that the predicted RSD values were generally lowest in the topsoil and increased with increasing soil depth (and with decreasing RD) (Table 3.3; Fig. 3.2). Similar observation was reported by De Baets *et al*. (2009); De Baets & Poesen (2010) where soil erodibility decreased with increasing RD.

Mean predicted RSD values at 0 - 0.4 m soil depth for Majulai and Migambo were respectively $4.43*10^{-12}$ and $1.20*10^{-14}$ for Guatemala grass, $6.10*10^{-5}$ and $2.74*10^{-4}$ for Napier grass and $4.43*10^{-3}$ and $2.24*10^{-4}$ for Tithonia shrub, indicating that plant roots can have a significant effect on soil resistance to erosion and that this effect is largely dependent on plant species. Lower RSD rates in Migambo than in Majulai can be attributed by the good rainfall distribution in Migambo which is responsible for greater plant growth. Mean RSD values for the 0 - 0.4 m soil depth were not significantly different at 5 % level ($p > 0.37$) in Majulai and ($p > 0.56$) in Migambo village. According to De Baets *et al*. (2007b) the predicted RSD values of the studied plants ranked very high (RSD < 0.01), with erosion-reducing potential in the following order Guatemala grass > Napier grass > Tithonia shrub. Guatemala grass had the highest erosion-reducing potential and hence has potential to increase the resistance of topsoil to concentrated flow erosion to a large extent.

Table 3.3: Mean root characteristics of the studied plants and effects of roots on predicted soil erosion control (RSD) in the West Usambara Mountains, Tanzania

Plant	Type of plant	Soil depth (m)	n	RD (kg/m^3)	RLD (km /m$^{3)}$	RSD
Majulai village						
Guatemala	Grass	0 – 0.1	3	63.4	41.8	$6.86*10^{-27}$
Napier	Grass	0 – 0.1	3	55.1	38.4	$1.74*10^{-32}$
Tithonia	Shrub	0 – 0.1	3	43.2	10.6	$2.18*10^{-6}$
Guatemala	Grass	0.1 – 0.2	3	55.4	39.7	$2.54*10^{-24}$
Napier	Grass	0.1 – 0.2	3	38.4	34.8	$9.99*10^{-17}$
Tithonia	Shrub	0.1 – 0.2	3	24.6	12.6	$1.15*10^{-9}$
Guatemala	Grass	0.2 – 0.3	3	46.3	39.5	$1.29*10^{-16}$
Napier	Grass	0.2 – 0.3	3	17.3	29.1	$1.37*10^{-10}$
Tithonia	Shrub	0.2 – 0.3	3	14.5	11.3	$3.47*10^{-4}$
Guatemala	Grass	0.3 – 0.4	3	38.6	22.7	$1.77*10^{-11}$
Napier	Grass	0.3 – 0.4	3	10.6	22.8	$2.44*10^{-4}$
Tithonia	Shrub	0.3 – 0.4	3	6.1	7.6	$1.74 * 10^{-2}$
LSD ($p \leq 0.05$)				15.9	5.1	$7.29 *10^{-3}$
Migambo village						
Guatemala	Grass	0 – 0.1	3	85.4	45.0	$2.66*10^{-42}$
Napier	Grass	0 – 0.1	3	51.4	200.0	$1.33*10^{-16}$
Tithonia	Shrub	0 – 0.1	3	41.5	7.6	$3.07*10^{-15}$
Guatemala	Grass	0.1 – 0.2	3	69.6	34.0	$2.60*10^{-33}$
Napier	Grass	0.1 – 0.2	3	45.0	280.0	$1.32*10^{-10}$
Tithonia	Shrub	0.1 – 0.2	3	28.6	8.5	$4.25*10^{-9}$
Guatemala	Grass	0.2 – 0.3	3	50.9	27.0	$4.89*10^{-23}$
Napier	Grass	0.2 – 0.3	3	18.3	36.0	$4.71*10^{-5}$
Tithonia	Shrub	0.2 – 0.3	3	14.7	6.1	$1.03*10^{-4}$
Guatemala	Grass	0.3 – 0.4	3	28.7	73.0	$4.79*10^{-14}$
Napier	Grass	0.3 – 0.4	3	10.3	76.0	$1.05*10^{-3}$
Tithonia	Shrub	0.3 – 0.4	3	7.1	3.4	$7.92*10^{-4}$
LSD ($p \leq 0.05$)				18.7	89.0	$5.51*10^{-4}$

n is the number of plants sampled per species; RD is root density; RLD is root length density; RSD is relative soil detachment rate, LSD is least significant difference

This is attributed to the high density of fine roots in the topsoil. The mean RD values at the 0 – 0.4 m soil depth were significantly higher at 5 % level ($p < 0.003$) in Majulai village and ($p < 0.002$) in Migambo village for Guatemala grass when compared to Napier grass and Tithonia shrub. However, Guatemala and Napier grass roots had higher protection to the 0 - 0.20 m thick topsoil as it was observed that the erosion-reducing effect of these grass roots decreased very rapidly with increasing soil depth when compared to Tithonia shrub. Guatemala and Napier grasses had high RD values and the large proportion of their fine roots makes them suitable for reducing concentrated flow erosion rates from the topsoil. The low erosion reducing potential of *Tithonia* shrub can be attributed to the rather low RD and/or to the absence of a fine root network in the topsoil. The erosion-reducing effect of Tithonia shrub is more pronounced at greater depths (0. 2 to 0.3 m), which can be attributed to the presence of smaller roots at larger depths. This observation is supported by the work of De Baets *et al*. (2007a) who found that erosion-reducing effects of RD decreased with increasing root diameter.

3.3.5 Comparison with other studies on root densities of the tropical grass species

Wanyama *et al*. (2012) studied rooting characteristics of tropical grass species and their effects as sediment filters in the riparian zone of Lake Victoria in Uganda where RD of Paspalum grass, Lemon grass, Elephant grass and Sugarcane were investigated. The results showed that RD for 0 - 0.4 m soil depth were 20.6 kg m^{-3} for Paspalum, 7.6 kg m^{-3} for Lemon grass, 3.8 kg m^{-3} for Elephant grass and 5.1 kg m^{-3} for Sugarcane. In Fig. 3.3 the RD distribution with soil depth for the 0 - 0.4 m depth is compared between this study and findings by Wanyama *et al*. (2012). For both studies root densities decreased with soil depth. However, this study had higher RD values than the results of Wanyama *et al*. (2012) except for Paspalum grass which had relatively similar RD values compared to that of Guatemala grass for the top 0 – 0.1m soil depth (Fig. 3.3).

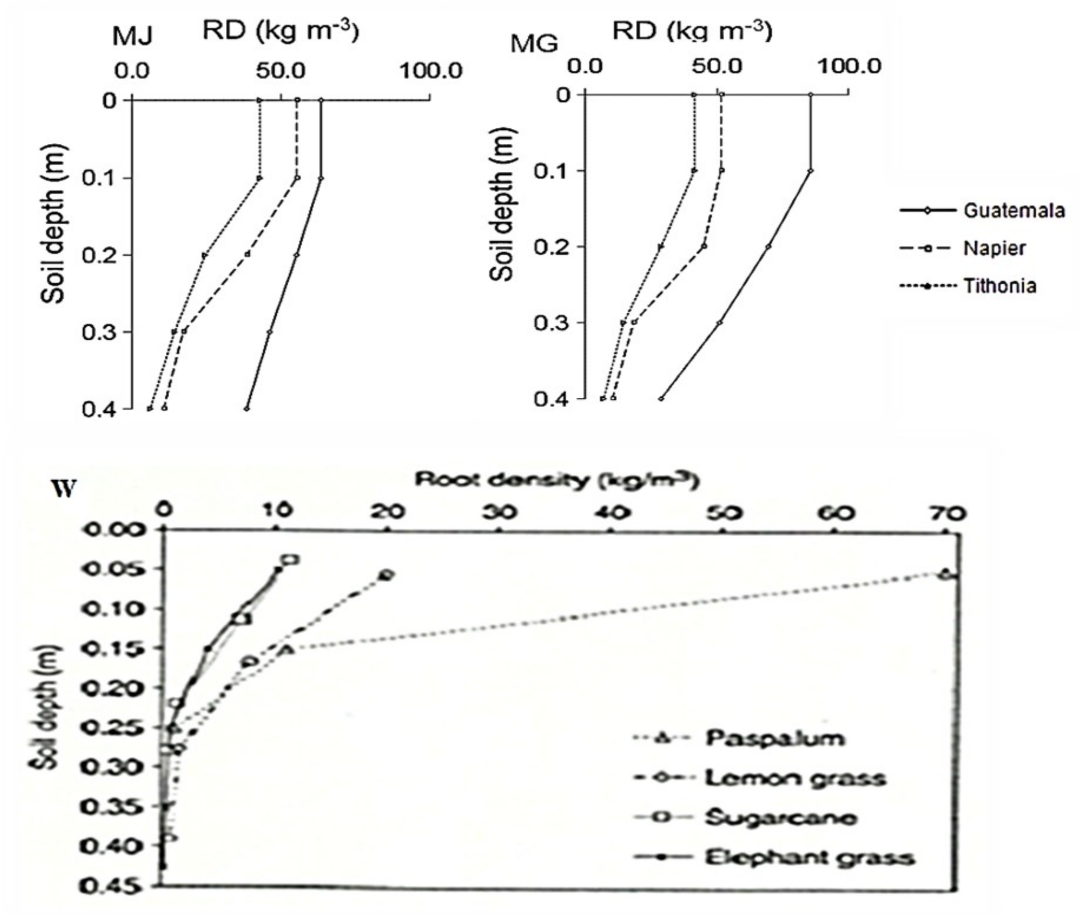

Figure 3.3: Comparing tropical grass species root densities of the studied grasses in the West Usambara Mountains, Tanzania (MJ & MG) and grasses in Lake Victoria, Uganda (W) according to Wanyama *et al*. (2012). MJ is Majulai village, MG is Migambo village

3.4 CONCLUSIONS AND RECOMMENDATIONS

For Guatemala and Napier grasses 100 % root mass consisted of root diameter less than 5 mm, while *Tithonia* shrub had a root mass with 70 % of root diameters less than 5 mm and 30 % greater than 5 mm. Guatemala grass had highest values of RD followed by Napier grass and *Tithonia* shrub (the least) in 0 – 0.4 m soil depth, while

RLD values for Guatemala and Napier grasses were almost the same in Majulai with low values for Tithonia shrub in both villages, whereas in Migambo Napier grass had very high values. Guatemala grass is the most effective species in reducing concentrated flow erosion rates in topsoil (0 - 0.4 m), followed by Napier grass while *Tithonia* shrub is the least effective. The erosion reducing potential of *Tithonia* shrub is more pronounced at greater depths.

Based on the analysis of the root properties of the studied plants, Guatemala grass is strongly recommended for controlling concentrated flow erosion in the study area. However, a combination of Guatemala grass or Napier grass and *Tithonia* shrub will result in a better protection of the topsoil at greater soil depths, but their compatibility should be investigated. In-depth studies to investigate physical RSD for different soil textures are recommended in order to come up with more representative RSD models. Studies are needed to evaluate more plants growing in various habitats for selection of plant species that can effectively control concentrated flow erosion rates.

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CHAPTER FOUR

4.0 EFFECTIVENESS OF SELECTED SOIL CONSERVATION PRACTICES ON SOIL EROSION CONTROL AND CROP YIELDS IN THE WEST USAMBARA MOUNTAINS, TANZANIA

ABSTRACT

Indigenous soil conservation measures such as *miraba* have been widely used in Usambara Mountains for controlling soil erosion but little has been reported about them. On-farm runoff experiments 22 m by 3 m were set from 2011 - 14 on *Acrisols* in Majulai and Migambo villages in the West Usambara Mountains, Tanzania. The aim was to investigate the effectiveness of *miraba* and *miraba* with various mulching materials in reducing runoff, soil and nutrient losses and improving productivity of maize (*Zea mays*) and beans (*Phaseolus vulgaris*). Results show that mean annual runoff coefficients (mm mm^{-1}) ranged from 0.72 for cropland with no soil conservation measure (control) to 0.15 for cropland with *miraba* and Tithonia (*Tithonia diversifolia*) mulching in Majulai village and respectively from 0.68 to 0.13 in Migambo village. Soil loss was significantly ($p < 0.05$) higher under control than under *miraba* with either *Tughutu* (*Vernonia myriantha*) or Tithonia mulching *e.g.* 184 vs. 20 in Majulai and 124 vs. 8 Mg ha^{-1} yr^{-1} for Migambo village in 2012. The *P*-factors were significantly ($p < 0.05$) higher under *miraba* sole than under *miraba* with mulching in Majulai village (0.18 vs. 0.11) and in Migambo village (0.10 vs. 0.05). The annual nutrient losses in kg $ha^{-1}yr^{-1}$ were significantly ($p < 0.05$) higher under control than under *miraba* with mulching 367 vs. 37 total N, 0.8 vs. 0.1 P and 14 vs. 4 K for Majulai village; 474 vs. 26 total N, 0.7 vs. 0.1 P and 20 vs. 1.2

K for Migambo village in 2012. Maize and bean yields were significantly ($p < 0.05$) higher under *miraba* with *Tughutu* mulching than under control (*e.g.* 2.0 vs. 0.7 Mg ha^{-1} for maize in Majulai in 2012). Thus *miraba* with *Tughutu* mulching is more effective in improving crop yields than *miraba* with Tithonia and *miraba* sole.

Key words: Runoff experiments, indigenous SWC, soil and nutrient losses, *miraba*, RUSLE, maize, beans.

4.1 INTRODUCTION

Soil erosion has been reported as a serious problem facing agricultural production globally (Faucette *et al*., 2004; Descheemaerker *et al*., 2006; Ajibade, 2008; Kimaro *et al*., 2008; Jiao *et al*., 2012). Soil erosion by water is a major factor causing land degradation in the Western Usambara highlands of Tanzania and severely affects soil functions resulting in low crop productivity (AHI, 2001; Tenge, 2005). Soil erosion by water is defined as the detachment and displacement of soil particles by water, resulting in the development of rills and gullies (Govers and Poesen, 1998). To overcome the problem of soil deterioration, the West Usambara farmers have developed local soil and water conservation (SWC) measures such as *miraba* which are rectangular grass bound strips that do not necessarily follow the contour lines (Msita *et al*., 2010), micro-ridges and stone bunds as an integral part of their farming systems (Tenge, 2005; Vigiak *et al* 2005; Msita *et al.,* 2010). Most of the introduced measures have often been rejected or minimally adopted because such measures *e.g.* bench and *Fanya Juu* terraces (hillside ditches made by throwing excavated soil on the upslope of the ditch, built along the contour lines at appropriate intervals depending on slope) were expensive in terms of labour and financial, while also their promoters paid little attention on indigenous practices.

Miraba are widely practised by farmers in the West Usambara Mountains. *Miraba* as a SWC measure is traditionally characterized by a wide spacing of grass strips across the slope and usually the spacing depends on the size of farm plots. For decades these SWC technologies were never a subject of scientific study to allow improvements be made to effectively address problems of soil degradation and low crop productivity (Vigiak *et al*., 2005). On the other hand, farmers have not been able to adjust these indigenous SWC techniques to rapidly changing farming systems and increasing intensity of land uses (Ellis-Jones and Tengberg, 2000; Vigiak *et al.,* 2005).

On steep slopes like in the West Usambara Mountains, bench terraces are highly recommended as the most effective soil and water conservation measure in cropland (Sheng, 2002; Tenge, 2005; Vigiak *et al*., 2005; Wickama *et al*., 2014). However, due to low adoption rates in Usambara Mountains, the solution would be to improve and use indigenous SWC technologies such as *miraba* for sustained agricultural productivity in the area. *Miraba* are established by using either Napier (*Pennisetum purpureum*) or Guatemala (*Tripsacum andersonii*) grasses. Grass strips forming *miraba* serve as barriers which capture soil particles that have been detached and transported with runoff from the cultivated land. Napier grass is mostly preferred because it is also used as forage for stall feeding, while Guatemala grass is appreciated for its drought resistance and to some extent is also used as forage for stall feeding. Studies on effectiveness of some SWC technologies such as bench terraces, *Fanya Juu* terraces, grass strips and *miraba* on soil erosion control and agricultural productivity have recently been carried out in the West Usambara Mountains (Tenge, 2005; Msita *et al*., 2010; Kyaruzi, 2013; Msita, 2013). However, the contribution of indigenous SWC technologies including *miraba* mostly practised in the study area have not fully been investigated for sustained agricultural productivity (Vigiak *et al*., 2005; Msita, 2013). Moreover, it has been reported that establishment of *miraba* is far cheaper than the construction of bench terraces (Msita, 2013). Therefore, efforts towards improving this technique are warranted.

Several erosion models are available to predict soil loss and to assess soil erosion risk (Vigiak *et al*., 2005; Kimaro *et al*., 2008). However, the Revised Universal Soil Loss Equation (RUSLE) is widely used for estimating potential soil erosion by water especially at regional and national level because of its relative simplicity and robustness (Renard *et al*., 1996; Kimaro *et al*., 2008; Zarris *et al*., 2011; Msita, 2013). This study applied RUSLE model to investigate the effectiveness of *miraba* and *miraba* with Tithonia (*Tithonia diversifolia*) and *Tughutu* (*Vernonia myriantha*) mulching materials in reducing runoff, soil and nutrient losses using maize and beans as test crops. Specifically, the study intended to: (i) quantify soil and nutrient losses under selected soil conservation practices (ii) determine rainfall-runoff responses under selected soil conservation practices (iii) select the best soil conservation practice using the Revised Universal Soil Loss Equation (RUSLE) and (iv) determine the influence of selected soil conservation practices on crop yield.

4.2 MATERIALS AND METHODS

4.2.1 Description of the study sites

The study was conducted in Migambo and Majulai villages which represent different agro-ecological zones in the West Usambara Mountains, Lushoto District, Tanzania (Fig. 4.1) located between longitudes 38^0 15' to 38^0 24' E and latitudes 4^0 34' to 4^0 48' S. The area is highly dissected with steep slopes ranging from 20 % to over 50 % and altitude of about 1402 m. a.s.l. in Majulai and 1682 m. a.s.l. in Migambo village. Migambo is humid cold with mean daily air temperature of 12 - 17 ^{0}C and annual precipitation is 700 - 2300 mm. Majulai is dry and warm with mean daily air temperature ranging between 16 and 21 ^{0}C and annual precipitation of 500 - 1700 mm. The monthly reference evapo-transpiration (ETo) as estimated by the local climate estimator software (New LocClim) (FAO, 2006) ranges from 100 mm to 145 mm.

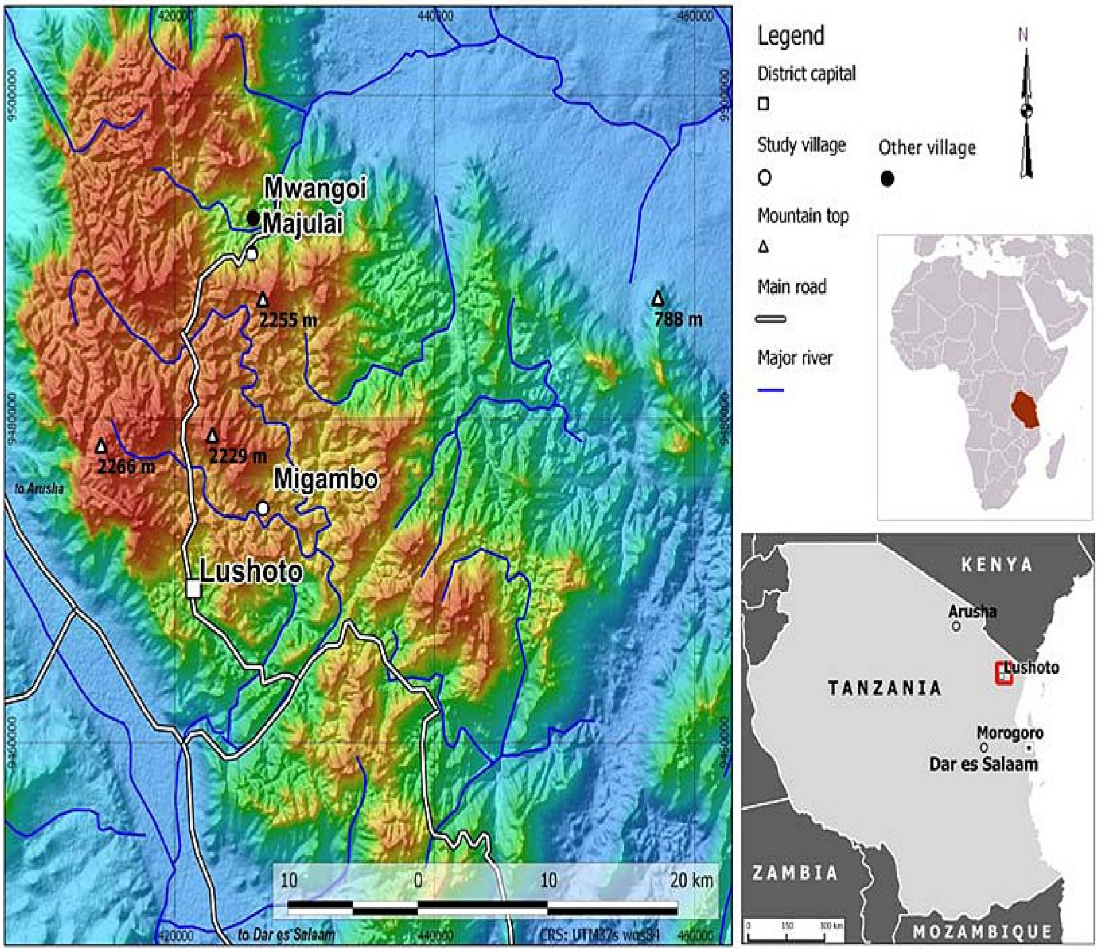

Figure 4.1: Location Map of Migambo and Majulai villages, Lushoto District, Tanzania. Source: Adapted from Msita (2013)

Majulai and Migambo villages support a large population density of more than 120.4 persons/km^2 (National Bureau of Statistics, 2012). Some selected soil and topographic properties and soil maps of Majulai and Migambo watersheds are presented in Appendices 1, 2 & 3. According to the World Reference Base (WRB) (FAO, 2014), the soil type in Majulai experimental site is classified as *Chromic Acrisol* (*Humic, Profondic, Clayic, Cutanic, Colluvic*) whereas in Migambo site the soil is *Haplic Acrisol* (*Humic, Profondic, Clayic, Colluvic*).

The main land uses include cultivation on slopes and in valleys, settlements on depressions, lower ridge summits and slopes and forest reserves on ridge summits and upper slopes. Vegetables such as carrots, onions, tomatoes, cabbages, and peas are grown as sole crops in valleys under rain fed or traditional irrigation. Beans are mainly grown during the long rainy season while maize is grown during the short rains. Round potatoes and fruits, namely peaches, plums, pears, avocado and banana are grown on ridge slopes under rain fed mixed farming. Round potatoes are also grown in valleys as sole crop or intercropped with maize.

4.2.2 *Miraba* establishment in runoff experiments

Miraba were established by using Napier grass (*Pennisetum purpureum*) barriers in runoff experiments in April 2011 about nine months before data collection started. Napier grass barriers forming *miraba* were established by planting tillers in a single row at 10 cm spacing (as per farmers' practise) perpendicular to slope. The grass barriers were maintained to about 50 cm wide strips to avoid reduction of cropland by grass barriers. The grass barriers were cut at about 25 cm above ground (Pfeifer, 1990), the low cutting reduce competition of space and sunlight with crops, while also stimulate tillering that make dense grass barriers for effective controlling soil erosion. In the current study Napier grass barriers across the slope were spaced 5 m apart to mimic the recommended maximum effective width of hand made bench terraces Sheng (2002). Along the slope Napier grass barriers were set at 3 m apart, wider by 1 m from the standard runoff plots to accommodate the space occupied by grass barriers.

It has been documented that soil conservation measures such as *Fanya Juu* and stone bunds tend to progressively form bench terraces when they are at narrow spacing (Sheng, 2002; Kaswamila, 2013). Moreover, the closer the grass strips are, the more effective they become (Kaswamila, 2013). Progressive bench terraces formation is also possible under *miraba* when adjusted to appropriate spacing of grass strips. Natural bench terraces formations as a result of *miraba* implementation are much less expensive compared to mechanical bench terraces construction. Bench terraces are highly recommended for use in Usambara Mountains (Shelukindo, 1995; AHI, 2001; Tenge, 2005, Vigiak *et al.,* 2005).

4.2.3 Experimental design

Closed runoff plots of 22 m x 3 m in a Randomized Complete Block Design (RCBD) were set along lower ridge slopes at 50 % slope in Majulai and 45 % slope in Migambo village. According to Sheng (2002) the slopes at this range recommended as the maximum slope for bench terraces implementation. The study area is dominated by steep slopes where maize and beans are mainly grown. The slopes of runoff plots were different between the two villages because we could not obtain suitable areas with exactly the same slopes. The runoff plots were enclosed by *miraba* and bounded by pieces of wood that protruded 15 cm above the soil surface to prevent inflow and outflow from the plot boarders. The pieces of wood were connected to three collector drums with hinged lids each drum having a volume of 220 litres.

Maize (*Zea mays*) and beans (*Phaseolus vulgaris*) were planted in rotation as test crops except under bare plots in 2012 and 2013/14 rainy seasons. Maize was planted during short rains (*vuli*), while beans were planted during long rains (*masika*) as per farmers' practise. The treatments included Runoff plots (Plate 4.1) with: (i) *Miraba* sole (***MI***) (ii) *Miraba* with *Tithonia* mulching (***MITH)*** (iii) *Miraba* with *Tughutu* mulching (***MITG*)** (iv) plots without SWC measure (Control) **(*CO*)** (v) Bare plots

Plate 4.1: a) Majulai plots layout b) Migambo plots layout c) Majulai plots with maize crop d) Migambo plots and application of farm yard manure. Plates by: Mwango, S.B. 12/03/2012 and 25/10/2012 for c

(***BA***), all replicated three times. Mulching materials used in this study were the leaves of the readily available shrubs in both villages namely *Alizeti Pori* (*Tithonia diversifolia*) and *Tughutu* (*Vernonia myriantha*). Tithonia has frequently been reported as a good green manure while also *Tughutu* is known to contain NPK (Wickama and Mowo 2001; Ikerra, 2004; Mowo *et al*., 2006). Samples were collected from each mulching material for determination of total N, available P, K^{+}, Mg^{2+}, Ca^{2+} and Na^{+}.

4.2.4 Rainfall data collection

Daily rainfall was measured from 1 January 2012 to 16 February 2014 using standard rain gauges and tipping buckets with a CR10 data logger (Campbell Scientific, Logan UT) installed at the experimental sites in Migambo and Majulai villages. The daily rainfall data were collected from the standard rain gauges by recording rainfall amount in litres and then converted in millimetre. The daily rainfall amount in millimetres from the tipping buckets data logger was downloaded using a laptop computer after every two months.

4.2.5 Runoff, sediment and nutrient loss determination

Runoff and sediment were collected daily from 1 January 2012 to 16 February 2014. Runoff volume was estimated by measuring the depth of water in cm in the collecting drums and then converted to volume of water in litres. Sediment load was estimated by sampling water in collecting drums after vigorously stirring the suspension by using a mop with strong wooden handle. The water sampling was done by lowering a one litre plastic bottle from the water surface to the bottom of the drum, and samples of about 300 ml were collected at the bottom, middle and upper part when runoff depth in the drum was above 25 cm. Heavy sediments in the drums were scooped out weighed and a 1 kg soil sample collected, oven dried for at least 24 hours at 105 ^{0}C and weighed for dry soil loss calculation. The suspended sediment samples were filtered using Whatman No. 42 filter paper and dried for at least 24 hours at 105 ^{0}C until constant weight was obtained (Yang *et al*., 2009) and the soil loss (Mg ha^{-1}yr^{-1}) was determined.

Soil losses from heavy sediments and from suspended materials from each runoff event were added to compute total soil loss for the events. These losses were finally added to compute total soil loss per annum. The soil samples for nutrient loss determination were collected by decanting the suspended sediment in buckets. In each runoff experimental site a soil profile was excavated and soil samples were collected from each horizon for pedological characterization. Undisturbed core soil samples were taken at 0 - 5 cm, 45 - 50 cm and 95 - 100 cm soil depth by Kopecky's core rings (100 cm^3) for bulk density, gravimetric moisture and available moisture determination. The soil was classified to tier-2 according to the World Reference Base for Soil Resources (WRB) (FAO, 2014).

Plate 4.2: Filtration of runoff samples by using locally made stands and funnels in Majulai village. Plates by: Mwango, S.B. 30/04/2012

4.2.6 Crop yields

Maize PAN 67 variety and beans Kilombero variety were planted in runoff plots during the 2012 and 2013/14 rain seasons with maize in the short rains (*vuli*) and beans in the long rains (*masika*) at the recommended spacing of 30 cm within rows and 75 cm between rows for maize and 25 cm within rows and 50 cm between rows for beans. Beans were always planted one month before the maize was harvested in Migambo and two weeks before harvesting maize in Majulai village, because in Migambo village maize stay longer in the field due to cold climate. Farmyard manure with 1.7 % N, 0.4 % P and 1.9 % K was basal and spot applied at the rate of 3.6 Mg ha^{-1} air-dry weight, DAP 18: 46: 0 NPK ratio and Urea 46 % N were applied at the rate of 80 kg ha^{-1}, but Urea was not applied for beans as per farmers' practise. At maturity maize and beans grains were harvested and dried to about 13 % moisture content.

4.2.7 Soil analysis

Soil analysis was done following the Moberg's (2001) Laboratory Manual. Organic carbon (OC) was measured using the dichromate oxidation method, total nitrogen (TN) by Kjeldahl method, available phosphorus (Bray-I), exchangeable bases (Ca^{2+} and Mg^{2+}) by atomic absorption spectrophotometer, exchangeable Na^{+} and K^{+} by flame photometer and pH water by normal laboratory pH meter.

4.2.8 Determination of the RUSLE factors

The RUSLE equation expresses average annual soil loss Mg ha^{-1} year^{-1} caused by sheet and rill erosion (Renard *et al*., 1996):

$A = RKLSCP$ ……………………………………………………………………… (1)

Where A is the long term average soil loss (Mg ha^{-1} year^{-1}), R is rainfall erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1}), K is the soil erodibility factor (Mg ha MJ^{-1} mm^{-1}), LS is dimensionless factor combining slope steepness (S) and slope length (L), C and P are dimensionless factors accounting respectively for crop cover and management and conservation practices.

The equation developed by Vrieling *et al*. (2010) was used to calculate R factor. Such that:

$R = 50.7\ MFI - 1405$ …………………………………………..……..………. (2)

Where MFI is the Modified Fournier Index calculated from:

$MFI = \sum_{n=1}^{\infty}(p^2)/P$ .... (3)

Where p is the average monthly rainfall (mm) and P is the average annual rainfall (mm). In the absence of any cover crop or soil protection measure, as for the bare plot, C and P factors are equal to 1. Thus K factor was calculated from:

$K = A_{\text{bare plot}} / (RLS)$………………………………………………………………. (4)

According to Mitchell & Bubenzer (1980):

$LS = [0.065 + 0.0456s + 0.006541s^2]$ x $(l/22)^{1/2}$………………………...……...…. (5)

Where: s, is the slope gradient in %; l, is the plot length in m; constant ½, is used where slope steepness is ≥ 5 %.

The effectiveness of soil conservation practices on reducing soil loss was determined by the use of C and P factors when compared to the bare plots. The C factor in the long rain season was function of the bean crop cover; in the off season the C factor was determined by weed cover, while in the short rains maize cover was considered.

The *C* factor was calculated as the ratio between the seasonal or annual soil losses of the control plot to the seasonal or annual soil losses of the bare plot. The *P* factor was calculated as the ratio between the seasonal or annual soil losses under *miraba* plots to the seasonal or annual soil losses under control plots.

C (*CO* plot) = *A* (*CO* plot) / *A* (*BA* plot)……………….…………………………….. (6)

P (MI plot) = A (MI plot) / *A* (*CO* plot)………………………………...……...... (7)

P (MITH plot) = A (MITH plot) / *A* (*CO* plot)………...………………...……....... (8)

P (MITG plot) = A (MITG plot) / *A* (*CO* plot)……….................................……..... (9)

Where: *A* (*CO* plot), is the soil loss (Mg ha^{-1} $season^{-1}$ or Mg $ha^{-1}yr^{-1}$) under control plots. *A* (*BA* plot), is the soil loss (Mg ha^{-1} $season^{-1}$ or Mg $ha^{-1}yr^{-1}$) under bare plots. *A (MI, MITH or MITG plot),* is respectively the soil loss (Mg ha^{-1} $season^{-1}$ or Mg $ha^{-1}yr^{-1}$) under *miraba*, *miraba* with Tithonia mulching and *miraba* with *Tughutu* mulching plots. The effectiveness of soil conservation practices on reducing soil loss was determined by the percent of *C* and *P* factors with reference to bare plots. The effectiveness of *miraba* on reducing nutrient losses was also calculated in percentages in respect of bare plots.

4.2.9 Data analysis

Bartlett's test for homogeneity of variances was conducted to test data normality using GenStat software (GenStat, 2011). The relationships between daily rainfall and daily runoff were determined by Linear Regression Analysis with threshold runoff values obtained from the X-axis intercept. Analysis of Variance (ANOVA) in GenStat statistical software (GenStat, 2011) was performed where Least Significant Difference ($LSD_{0.05}$) was used to detect mean differences between treatments.

4.3 RESULTS AND DISCUSSION

4.3.1 Rainfall erosivity between the two villages with contrasting climatic conditions

Rainfall distribution in the two villages is presented in Fig. 4.2, while the annual and seasonal rainfalls recorded during the two consecutive years are presented in Table 4.1.

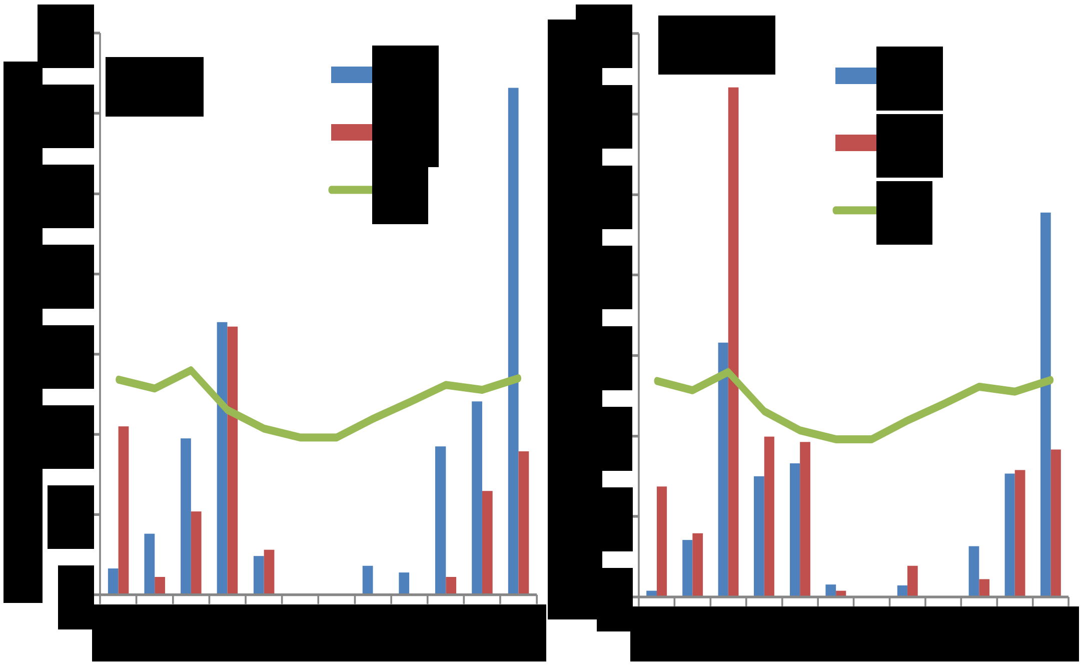

Figure 4.2: Rainfall distribution in Majulai and Migambo villages and estimated reference evapo-transpiration (ETo) measured during 2012 and 2013; ETo determined according to New LocClim estimator (FAO, 2006)

The results in Fig. 4.2 indicate that, Migambo village received more rainfall with good distribution in a year than in Majulai village where prolonged months of dry spells were observed. It can also be seen that, as the rainfall depth was higher in Majulai village than Migambo village in 2012, rainfall erosivity *R* factor is also higher in Majulai, while in 2013 the higher values of rainfall depth and *R* factor were observed in Migambo village (Table 4.1).

Table 4.1: Rainfall measured in Majulai and Migambo villages Lushoto District, Tanzania

	Majulai		Migambo	
	2012	2013	2012	2013
Rainfall (mm)				
Long rains (Feb.- May)	329.3	258.0	359.4	552.1
Offseason rains (Aug – Sept.)	28.7	0	7.1	23.4
Short rains (Oct. – Jan.)	636.9	165.1	415.8	222.7
Annual rainfall	906	528	718	826
R (MJ mm ha^{-1} h^{-1} $year^{-1}$)	7774	3857	5859	7247

4.3.2 Soil loss in relation to SWC measures and the two villages with contrasting climatic conditions

From our results (Table 4.2), Majulai village had significantly ($p < 0.001$) higher annual soil losses than Migambo in 2012, but in 2013 annual soil losses were significantly ($p < 0.001$) higher in Migambo than in Majulai village. The difference in soil losses between the two villages can partly be attributed to the rainfall depth (Table 4.1), as it can clearly be seen that the higher the rainfall depth the higher the soil losses in the studied villages. Kabanza *et al*. (2013) observed soil losses in the Makonde plateau being higher than in inland plains and rainfall depth was the main contributing factor. The relatively steeper slopes in Majulai (50 %) than in Migambo (45 %) could also explain the soil loss differences. Liu *et al*. (1994) observed slope gradients to be strong determinants of soil loss. On the other hand soil losses differed significantly ($p < 0.001$) between SWC measures in both villages. Soil losses followed the trend that bare plots > cropland with no SWC measures > cropland with *miraba* sole > cropland with *miraba* and Tithonia or *Tughutu* mulching.

The reduced soil losses under *miraba* and *miraba* with mulches could be explained by the effect of grass barriers forming *miraba* that captured some soil sediments that

Table 4.2: Annual soil losses measured in Majulai and Migambo villages Lushoto District, Tanzania

Soil loss Mg ha^{-1} $year^{-1}$		Majulai 2012	Majulai 2013	Migambo 2012	Migambo 2013
Bare plots	Replicates				
	1	254.6	100.6	175.6	177.1
	2	262.7	107.9	182.0	188.3
	3	266.9	105.7	183.6	186.6
	Mean	261.4	104.7	180.4	184.0
Plots with maize or beans	1	179.6	72.9	124.1	133.3
	2	183.3	76.8	124.3	129.8
	3	187.8	77.2	124.4	131.6
	Mean	183.6	75.6	124.3	131.6
Miraba with maize or beans	1	34.7	12.2	13.3	14.9
	2	35.9	11.7	13.4	13.4
	3	33.6	14.3	13.5	14.3
	Mean	34.7	12.7	13.4	14.2
Miraba with Tithonia and maize or beans	1	17.58	5.42	8.02	5.30
	2	20.03	8.20	7.58	4.76
	3	20.05	9.09	7.97	5.18
	Mean	19.22	7.57	7.86	5.08
Miraba with *Tughutu* and maize or beans	1	18.47	5.62	7.97	5.47
	2	20.10	9.34	7.43	5.18
	3	20.02	9.33	7.24	5.27
	Mean	19.50	8.10	7.55	5.31
LSD ($P \leq 0.05$)		4.14	4.06	4.14	4.06
SE		1.39	1.37	1.39	1.37

LSD: least significant difference; SE: standard error of means

were with runoff. Wanyama *et al*. (2012) in Lake Victoria Uganda also reported grass strips to effectively trap more than 70 % sediments under natural rainfall. Besides *miraba* were progressively forming bench terraces such that the terrace height reached about 1 m in Migambo and 0.7 m in Majulai village after about three years of experimentation. The terraces so formed reduced the slope steepness, runoff velocity and increased rate of infiltration. This ultimately reduced runoff volume and sediment losses. Similarly, mulches also reduced runoff velocity, thereby increasing rate of infiltration and reducing runoff volume and sediment losses. Such observations were also reported by Bajracharya *et al*. (2005) in Nepal where mulching was found to reduce annual soil loss by 60 to 90 percent in maize – mustard cropping system as compared to conventional farmers' practice.

4.3.3 Rainfall-runoff responses under selected soil conservation practices

The slope of the regression line was used as a measure of the rainfall-runoff response The rainfall-runoff response varied between the villages and between soil conservation measures (Fig. 4.3a). The differences can strongly be explained by the influences of the studied soil conservation measures; bare plots had the highest annual runoff coefficient as for runoff depth, while *miraba* with Tithonia and *miraba* with *Tughutu* mulching had the lowest (Table 4.3 & Fig. 4.3). The rainfall threshold values to initiate runoff varied between the soil conservation measures and between the studied villages. These differences were also directly associated with the effects of soil conservation measures and the differences in climatic conditions between the villages (Fig. 4.2).

Table 4.3: Daily runoff (mm) (Y) response to daily rainfall (mm) (X) for Majulai and Migambo villages in the West Usambara Mountains, Tanzania

Village/ Treatments	Regressions equations	Runoff thresholds	R^2	No. of rainfall incidences	No. of runoff observations
Majulai					
Bare plots	Y=0.230X-0.79	3.4	0.8	118	353
Control	Y=0.190X-0.72	3.8	0.8	118	353
Miraba	Y=0.065X-0.26	4.0	0.6	118	353
Miraba+Tithonia	Y=0.038X-0.15	4.2	0.5	118	353
Miraba+*Tughutu*	Y=0.037X-0.16	4.2	0.5	118	353
Migambo					
Bare plots	Y=0.200X-0.76	3.8	0.9	122	365
Control	Y=0.160X-0.68	4.3	0.9	122	365
Miraba	Y=0.040X-0.19	4.7	0.8	122	365
Miraba+Tithonia	Y=0.030X-0.13	5.0	0.9	122	365
Miraba+*Tughutu*	Y=0.027X-0.15	4.9	0.8	122	365

The rainfall threshold values to initiate runoff follow the trend that *miraba* with Tithonia and *miraba* with *Tughutu* mulching > *miraba* sole > cropland with no SWC measures > bare land in both villages. *Miraba* with mulching had the highest rainfall threshold values *e.g.* 5.0 mm in Migambo village and lowest values under bare land *e.g.* 3.4 mm in Majulai village. The observed rainfall threshold values are very low implying that the soils of the West Usambara Mountains are very sensitive to runoff and therefore to soil loss, thus implementation of improved *miraba* with mulching could be very effective way to curb soil degradation by water erosion in the area.

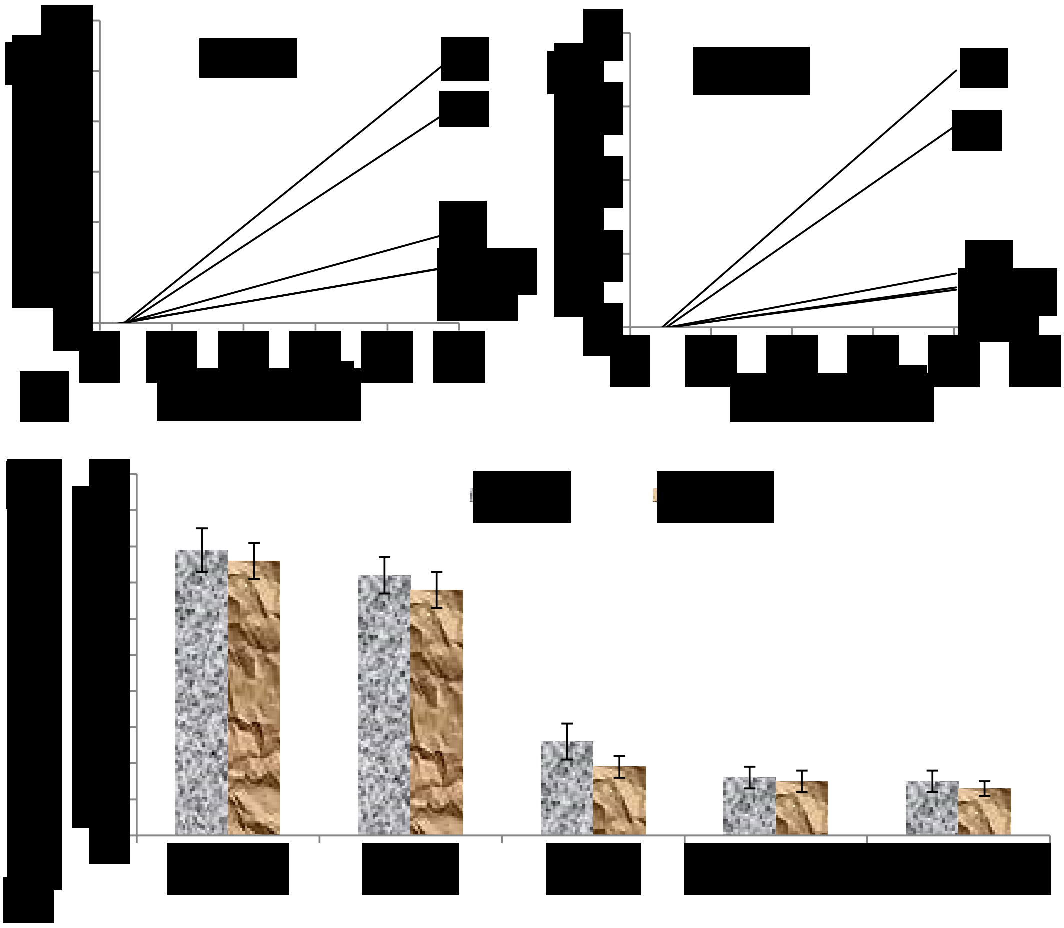

Figure 4.3: a) Rainfall-runoff response curves for Majulai and Migambo b) runoff coefficients for different soil and water conservation measures in the West Usambara Mountains, Tanzania. Key: BA Bare plots; CO Control; MI *Miraba* sole; MI+TG *Miraba* with *Tughutu* mulching and MI+TH *Miraba* with Tithonia mulching

4.3.4 Effectiveness of soil conservation practices in relation to RUSLE factors

The relative effectiveness of soil conservation practices with reference to soil losses from cropland with no SWC measures are presented in Fig. 4.4. It can clearly be seen that *miraba* sole, *miraba* with Tithonia and *miraba* with *Tughutu* mulching were more effective in reducing soil loss in Migambo than in Majulai village. This can be attributed to the differences in rainfall distribution where the poor rainfall distribution in Majulai village caused Napier grass in the *miraba* to die during dry spells, while the reliable rainfall in Migambo made Napier grass barriers that form *miraba* to persist throughout the year and thus forming denser grass strips than in Majulai village. It is evident from Fig. 4.4 that *miraba* reduced soil losses by about 80 % in Majulai and 90 % in Migambo village relative to soil losses from cropland with no SWC measures. On the other hand *miraba* with Tithonia and *Miraba* with *Tughutu* mulching reduced soil losses by 90 % in Majulai and 95 % in Migambo village relative to soil losses from cropland with no SWC measures (Fig. 4.4).

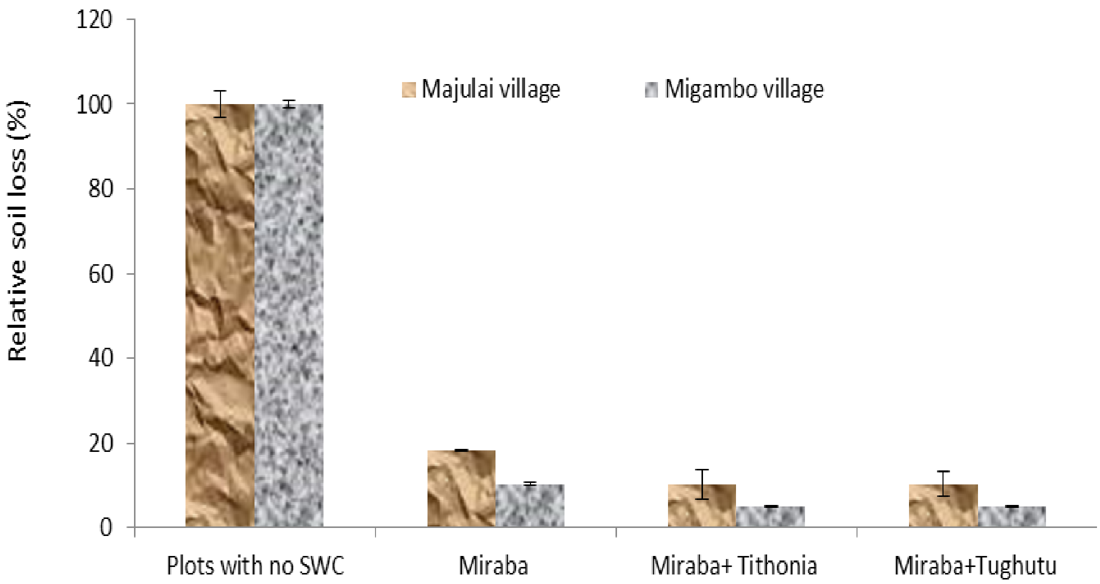

Figure 4.4: The mean relative soil loss with STDEV from 3 replicates under the studied soil conservation practices in Majulai and Migambo villages based on measurements from 2012 - 2013

Based on the work by Kabanza *et al*. (2013), the *C* and *P* RUSLE factors were found to provide better insight than other attributes when assessing the effectiveness of soil conservation measures. The observed *K* factors were 0.0016 (Mg ha MJ^{-1} mm^{-1}) for

Chromic Acrisol (*Clayic*) in Majulai and 0.0018 (Mg ha MJ^{-1} mm^{-1}) for *Haplic Acrisol* (*Clayic*) in Migambo village (Table 4.5). These *K* factor values are very low, indicating high susceptibility of the studied soils to erosion. More erodible soils such as silt loams have their *K* factor ranging from 0.03 – 0.05 (Mg ha MJ^{-1} mm^{-1}) (Mtakwa *et al.,* 1987; Poesen, 1992).

The *P* factor values are much higher in Majulai than in Migambo village (Table 4.4 & 4.5) indicating that the studied soil conservation practices have stronger effect in Migambo than in Majulai village. This can be explained by the good rainfall distribution in Migambo as compared to Majulai village which experiences long dry spells (Fig. 4.2) resulting natural death of *miraba* Napier grass and, thus, reducing its effectiveness. Similarly significant differences were observed between soil conservation practices where *Miraba* with Tithonia and *Miraba* with *Tughutu* mulching were more effective in reducing soil loss than *miraba* sole and control (plots with maize or beans crop).

Table 4.4: RUSLE factors for the Majulai and Migambo villages in the West Usambara Mountains, Tanzania based on soil loss measurements on runoff plots for the year 2012 and 2013

RUSLE factors		n	Majulai 2012	Majulai 2013	Migambo 2012	Migambo 2013	Sign.
R (MJ mm ha^{-1} h^{-1} $year^{-1}$)		1	7774	3857	5859	7247	ns
K (Mg h MJ^{-1} mm^{-1})		1	0.0018	0.0015	0.0020	0.0017	ns
C (dimensionless)							
	Maize and beans	3	0.71	0.70	0.70	0.70	ns
P (dimensionless)							
	Miraba	3	0.19	0.17	0.10	0.10	***
	Miraba+Tithonia	3	0.11	0.10	0.06	0.04	***
	Miraba+*Tughutu*	3	0.11	0.10	0.06	0.04	***
	LSD ($p \leq 0.05$)		0.03	0.03	0.03	0.03	

LSD: least significant difference; Sign. ns: not significant; ***: $p < 0.001$. Mann-Whitney U test for *R*, *K* and *C* factors; Nested ANOVA for *P* variable from three replicates

This is due to the fact that grass barriers forming*miraba* and mulches tend to reduce runoff speed and thus increasing the rate of infiltration. This tendency was also reported by Duran *et al*., (2006), Reubens *et al*., (2007), Liu *et al*., (2012) and Birru *et al*., (2012). The most effective soil conservation practices in both villages are thus *miraba* with Tithonia and *miraba* with *Tughutu* mulching (P = 0.11 for Majulai and P = 0.002 for Migambo village).

Table 4.5: RUSLE factors for the Majulai and Migambo villages in the West Usambara Mountains, Tanzania based on soil loss measurements on runoff plots from 2012-2014 rain seasons

RUSLE factors		Majulai Median	Majulai IQR	n	Migambo Median	Migambo IQR	n	Sign.
R (MJ mm ha^{-1} h^{-1} yr^{-1})		5816	1958	2	6553	694	2	ns
K (Mg h MJ^{-1} mm^{-1})		0.0016	0.0002	2	0.0018	0.0002	2	ns
C (dimensionless)		Mean	STDEV		Mean	STDEV		
	Beans/weed/Maize	0.71	0.02	6	0.70	0.005	6	ns
P (dimensionless)		Mean	STDEV		Mean	STDEV		
	Miraba	0.18	0.002	6	0.10	0.003	6	***
	Miraba+Tithonia	0.11	0.03	6	0.05	0.002	6	***
	Miraba+*Tughutu*	0.11	0.02	6	0.05	0.002	6	***
	LSD ($p \leq 0.05$)	0.03			0.03			

LSD: least significant difference; IQR: inter-quartile range; STDEV: standard deviation; n: number of observations from 3 replicates for 2 years period; Sign. ns: not significant; ***: p < 0.001. Friedman test for R, K and C factors; Nested ANOVA for P variable

4.3.5 Nutrient losses under the studied SWC measures

Soil nutrient losses under soil conservation practices are presented in Fig. 4.5. Soil nutrient losses were significantly ($p < 0.001$) different between SWC practices. The differences in soil nutrient losses can directly be associated with the effects of soil conservation practices intervention (Table 4.6). Soil nutrient losses followed the trend that bare plots > cropland with no SWC measures > cropland with *miraba* sole > *miraba* with *Tughutu* and *miraba* with Tithonia mulching. Msita (2013) in Migambo village, Tanzania reported lower losses of total N, P and K^+ in plots with

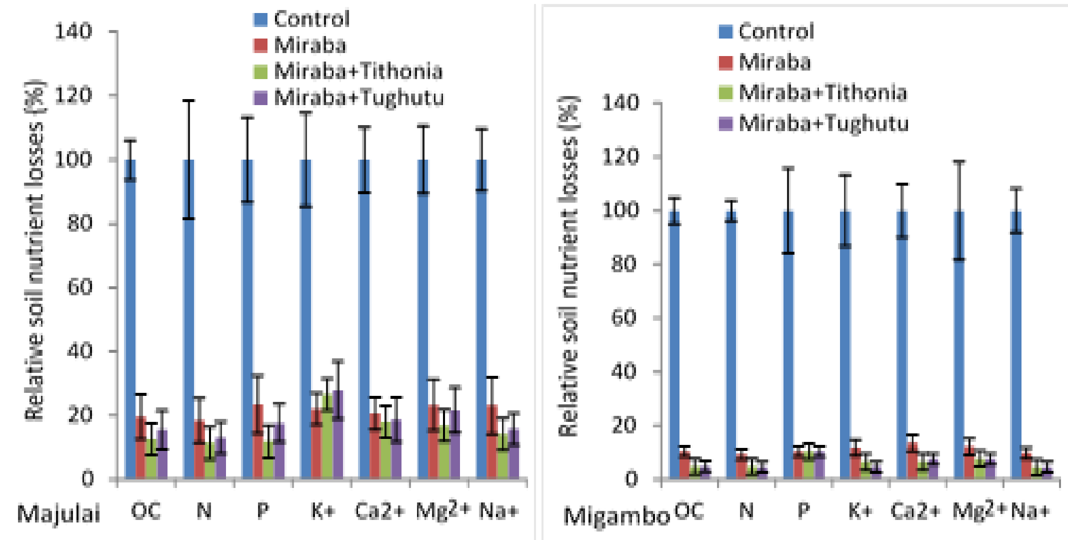

Figure 4.5: The mean relative nutrient loss under the studied soil conservation practices in Majulai and Migambo villages based on measurements from 2012 – 2013

Table 4.6: Soil nutrient loss (kg ha^{-1} year^{-1}) under the studied soil conservation practices in Majulai and Migambo villages

Village (Year)	Treatments	n	OC	N	P	K^+	Ca^{2+}	Mg^{2+}	Na^+
Majulai									
	Bare	72	4835.7	478.8	1.0	41.3	80.2	18.0	15.5
	Control	72	3049.7	306.5	0.8	13.6	62.7	18.3	8.8
	Miraba	72	632.7	59.2	0.2	2.7	12.8	4.0	2.3
	Miraba+Tithonia	72	414.7	36.6	0.1	3.8	8.2	2.9	1.4
2012	*Miraba*+*Tughutu*	72	518.3	42.5	0.1	4.1	11.5	4.0	1.5
	Bare	46	2024.3	176.3	0.7	5.9	23.9	8.4	6.5
	Control	46	1496.7	125.7	0.9	6.8	25.9	8.4	4.6
	Miraba	46	260.7	20.3	0.2	1.8	5.5	2.2	0.8
	Miraba+Tithonia	46	158.7	12.6	0.1	1.6	7.7	1.6	0.5
2013	*Miraba*+*Tughutu*	46	187.7	13.9	0.2	1.6	5.1	1.8	0.6
Migambo									
	Bare	51	6092.3	548.0	0.8	12.0	371.1	57.2	11.3
	Control	51	4908.7	474.3	0.7	19.7	262.1	46.3	8.8
	Miraba	51	450.0	40.7	0.1	1.9	30.7	4.9	0.8
	Miraba+Tithonia	51	251.7	27.2	0.1	1.7	20.3	4.5	0.5
2012	*Miraba*+*Tughutu*	51	276.7	26.0	0.1	1.2	20.2	4.3	0.5
	Bare	71	6308.7	525.4	1.2	15.9	437.6	74.4	12.6
	Control	71	4418.0	421.6	1.2	19.7	266.8	49.8	8.4
	Miraba	71	531	43.8	0.1	2.8	41.1	6.8	0.9
	Miraba+Tithonia	71	192.7	15.8	0.1	0.9	14.5	3.0	0.3
2013	*Miraba*+*Tughutu*	71	183	16.4	0.1	0.7	15.4	3.1	0.3

miraba, farmyard manure and Tithonia mulching than in cropland with no SWC measures. The relative effectiveness of soil conservation practices with reference to soil nutrient losses from cropland with no soil conservation measures are presented in Fig. 4.5. There are obvious differences in soil nutrient losses control between soil conservation measures. It is clear that *miraba* with mulching reduced most of soil nutrients losses by about 95 % in Migambo and 85 % in Majulai village, while *miraba* sole reduced nutrient losses by 90 % in Migambo and about 80 % in Majulai village (Fig. 4.5).

4.3.6. Impact of soil conservation practices on crop yields

The yields of maize and beans are presented in (Table 4.7). The results show that there is a significant ($p < 0.05$) difference in crop yields between soil conservation practices and between the two studied years in both villages. In Majulai village maize grain yields were higher under *miraba* with *Tughutu* mulching than under *miraba* with Tithonia, *miraba* sole and control in 2012, but there was no maize yields in 2013 due to drought. The trend of bean grain yields followed the trend: *miraba* with *Tughutu* > *miraba* with Tithonia > *miraba* sole > under the control. The trends was similar in Migambo village where *miraba* with *Tughutu* > *miraba* with Tithonia > *miraba* sole > control for both maize and beans grain yields (Table 4.7).

Maize grain yields were significantly ($p < 0.05$) higher in 2013 than in 2012, but there were no significant ($p > 0.05$) differences in beans grain yields between the two years of study, however, there is relatively higher beans grain yields in 2013 than in 2012. There were also some differences in maize and beans yields between the two villages, with higher yields in Migambo than Majulai. The observed crop yields under the studied SWC practices were higher than the average yields according to (FAO, 2010) of 1.5 Mg ha^{-1} for maize and of 0.7 Mg ha^{-1} for beans in Tanzania. It is clearly observed that the crop yield differences between treatments are highly influenced by *miraba* practices intervention, and could partly be explained by differences in climatic conditions of the two villages. The rainfall in Majulai is unreliable while Migambo village experiences reliable rainfall with a fair distribution during the growing seasons (Fig. 4.2).

Table 4.7: Impact of soil conservation practices on crop yields in Majulai and Migambo villages

Village	SWC measures	N	Mean crop grains Yield (Mg ha^{-1}) in 2012		Mean crop grains Yield (Mg ha^{-1}) in 2013		
			Maize	Beans	Maize	Beans	LSD ($p \leq 0.05$)
Majulai							
	Plots with no SWC	3	0.71	0.59	0.0	0.59	0.15
	Miraba sole	3	1.26	0.81	0.0	0.85	0.15
	Miraba with Tithonia	3	1.62	0.89	0.0	1.04	0.15
	Miraba with *Tughutu*	3	1.97	0.93	0.0	1.09	0.15
	LSD ($p \leq 0.05$)		0.15	0.15	0.0	0.15	
	SE.		0.05	0.05		0.05	
Migambo							
	Plots with no SWC	3	1.57	0.64	1.64	0.67	0.41
	Miraba sole	3	2.58	0.81	3.12	0.92	0.41
	Miraba with Tithonia	3	3.18	0.90	4.05	1.06	0.41
	Miraba with *Tughutu*	3	3.79	0.95	4.83	1.14	0.41
	LSD ($p \leq 0.05$)		0.41	0.41	0.41	0.41	
	SE		0.14	0.14	0.14	0.14	
Majulai * Migambo							
	LSD ($p \leq 0.05$)		0.32	0.32		0.12	
	SE		0.11	0.11		0.04	

LSD: least significant difference; SE: standard error of means

In 2012 the average maize yields in Majulai village increased by 177 % under *miraba* with *Tughutu*, 128 % under *miraba* with Tithonia and 78 % under *miraba* sole while there were no maize yields in 2013 due to drought. A study by Msita (2013) reported increased maize yields by 57 % under *miraba* as compared to control in Migambo village, while bean yields did not differ, the maize yield differences were associated with the improved soil properties due to the effects of *miraba.* Bean grain yields in 2012 and 2013 respectively increased by 58 % and 85 % under *miraba* with *Tughutu*, 51 % and 76 % under *miraba* with Tithonia and 37 % and 44 % higher in plots with *miraba* sole than under control.

However, in Migambo village during the same period the average maize yield increased by 149 % and 195 % under *miraba* with *Tughutu*, 109 % and 147 % under *miraba* with Tithonia and 70 % and 90 % higher under *miraba* sole than under control. Tenge (2005) in the West Usambara Mountains reported an increased maize and beans yields respectively by 1800 kg ha^{-1} and 200 kg ha^{-1} in plots with grass strips against an average yield of 1250 kg ha^{-1} and 150 kg ha^{-1} in plots without SWC measure. The crop yield increments were also associated with the effects of the intervened grass strips.

Bean grain yields in 2012 and 2013 respectively increased by 48 % and 70 % under *miraba* with *Tughutu*, 41 % and 58 % under *miraba* with Tithonia and 27 % and 37 % higher in plots with *miraba* sole when compared with control. It is clear that soil conservation measures contribute to higher crop yields by reducing the loss of plant nutrients and assuring a better water supply to the crop. The study by Wickama *et al*. (2014) in the West Usambara Mountains observed the average maize and bean yields of 270 % and 583 % higher in well managed farms with good quality terraces, well maintained grass strips, good quality seed for crops, adequate use of manure or fertilizer as compared to the control i.e. the farms with no terracing, no grass strips, use of local seed material, little use of manure and no use of fertilizer and no tree cover. The yield differences was reported to be influenced by the sustainable land management categories studied.

4.4 CONCLUSIONS AND RECOMMENDATIONS

Rainfall erosivity *R* and soil erodibility *K* factors did not differ significantly between the studied villages. Soil loss was significantly ($p < 0.05$) higher under cropland with no soil conservation measures (control) than under *miraba* with mulching. The *P* factors were significantly ($p < 0.05$) higher under *miraba* sole than under *miraba* with mulching. The annual nutrient losses were significantly ($p < 0.05$) higher under control than under *miraba* with mulching. Maize and bean yields differed significantly ($p < 0.05$) between soil conservation practices in the following order: *miraba* with *Tughutu* mulching > *miraba* with Tithonia mulching > *miraba* sole > control. Whereas *miraba* with either *Tughutu* or Tithonia mulching showed greater potential in reducing soil and nutrient losses than *miraba* sole, *miraba* with *Tughutu* mulching was more effective in improving crop yields than *miraba* with Tithonia and *miraba* sole. Despite the soils of the West Usambara Mountains susceptibility to erosion, the *C* and *P* factors indicate that these soils are responsive to soil conservation measures.

More local shrubs and grasses should be investigated for use as both green manure and soil conservation measure under *miraba*. Further research needs to be conducted to investigate effectiveness of the studied soil conservation practices on watershed to mitigate river stream sedimentation. It is strongly recommended that Tithonia and *Tughutu* shrubs be planted in the borders of the farm plots along the slope for easy availability. It is also recommended in Majulai village that drought resistant grasses such as Guatemala be used for establishing *miraba* since Napier grass which is mostly preferred for fodder is sensitive to drought.

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CHAPTER FIVE

5.0 EFFECTIVENESS OF MULCHING UNDER *MIRABA* IN CONTROLLING SOIL EROSION, FERTILITY RESTORATION AND CROP YIELD IN THE WEST USAMBARA MOUNTAINS, TANZANIA

ABSTRACT

Soil erosion is a major threat to food security in rural areas of Africa. Field experiments were conducted from 2011 - 14 in Majulai and Migambo villages with contrasting climatic conditions in the West Usambara Mountains, Tanzania. The aim was to investigate the effectiveness of mulching in reducing soil erosion and restoring soil fertility for productivity of maize (*Zea mays*) and beans (*Phaseolus vulgaris*) under *miraba,* a unique indigenous soil conservation measure in the area. Soil loss was significantly higher ($p < 0.05$) under *miraba* sole than under *miraba* with mulching *e.g*. 35 vs. 20 and 13 vs. 8 Mg ha^{-1} year^{-1} for Majulai and Migambo villages, respectively, in 2012. The *P*-factor value under *miraba* was significantly higher ($p < 0.05$) 0.18 in Majulai than 0.10 in Migambo village. Soil fertility status was significantly higher ($p < 0.05$) under *miraba* with *Tughutu* mulching than under *miraba* sole *e.g*. 0.35 vs. 0.25 % total N, 37 vs. 22 mg kg^{-1} P and 0.6 vs. 0.2 cmol (+) kg^{-1} K for Majulai village; 0.46 vs. 0.38 total N, 17.2 vs. 10.2 mg kg^{-1} P and 0.50 vs. 0.2 cmol (+) kg^{-1} K for Migambo village. Maize and bean yields (Mg ha^{-1}) were significantly higher ($p < 0.05$) under *miraba* with *Tughutu* mulching than under *miraba* sole, 2.0 vs. 1.3 for maize and 0.9 vs. 0.8 for beans in Majulai; 3.8 vs. 2.6 for maize and 1.0 vs. 0.8 for beans in Migambo village in 2012. This implies that *Tughutu* mulching is more effective in improving crop yield than Tithonia, though

both could potentially protect the arable land from degradation caused by water erosion under *miraba*.

Key words: Soil and water conservation practices, runoff experiments, Tithonia, *Tughutu*, maize, beans

5.1 INTRODUCTION

Soil erosion is affecting all the continents and has been accelerated by human use and abuse of the land (Mandal and Sharda, 2013; Ligonja and Shrestha, 2013; Zhao *et al*., 2013; Lieskovsky and Kenderessy, 2014). Soil erosion by water and tillage in Mountainous areas of Sub-Saharan Africa, including the Usambara Mountains in Tanzania, have been identified as a major constraint to generating enough food to feed the escalating population, while cropland is becoming scarce and no longer productive due to soil erosion (Pimentel *et al*., 1987; Kimaro *et al*., 2008).

Many soil control measures ranging from indigenous ones such as *miraba* (rectangular grass bound strips that do not necessarily follow contour lines (Msita, 2013)), micro-ridges, stone bunds and introduced ones such as bench terraces, *Fanya Juu* terraces (hillside ditches made by throwing excavated soil on the upslope of the ditch, built along contour lines at appropriate intervals depending on slope gradient), grass strips and agro forestry have been implemented in the West Usambara Mountains to combat the problems of soil erosion. *Miraba* is the most preferred and widely practised indigenous technology by farmers in the West Usambara Mountains. *Miraba* is an indigenous SWC measure unique in the West Usambara Mountains, established by using either Napier (*Pennisetum purpureum* Schumach) or

Guatemala (*Tripsacum andersonii* J.R. Gray) grass barriers. In this study, *miraba* were established using Napier grass because it is mostly preferred as it is also used as fodder.

Currently, there is a growing interest and recognition of indigenous soil and water conservation (SWC) technologies on soil erosion control (Msita, 2013). However, the effectiveness of such technologies is not fully understood. Furthermore, these technologies have, for decades, been left traditional in the absence of scientific interventions such as mulching for improvements (Vigiak *et al*., 2005; Huenchuleo *et al*., 2012; Bizoza, 2014; Tesfaye *et al*., 2014). Mulching has been frequently documented to play an important role in controlling soil erosion (Morera *et al*., 2010; Fernández *et al*., 2012; Xu *et al*., 2012; Lee *et al*., 2013).

A study by Bajracharya *et al*. (2005) in Nepal reported mulching to reduce annual soil loss by 60 % to 90 % as compared to conventional farmers' practice. Moreover, it reduced annual soil nutrient losses such as: soil organic matter by 52 %, total nitrogen by 46 %, available P_2O by 32 % and exchangeable K_2O by 53 % in maize - mustard cropping system. Similarly, in maize + soybean - mustard cropping system, the annual losses of organic matter, total nitrogen, available P_2O and exchangeable K_2O were reduced by 58 %, 49 %, 26 % and 60 %, respectively. Lal (1997) in West Nigeria reported beneficial effects of mulching on agronomic productivity and increased maize grain yield due to improvements in soil quality.

A study by Msita (2013) in a humid and cold part of the West Usambara Mountains revealed *miraba* to be effective in reducing runoff, soil and nutrient losses and increasing maize yields when combined with farmyard manure and *Tithonia* mulching. However, the contribution of mulching on controlling soil erosion and improving crop yield was not singled out as a separate variable. Besides, the study by Msita (2013) was carried out in a humid and cold climate, thus the results could not be directly applied in other areas with different soils and climatic conditions.

In the current study, two types of shrubs, namely *Tithonia diversifolia* (Hemsl.) A. Gray (locally known as *Alizeti Pori*) and *Vernonia myriantha* Hook f. (locally known as *Tughutu*), were used as mulching materials. These shrubs were chosen because they are readily available in the respective villages and in the West Usambara Mountains in general. Besides, they have been documented to be potential local resources of NPK and OC (Wickama and Mowo, 2001; Mowo *et al*., 2006). Moreover, *Tughutu* is a local shrub that is perceived by farmers in the West Usambara Mountains as a wonderful plant for its ability of improving soil fertility and increasing crop yields around it, thus it was innovative to include it as a mulching material under *miraba* and compare its effectiveness with Tithonia shrub that was promoted by Msita (2013). Furthermore, the effectiveness of *Tughutu* and Tithonia mulching were tested and compared in different climatic conditions for explicit conclusive remarks.

Maize and beans were used as test crops because these are the main food crops in the study area and they are mainly cultivated on the slopes. The objectives of this study were to: (i) quantify runoff and soil losses under mulching in *miraba* - maize/beans land utilization ii) establish relationship between runoff, rainfall depth and mulching cover in *miraba*-maize/beans land utilization (iii) determine the effect of mulching materials on soil fertility restoration under *miraba* (iv) select the best mulching material for controlling soil erosion and improving crop yield.

5.2 MATERIALS AND METHODS

5.2.1 Description of the study sites

Migambo and Majulai villages are located in West Usambara Mountains, Lushoto District, Tanzania (Fig. 5.1) between 38^0 15' E to 38^0 24' E and 4^0 34' S to 4^0 48' S. Migambo is humid cold with mean annual air temperature of 12 ^{0}C - 17 ^{0}C and annual precipitation is 800 - 2300 mm. Majulai is dry warm with mean annual air temperature between 16 ^{0}C and 21 ^{0}C and annual precipitation of 500 - 1700 mm. The monthly reference evapo-transpiration (ETo) as estimated by the local climate estimator software (NewLocClim) (FAO, 2006) ranges from 100 mm to 145 mm. The West Usambara Mountains support a large population density more than 120.4 persons/km^2 (National Bureau of Statistics, 2012).

Soil maps of Majulai and Migambo village are presented in Appendix 2 & 3. According to WRB (FAO, 2014) the soil type in Majulai site classifies as *Chromic Acrisol* (*Humic, Profondic, Clayic, Cutanic, Colluvic*) whereas in Migambo site the soil is *Haplic Acrisol* (*Humic, Profondic, Clayic, Colluvic*). The main land uses include cultivation, settlements, lower ridge summits and slopes and forest reserves. Vegetables such as carrots, onions, tomatoes, cabbages, and peas are grown as sole crops in valleys under rain fed or traditional irrigation. Beans are mainly grown during long rains while maize in short rains, round potatoes and fruits namely peaches, plums, pears, avocado, and banana are grown on ridge slopes under rain fed mixed farming. Round potatoes are also grown in valleys as sole crop or intercropped with maize.

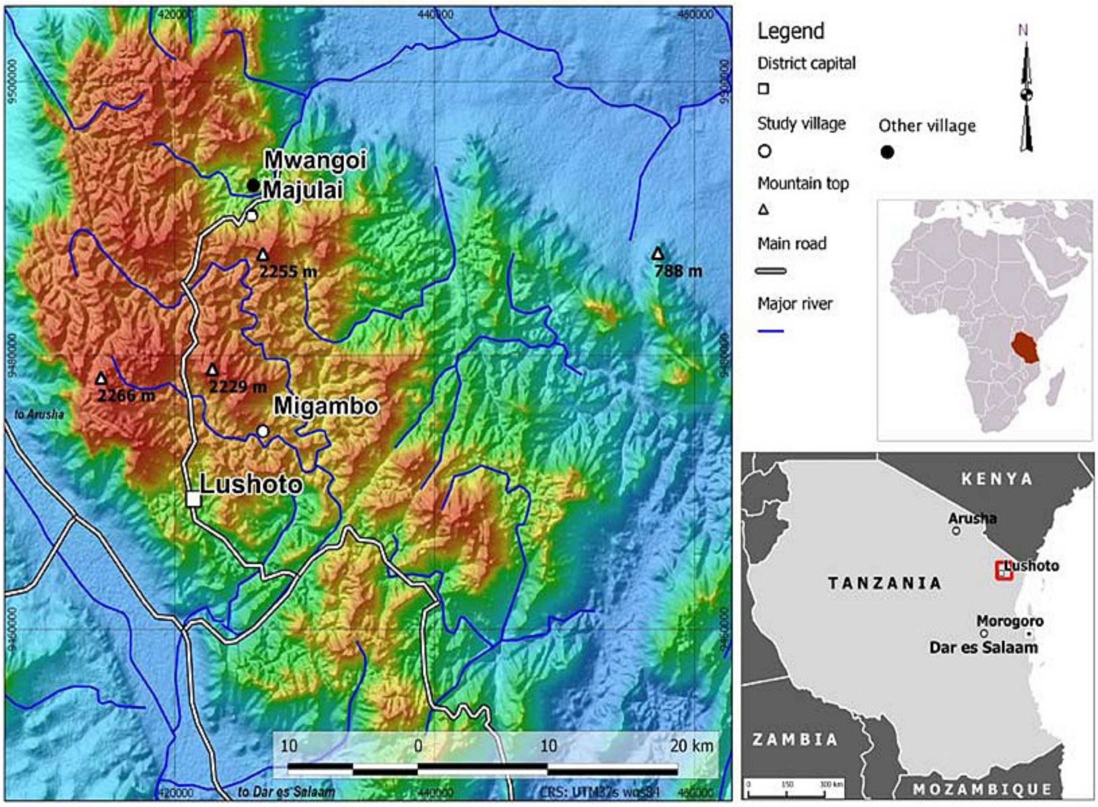

Figure 5.1: Location map of Migambo and Majulai villages, Lushoto District, Tanzania. Source: Adapted from Msita (2013)

5.2.2 Establishment of *miraba* in runoff experiments

Miraba were established by using Napier grass (*Pennisetum purpureum*) barriers in runoff experiments in April 2011. Data was collected nine months later. Napier grass barriers forming *miraba* were established by planting tillers in a single row at 10 cm spacing (as per farmers' practise) perpendicular to slope. The grass barriers were maintained to about 50 cm wide strips to avoid reduction of cropland by the grass barriers. The grass barriers were cut at about 25 cm above ground (Pfeifer, 1990), the low cutting reduce competition of space and sunlight with crops, while also stimulate tillering that make dense grass barriers for effective controlling soil erosion. Napier grass barriers across the slope were spaced 5 m apart to mimic the effective width of hand made bench terraces. The spacing of Napier grass barriers forming *miraba* along the slope was set at 3 m apart, wider by 1 m from the standard runoff plots to accommodate the space occupied by grass barriers.

5.2.3 Experimental design

Closed runoff plots of 22 m x 3 m in a Randomized Complete Block Design were set along lower ridge slopes at 50 % slope in Majulai and 45 % slope in Migambo village. According to Sheng (2002) the slopes at this range recommended as the maximum slope for bench terraces implementation. The study area is dominated by steep slopes where maize and beans are mainly grown. The slopes of runoff plots were different between the two villages because we could not obtain suitable areas with exactly the same slopes. The runoff plots were enclosed with *miraba* and the sideways supported by pieces of wood that protruded about 15 cm above the soil surface and that connected to the 120 litre collector drums with hinged lids. Maize (*Zea mays*) and beans (*Phaseolus vulgaris*) were planted in rotation as test crops except under bare plots in 2012/13 and 2013/14 rainy seasons, maize was planted during short rains (*vuli*) while beans in long rains (*masika*) as per farmers' practise. The treatments included plots with (i) *Miraba* sole and planted with maize or beans (control) ***MI*** (ii) *Miraba* with *Tithonia* mulching and planted with maize or beans ***MITH*** (iii) *Miraba* with *Tughutu* mulching and planted with maize or beans ***MITG***, all replicated three times.

5.2.4 Mulch application and cover determination

The leaves of shrubs namely *Tithonia diversifolia* (*Alizeti Pori*) and *Vernonia myriantha* (*Tughutu*) were used as mulching materials in both villages (Plate 5.1).

The mulching was applied under *miraba* two weeks after crops germination at the rate of 3.6 Mg ha^{-1} dry weight, the amount that ensure complete coverage on the soil.

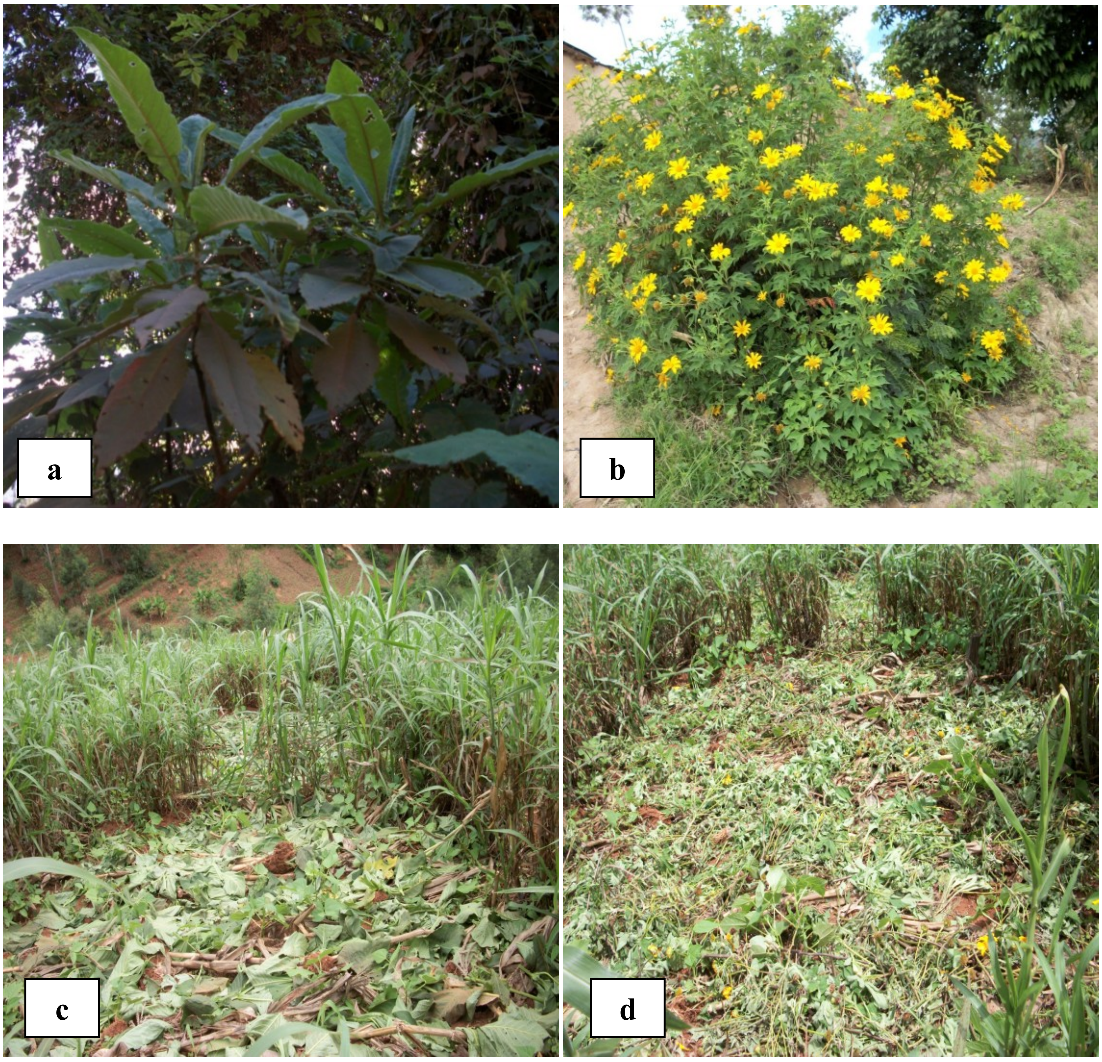

Plate 5.1: a) *Vernonia myriantha* (*Tughutu*) b) *Tithonia diversifolia* (*Alizeti Pori*) c) *Miraba* with Tughutu mulching d) *Miraba* with Tithonia mulching. Plates by: Mwango, S.B. 10/04/2012

The percent mulch cover was determined by line transect method where the presence or absence of soil surface contact cover were recorded from both mulches and crop residues because it was very difficult to separate them. The recording was done by laying down along the diagonals in each plot a marked thread at 10 cm intervals as proposed by Nill *et al*. (1996). This procedure was done after every rainstorm throughout the year. Samples were collected from each mulching material for determination of total N, available P, K^+, Mg^{2+}, Ca^{2+} and Na^+.

5.2.5 Rainfall data collection

Daily rainfall was measured from 1 January 2012 to 16 February 2014 using standard rain gauges and tipping buckets with a CR10 data logger (Campbell Scientific, Logan UT) installed at the experimental sites in Migambo and Majulai villages. The daily rainfall data were collected from the standard rain gauges by recording rainfall amount in litres and then converted in millimetres. The daily rainfall amounts in millimetres from the tipping buckets data logger were downloaded using a laptop computer after every two months.

5.2.6 Runoff, sediment and nutrient loss determination

Runoff and sediment was collected daily from 1 January 2012 to 16 February 2014. Runoff volume was estimated by measuring the depth of water in cm in the collecting drums and then converted to volume of water in litres. Sediment load was estimated by sampling water in collecting drums after vigorously stirring the suspension by using a mop with strong wooden handle. The water sampling was done by lowering a one litre plastic bottle from the water surface to the bottom of the drum, and samples of about 300 ml were collected at the bottom, middle and upper part when runoff depth in the drum was above 25 cm.

Heavy sediments in the drums were scooped out weighed and a 1 kg soil sample collected, oven dried for at least 24 hours at 105 ^{0}C and weighed for dry soil loss calculation. The suspended sediment samples were filtered using Whatman No. 42 filter paper and dried for at least 24 hours at 105 ^{0}C until constant weight was obtained (Yang *et al*., 2009) and the soil loss (Mg $ha^{-1}yr^{-1}$) was determined. Soil losses from heavy sediments and from suspended materials from each runoff event were added to compute total soil loss for the events. Soil losses from all runoff events were finally added to compute total soil loss per annum. The soil samples for nutrient loss determination were collected by decanting the suspended sediment in buckets.

5.2.7 Soil characterization at experimental sites

At each runoff experimental site a soil profile was excavated and soil samples were collected from each horizon for characterization. Undisturbed core soil samples were taken at 0 - 5 cm, 45 - 50 cm and 95 - 100 cm soil depth by Kopecky's core rings (100 cm^3) for bulk density, gravimetric moisture and available moisture determination. The soil was classified to tier-2 according to the World Reference Base for Soil Resources (WRB) (FAO, 2014).

5.2.8 Determination of soil fertility restoration

The effectiveness of mulching materials under *miraba* on soil fertility restoration was determined by taking composite top soil samples of 0 to 30 cm depth plough layer from each treatment for the analysis of pH, OC, total N, available P, K^+, Ca^{2+}, Mg^{2+} and Na^+. Undisturbed core soil samples were collected at 0 - 5 cm depth for bulk density, gravimetric moisture content and available water content determination. Soil samples were collected at the end of every cropping season i.e. long rains and short rains from 2012 to 2013/14.

5.2.9 Crop yields

Maize (*Zea mays*) variety PAN 67 and beans (*Phaseolus vulgaris*) Kilombero variety were planted in runoff plots during the 2012 and 2013 rain seasons with maize in the short rains (*vuli*) and beans in the long rains (*masika*) at a recommended spacing of 30 cm within rows and 75 cm between rows for maize and 25 cm within rows and 50 cm between rows for beans. Beans were always planted one month before maize was harvested in Migambo and two weeks before harvesting maize in Majulai village, because in Migambo village maize stay longer in the field due to cold climate. Farmyard manure with 1.7 % N, 0.4 % P and 1.9 % K was basal and spot applied at the rate of 3.6 Mg ha^{-1} air-dry weight, DAP 18: 46: 0 NPK ratio and Urea 46 % N were applied at the rate of 80 kg ha^{-1}, but Urea was not applied for beans as per farmers' practise. At maturity maize and beans grains were harvested and dried to about 13 % moisture content.

5.2.10 Soil analysis

Soil analysis was done following Moberg's (2001) laboratory manual. Organic carbon (OC) was measured using the dichromate oxidation method, total nitrogen (TN) by Kjeldahl method, available phosphorus (Bray-I), exchangeable bases (Ca^{2+} and Mg^{2+}) by atomic absorption spectrophotometer, exchangeable Na^{+} and K^{+} by flame photometer and pH water by normal laboratory pH meter.

5.2.11 Determination of the RUSLE factors

The RUSLE equation expresses average annual soil loss Mg ha^{-1} $year^{-1}$ caused by sheet and rill erosion (Renard *et al*., 1996):

$A = RKLSCP$ .... (1)

Where A is the average soil loss (Mg ha^{-1} year^{-1}), R is rainfall erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1}), K is the soil erodibility factor (Mg ha MJ^{-1} mm^{-1}), LS is dimensionless factor combining slope steepness (S) and slope length (L), C and P are dimensionless factors accounting respectively for crop cover and management and conservation practices. The equation developed by Vrieling *et al*. (2010) was used to calculate R the factor. Such that: $R = 50.7\ MFI - 1405$……..…………………..…. (2)

Where MFI is the Modified Fournier Index calculated from:

$MFI = \sum_{n=1}^{\infty} (p^2)/\text{P}$…………………………………………………..…. (3)

Where p is the long term average monthly rainfall (mm) and P is the average annual rainfall (mm). In the absence of any cover crop or soil protection measure, as for the bare plot, C and P factors are equal to 1. Thus K factor was calculated from:

$K = A_{\text{bare plot}} / (RLS)$……………………….……………………………...…… (4)

According to Mitchell & Bubenzer, (1980):

$LS = [0.065 + 0.0456\text{s} + 0.006541\text{s}^2] \times (l/22)^{1/2}$…………..…………………..…….... (5)

Where: s, is the slope gradient in %; l, is the plot length in m; the constant ½, is used where the slope steepness is ≥ 5 %.

The effectiveness of mulching materials under *miraba* on reducing soil loss was determined by the use of C factors when compared to the *miraba* plots without mulching. Therefore, the C factor was calculated as the ratio between the seasonal or annual soil losses under *miraba* plots with mulching to the seasonal or annual soil loss under miraba plots without mulching.

C (TH plot) = A (MITH plot) / A (*MI* plot)……………...….…………...………..... (6)

C (TG plot) = A (MITG plot) / A (*MI* plot)……………...………………...……..... (7)

Where: A (*MI* plot), is the soil loss (Mg ha^{-1} season^{-1} or Mg ha^{-1}yr^{-1}) under *miraba* plots without mulching. *A (MITH plot),* is the soil loss (Mg ha^{-1} season^{-1} or Mg ha^{-}

^{1}yr^{-1}) under *miraba* plots with *Tithonia* mulching. *A (MITG plot),* is the soil loss (Mg ha^{-1} season^{-1} or Mg ha^{-1}yr^{-1}) under *miraba* plots with *Tughutu* mulching. The effectiveness of mulching materials under *miraba* on reducing soil loss was determined by the percent of *C* factor with reference to *miraba* plots without mulching. The effectiveness of mulching materials under *miraba* on reducing nutrient losses was also calculated in percentages compared to *miraba* plots without mulching.

5.2.12 Data analysis

Bartlett's test for homogeneity of variances was conducted to test data normality using GenStat software (GenStat, 2011). Regression analysis was used to determine the rainfall and mulch cover- runoff responses, where the rainfall and percent mulch cover threshold values to initiate runoff were obtained at the X-axis intercept. Analysis of Variance (ANOVA) in GenStat statistical software (GenStat, 2011) was performed where Least Significant Difference ($LSD_{0.05}$) was used to detect mean differences between treatments. Box and whisker plots were used to visualize the effectiveness of mulching on soil fertility restoration.

5.3 RESULTS AND DISCUSSION

5.3.1 Rainfall erosivity between the two villages with contrasting climatic conditions

The annual and seasonal rainfalls recorded during the two consecutive years are presented in Table 5.1. It can be seen that, as the rainfall depth was higher in Majulai village than Migambo village in 2012 rainfall erosivity *R* factor is also higher in Majulai, while in 2013 the higher values of rainfall depth and *R* factor was observed in Migambo village (Table 5.1).

Table 5.1: Rainfall measured in Majulai and Migambo villages Lushoto District, Tanzania

	Majulai		Migambo	
Rainfall (mm)	2012	2013	2012	2013
Long rains (Feb.- May)	329.3	258.0	359.4	552.1
Offseason rains (Aug – Sept.)	28.7	0.0	7.1	23.4
Short rains (Oct. – Jan.)	636.9	165.1	415.8	222.7
Annual	906.0	528.0	718.0	826.0
R (MJ mm ha^{-1} h^{-1} $year^{-1}$)	7 774.0	3 857.0	5 859.0	7 247.0

5.3.2 Soil loss in relation to the studied SWC practices and the two villages with contrasting climatic conditions

Majulai village had significantly higher ($p < 0.001$) annual soil losses than Migambo in 2012, while in 2013 Migambo experienced significantly ($p < 0.001$) higher annual soil losses than Majulai. The difference in soil losses between the two villages can partly be attributed to the rainfall depth (Table 5.2). It can clearly be observed that, the higher the rainfall depth the higher the soil losses in the studied villages. Similar observations were reported by Kabanza *et al*. (2013), where soil losses in Makonde plateau were much higher than inland plains and rainfall depth was spotted as the main contributing factor. The relatively steeper slope in Majulai than Migambo could also explain the soil loss differences. On the other hand soil loss differed significantly ($p < 0.001$) between SWC measures. The soil losses followed the trend: cropland with no SWC measures > cropland with *miraba* sole > cropland with *miraba* and Tithonia or *Tughutu* mulching. A similar observation was reported by Bajracharya *et al*. (2005) in Nepal where mulching was found to reduce annual soil loss by 60 to 90 % in maize - mustard cropping system as compared to conventional farmers' practice.

Table 5.2: Annual soil losses measured in Majulai and Migambo villages Lushoto District, Tanzania

			Majulai		Migambo	
Soil loss Mg ha^{-1} $year^{-1}$			2012	2013	2012	2013
		Replicates				
	Plots with maize or beans	1	179.6	72.9	124.1	133.3
		2	183.3	76.8	124.3	129.8
		3	187.8	77.2	124.4	131.6
		Mean	183.6	75.6	124.3	131.6
	Miraba with maize or beans					
		1	34.7	12.2	13.3	14.9
		2	35.9	11.7	13.4	13.4
		3	33.6	14.3	13.5	14.3
		Mean	34.7	12.7	13.4	14.2
	Miraba with Tithonia and maize or beans	1	17.58	5.42	8.02	5.30
		2	20.03	8.20	7.58	4.76
		3	20.05	9.09	7.97	5.18
		Mean	19.22	7.57	7.86	5.08
	Miraba with *Tughutu* and maize or beans	1	18.47	5.62	7.97	5.47
		2	20.01	9.34	7.43	5.18
		3	20.02	9.33	7.24	5.27
		Mean	19.50	8.10	7.55	5.31
	LSD ($P \leq 0.05$)		2.75	2.61	2.75	2.61
	SE		0.91	0.86	0.91	0.86

LSD: least significant difference; SE: standard error of means

5.3.3 Runoff responses to rainfall and mulching cover under *miraba*

The annual runoff depth as indicated by runoff coefficient values were significantly ($p < 0.05$) higher in cropland with *miraba* than under *miraba* with Tithonia and *miraba* with *Tughutu* mulching (Fig. 5.2). This implies that the studied mulching materials are an effective way in reducing runoff under *miraba* and protecting the land from degradation by water erosion. There are also significant differences in runoff depth between the studied villages, where Majulai had higher values of runoff coefficients than Migambo village. The higher runoff coefficient values in Majulai can be explained by the steeper slopes than in Migambo village. The rainfall and mulch cover threshold values to initiate runoff varied between the studied villages and between SWC measures. The variation of threshold values were directly associated with the effects of mulching materials and the differences in climatic conditions and the terrain steepness in the studied villages.

As it can be seen from Table 5.3 the threshold rainfall values to initiate runoff is 1.5 mm when straw cover is 20 % under *miraba*, 2.8 mm and 2.9 mm when Tithonia or *Tughutu* mulching cover is 36 % under *miraba* in Majulai village. In Migambo village the threshold rainfall values to initiate runoff were; 1.5 mm when straw cover is 19 % under *miraba*, 3.0 mm when the Tithonia or *Tughutu* mulching cover is 30 % under *miraba*. This has strong implication that *miraba* are susceptible to runoff when left without mulching. Therefore implementation of mulches under *miraba* in the West Usambara Mountains are effective way of protecting arable land from degradation caused by water erosion.

Table 5.3: Daily runoff (mm) response (Y) to mulching cover (%) (X1) and rainfall (mm) (X2) for Majulai and Migambo villages in the West Usambara Mountains, Tanzania

Village/ Treatments	Regression equations	Runoff Thresholds vs. X1	Runoff Thresholds vs. X2	R^2	Sign. mulch cover	Sign. rainfall	cover observ ations	Rainfall occasion s
Majulai								
Miraba	Y=-0.30-0.015X1+0.2X2	20	1.5	0.57	ns	***	318	106
Miraba+Tithonia	Y=-0.20-0.0055X1+0.069X2	36	2.8	0.57	***	***	318	106
Miraba+*Tughutu*	Y=-0.20-0.0055X1+0.071X2	36	2.9	0.56	***	***	318	106
Migambo								
Miraba	Y=-0.25-0.013X1+0.16X2	19	1.5	0.75	*	***	327	109
Miraba+Tithonia	Y=0.15-0.0045X1+0.05X2	33	3.0	0.77	***	***	327	109
Miraba+*Tughutu*	Y=0.16-0.0048X1+0.051X2	33	3.0	0.74	***	***	327	109

Key: Sign. ns = not significant; sign. * = significant at $p < 0.05$; significant *** = significant at $p < 0.001$

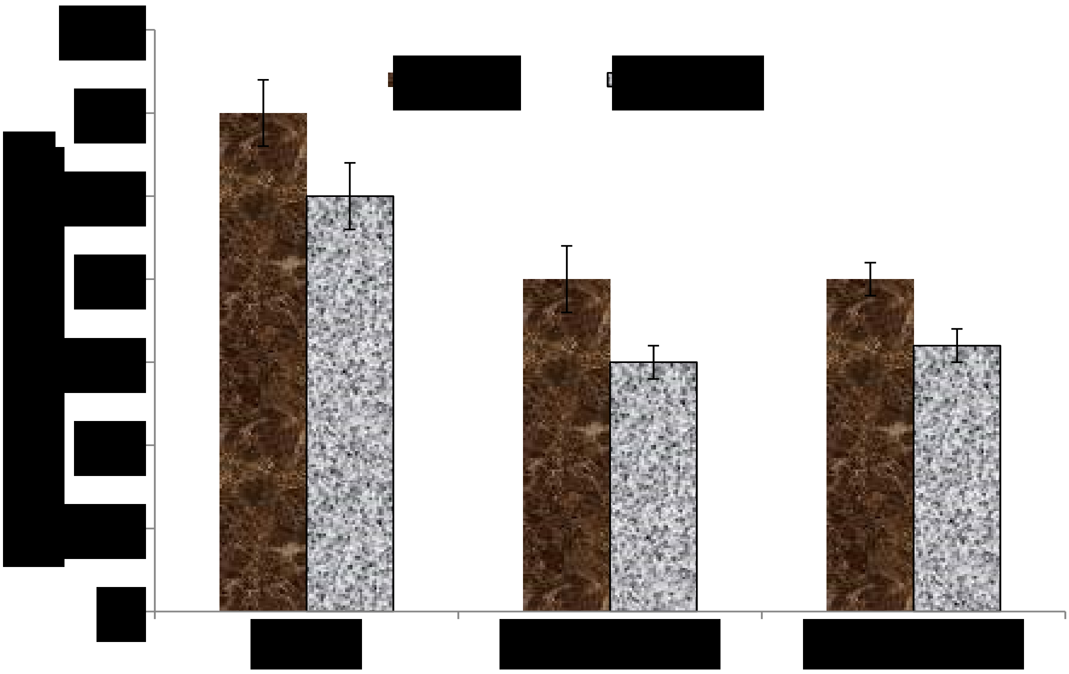

Figure 5.2: Annual runoff coefficients for the studied mulching materials in the West Usambara Mountains, Tanzania

5.3.4 Effectiveness of mulching covers in relation to RUSLE factors

The relative effectiveness of mulching covers with reference to soil losses from plots with no mulching cover is presented in Fig. 5.3. There were no significant ($p < 0.05$) soil loss differences between mulching covers. However, the soil losses under mulching cover were higher in Majulai than in Migambo village. As the surface soil texture between the two village was similar (Appendix 1), the differences in soil loss could probably be influenced by the steeper slopes in Majulai than in Migambo village. This observation is supported by Ziadat and Taimeh (2013) who also observed slope to explain about 89 % of the variation in runoff and soil loss. Relative to soil losses from cropland with *miraba*, it can be seen that Tithonia mulch reduced soil losses by 55 % in Majulai and 50 % in Migambo village, while *Tughutu* mulch reduced soil losses by 56 % in Majulai and 50 % in Migambo village.

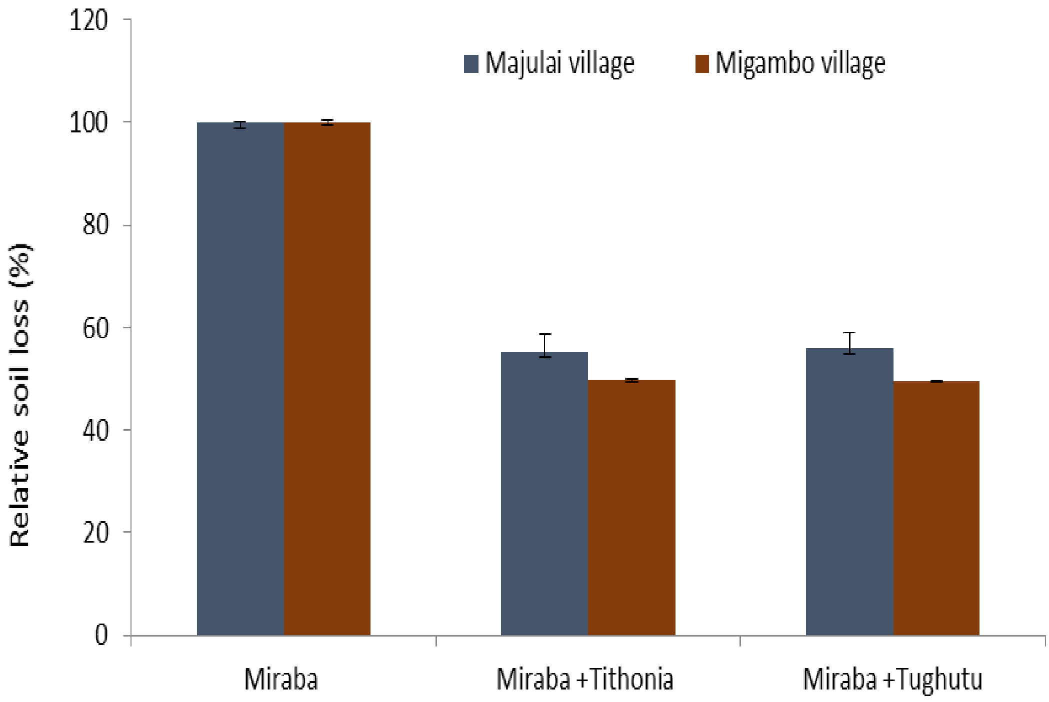

Figure 5.3: The mean relative soil loss with standard deviations (STDEV) from 3 replicates under mulching cover in Majulai and Migambo villages based on measurements from 2012 – 2013.

The observed *K* factors were 0.002 (Mg ha MJ^{-1} mm^{-1}) for *Chromic Acrisol* in Majulai and *Haplic Acrisol* in Migambo village (Table 5.3 & 5.4). The *K* value is very low which indicate the high susceptibility of the studied soils to erosion. More erodible soils such as silt loam soils reported to have *K* factor ranging from 0.03 – 0.05 (Mg h MJ^{-1} mm^{-1}) (*e.g.* Poesen, 1992). The *C* factor values did not significantly differ between the villages, though were relatively much higher in Majulai than in Migambo village (Table 5.4) indicating that mulches have slightly stronger effect in Migambo than in Majulai village. This can be explained by the steeper slopes in Majulai than in Migambo village which accelerate the speed of running water and thus increased rate of soil erosion (Liu *et al*., 1994; Morgan and Duzant, 2008). On the other hand, *miraba* with Tithonia and *miraba* with *Tughutu* mulching were significantly more effective in reducing soil loss than *miraba* sole (control). This is due to the fact that mulches tend to reduce runoff speed and thus increasing rate of infiltration. Other researches by Lal (1997), Duran *et al*. (2006), Birru *et al*. (2012) and Fernández *et al*., (2012) also reported reduced soil losses as a result of improved infiltration and soil structure stability under mulching. However, the effectiveness of Tithonia and *Tughutu* mulching materials in reducing runoff and soil losses did not differ but were significantly much more effective than maize or beans cover in both villages (Table 5.4). The *C* factors for Tithonia and *Tughutu* were less low in 2013 than in 2012 (Table 5.3); this was probably due to the fact that with time the soil under mulching had increased the organic carbon contents, which resulted to an increased rate of infiltration and resistant of soil to erodibility. Lal (1997) also observed reduced soil losses as a result of improved infiltration and soil structure stability under mulching.

Table 5.4: RUSLE factors for the Majulai and Migambo villages in the West Usambara Mountains, Tanzania based on soil loss measurements on runoff plots for the year 2012 and 2013

RUSLE factors	Mulching and maize cover	n	Majulai		Migambo		Sign.
			2012	2013	2012	2013	
R (MJ mm ha^{-1} h^{-1} $year^{-1}$)		1	7774	3857	5859	7247	ns
K (t h MJ^{-1} mm^{-1})		1	0.002	0.002	0.002	0.002	ns
P (dimensionless)	*Miraba*	3	0.19	0.17	0.10	0.10	***
C (dimensionless)							
	Maize, weed and beans	3	0.71	0.70	0.70	0.70	ns
	Tithonia	3	0.60	0.50	0.60	0.40	*
	Tughutu	3	0.60	0.50	0.60	0.40	*
	LSD (p ≤ 0.05)		0.14	0.14	0.14	0.14	

LSD: least significant difference; Sign. ns: not significant; *: $p < 0.05$; ***: $p < 0.001$. Mann-Whitney U test for *R*, *K* and *P* factors; Nested ANOVA for *C* variable

Table 5.5: RUSLE factors for the Majulai and Migambo villages in the West Usambara Mountains, Tanzania based on soil loss measurements on runoff plots from 2012-2013 rain seasons

RUSLE factors	Mulching and maize cover	Majulai Median	Majulai IQR	n	Migambo Median	Migambo IQR	n	Sign.
R (MJ mm ha^{-1} h^{-1} yr^{-1})		5816	1958	2	6553	694	2	ns
K (t h MJ^{-1} mm^{-1})		0.0016	0.0002	2	0.0018	0.0002	2	ns
P (dimensionless)								
	Miraba	0.18	0.002	6	0.10	0.003	6	***
C (dimensionless)		Mean	STDEV		Mean	STDEV		
	Beans, weed and Maize	0.71	0.02	6	0.70	0.005	6	ns
	Tithonia	0.55	0.14	6	0.50	0.02	6	ns
	Tughutu	0.55	0.13	6	0.50	0.02	6	ns
	LSD ($p \leq 0.05$)	0.14			0.14			

LSD: least significant difference; IQR: inter-quartile range; STDEV: standard deviation; n: number of observations for 3 replicates in 2 years period; Sign. ns: not significant; ***: $p < 0.001$. Friedman test for *R*, *K* and *P* factors; Nested ANOVA for *C* variable.

5.3.5 Influence of mulching cover to soil fertility restoration

Chemical properties of mulching materials are presented in Table 5.6. The median, interquartile range, minimum and maximum values of soil nutrients are presented by box and whisker plots in Fig. 5.4 & 5.5, where the boxes represent interquartile ranges with median values dividing the boxes and whiskers represent the minimum and maximum values. It can clearly be seen that *Tughutu* had the higher nutrient contents than Tithonia shrub. The higher nutrient contents in *Tughutu* than in Tithonia shrub could probably be explained by the ability of *Tughutu* shrub to extract nutrients from the soil. Other researchers Wickama and Mowo (2001) also found similar situation where higher NPK contents were observed in *Tughutu* than in Tithonia shrub.

It was also found that most of the studied soil nutrients were significantly ($p < 0.05$) different between SWC practices and between the two villages except for Ca^{2+} and Na^{+}. The contents of P, K^{+} and Mg^{2+} were significantly higher at ($p < 0.001$) while

OC and total N at ($p < 0.003$). All the studied soil nutrients were significantly ($p < 0.05$) higher under *miraba* with *Tughutu* and Tithonia mulching than under *miraba* sole except for Ca^{2+} and Na^{+} which did not significantly ($p > 0.05$) differ in both villages. Though most of soil nutrients were not significantly different but the general trend was: *miraba* with Tughutu > *miraba* with Tithonia > *miraba* sole.

Table 5.6: Chemical properties of mulching materials and farm yard manure applied in Majulai and Migambo villages

	Plant nutrients content %					
Mulching materials	N	P	K	Ca	Mg	Na
Tithonia	3.3	0.3	6.1	1.2	0.7	0.04
Tughutu	3.6	0.3	6.3	1.4	0.9	0.04
Farm yard manure	1.7	0.4	1.9	0.9	0.6	0.07

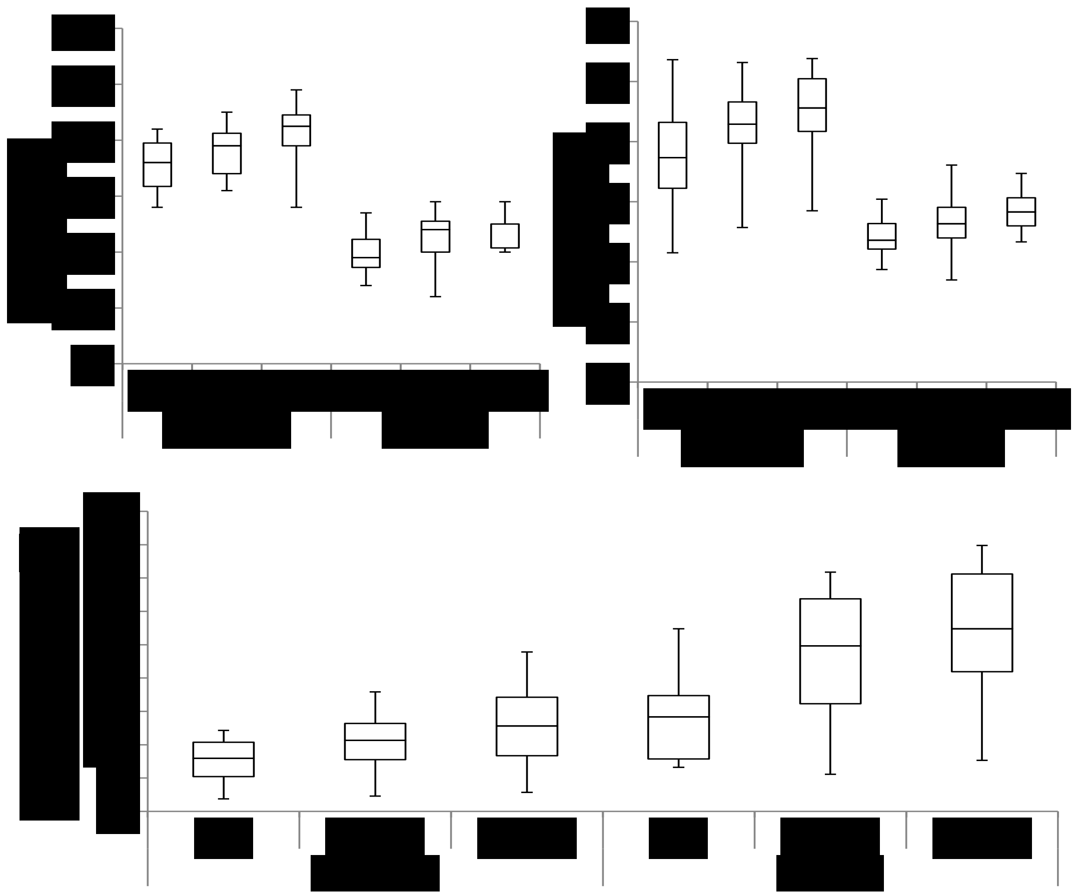

Figure 5.4: The influence of soil conservation measures on the status of OC, total N and P in the studied villages

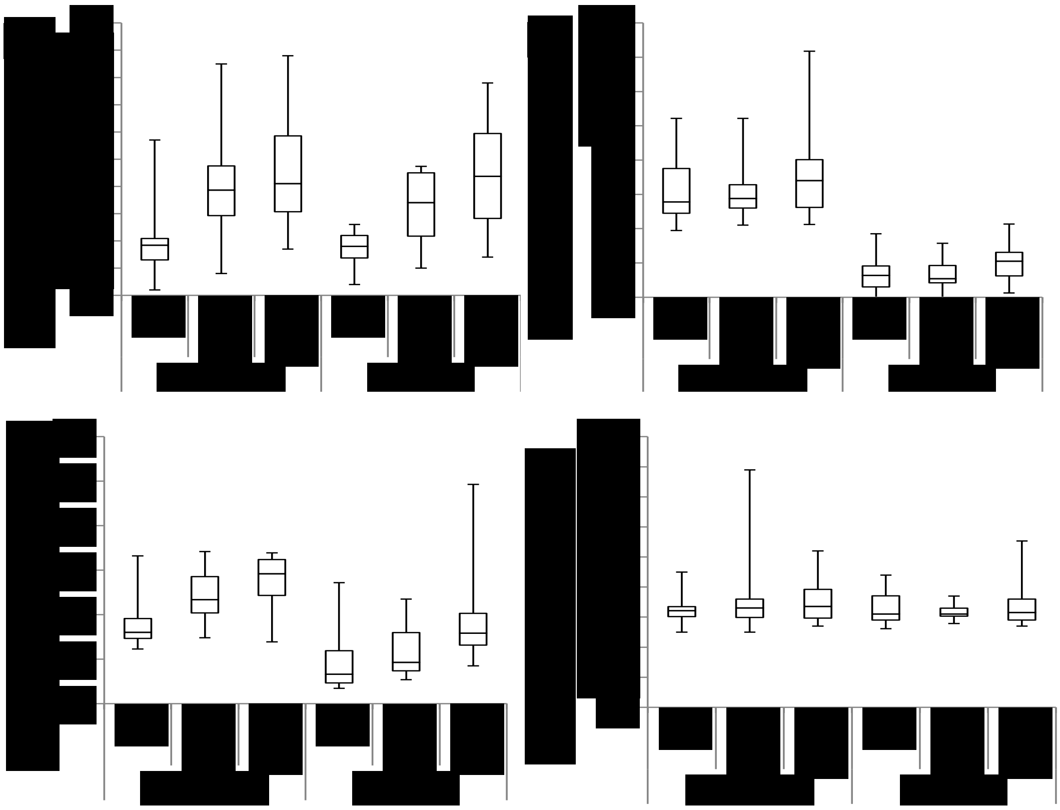

Figure 5.5: The influence of soil conservation measures on the status of K^+, Ca^{2+}, Mg^{2+} and Na^+ in the studied villages

The higher soil fertility status under mulching than under *miraba* sole can directly be associated with the intervention of *Tughutu* and Tithonia mulching. This observation is strongly supported by the fact that *Tughutu* and Tithonia mulching materials revealed to contain appreciable amount of N, P and K (Table 5.6). Upon decomposition, mulches release nutrients to the soil thus lead to restored soil nutrients. This observation was strongly supported by Xu *et al*. (2012) where terraced orchard with grass cover was found more effective in improving soil fertility especially soil organic matter, available N, P and K and bulk density, saturated hydraulic conductivity and aggregate stability than terraced orchard without grass cover. Besides mulches were found to be effective in reducing soil nutrient losses thus in this study cropland under mulches had higher soil fertility than those without. Similar observations were reported by Bajracharya *et al*. (2005) in Nepal where mulching was found to reduce annual nutrient losses such as organic matter by 52 percent, total nitrogen by 46 percent, available P_2O by 32 percent and exchangeable K_2O by 53 percent in maize – mustard cropping system as compared to conventional farmers' practice.

5.3.6 Impact of mulching to crop productivity in the two studied villages

The yield of maize and beans are presented in Fig. 5.6. The results show that maize grain yields in 2012 in Majulai village were significantly ($p < 0.05$) different between SWC practices. The crop yield followed the trend that: *miraba* with *Tughutu* mulching > *miraba* with Tithonia mulching > *miraba* sole. Beans grain yield did not significantly differ between SWC practices. There was no maize grain yield in 2013 due to drought. In Migambo village maize and beans grain yields were significantly ($p < 0.05$) different with the trend: *miraba* with *Tughutu* > *miraba* with Tithonia > *miraba* sole. Maize grain yields were significantly higher ($p < 0.05$) in 2013 than in 2012, while beans grain yields did not differ, but, it was relatively higher in 2013 than in 2012.

The observed crop yields under the studied SWC practices were higher than the average yields according to (FAO, 2010) of 1.5 Mg ha^{-1} for maize and of 0.7 Mg ha^{-1} for beans in Tanzania. There were also some differences in maize and beans yields between the two villages, with higher yields in Migambo than Majulai. The crop yield differences between SWC practices can be explained by the influences of mulching application that lead to improved soil fertility, while the crop yield differences between villages could partly be caused by the reliable rainfall for crop production in Migambo village while in Majulai village rainfall was not reliable in its growing seasons.

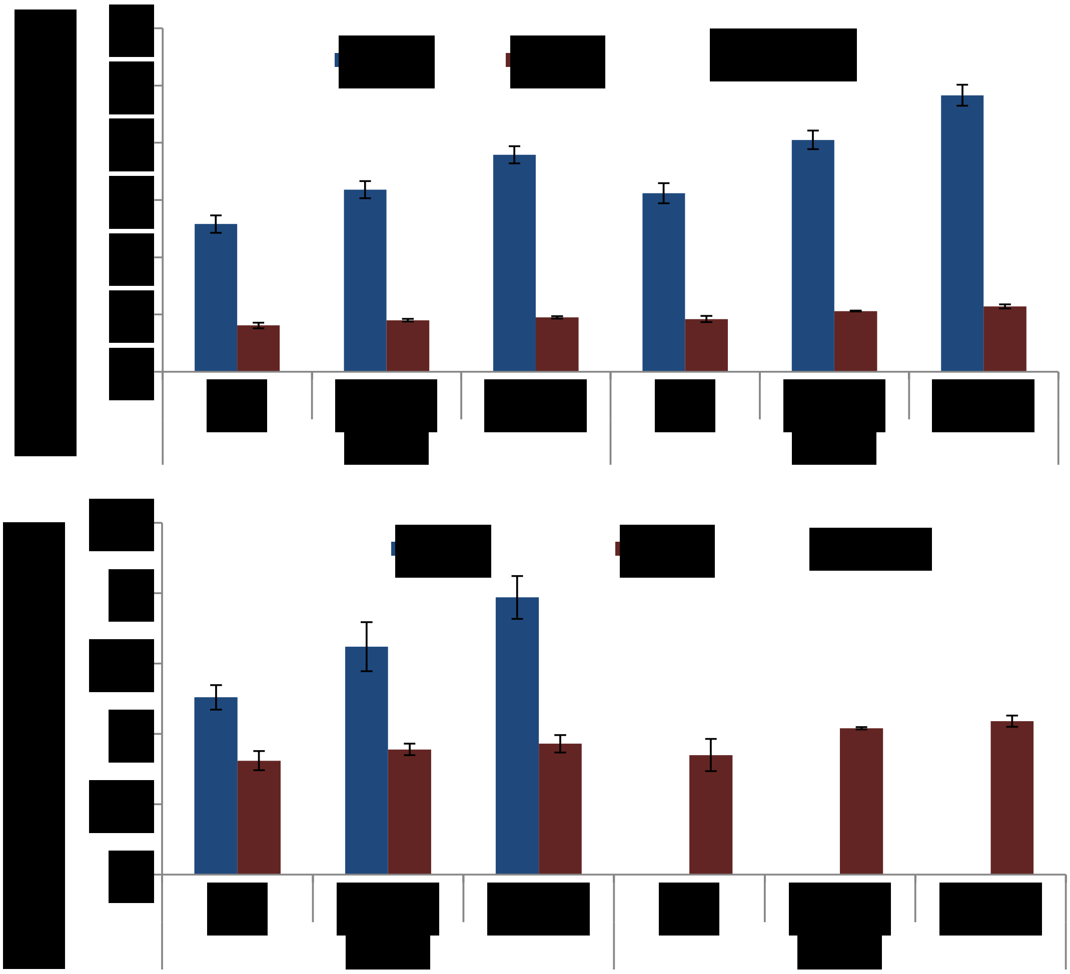

Figure 5.6: Impact of mulching to crop yield in Majulai and Migambo villages

Mulching materials increased maize grain yield in the following order: *Tughutu* mulching increased maize grains yield by 56 % and Tithonia mulching by 29 %, there were no maize grain yield in 2013 due to drought. Beans grain yields increased by 15 % due to *Tughutu* and 10 % due to Tithonia mulching in 2012, while in 2013 *Tughutu* increased by 28 % and Tithonia by 22 % as compared to plots with *miraba* sole in Majulai village. In Migambo village the trend was similar where maize grains yield respectively increased by 47 % and 24 % under *Tughutu* and Tithonia mulching in 2012, while in 2013 *Tughutu* and Tithonia increased maize grains yields by 55 %

and 30 % respectively as compared to plots with *miraba* sole. Beans grains yield was increased by 17 % under *Tughutu* and 11 % under Tithonia, while in 2013 *Tughutu* increased beans grains yield by 24 % and 15 % by Tithonia mulching as compared to plots with *miraba* sole. The higher grain yield under mulching was also reported by Lal (1997) in West Nigeria who found an increased maize grain yield due to soil quality improvements as a result of mulching. Similarly, Lee *et al*. (2013) observed an improved plant germination and growth under coir geotextile mulching.

The higher crop yields under *Tughutu* than under Tithonia mulching can be explained by the higher nutrients contents in *Tughutu* than in Tithonia mulching material. Moreover studies by Wickama and Mowo (2001) and Mowo *et al*. (2006) reported the rate of decomposition of *Tughutu* to be much faster than Tithonia. It has been revealed that the faster the rate of decomposition of organic materials the better the supply of nutrients as compared to slow decomposing materials (Palm *et al*., 2001; Giller *et al*., 2006). This implies that the intervention of *Tughutu* mulching under *miraba* could sustainably and effectively improve crop yields in the West Usambara Mountains.

5.4 CONCLUSIONS AND RECOMMENDATIONS

Although both *Tughutu* and Tithonia mulches showed great potential in reducing runoff, soil and nutrient losses under *miraba*, *Tughutu* mulching was more effective in improving crop yield than Tithonia mulching. The rainfall erosivity, assessed by the *R* factor, is clearly distinct in the two villages and this is linked to climatic condition differences. Despite the fact that the soils of the West Usambara Mountains are susceptible to erosion, the *C* factors indicate these soils are responsive to mulching. Investigations of more local shrubs and grasses for use as both green manure and mulches under *miraba* are encouraged. It is strongly recommended that Tithonia and *Tughutu* shrubs be planted in the borders of the farms plots to easier their availability.

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CHAPTER SIX

6.0 THE INFLUENCE OF SELECTED SOIL CONSERVATION PRACTICES ON SOIL PROPERTIES AND CROP YIELDS IN THE WEST USAMBARA MOUNTAINS, TANZANIA

ABSTRACT

The West Usambara Mountains in Tanzania are severely affected by soil erosion which has led to deterioration of soil properties and reduced crop yields. Indigenous soil erosion control measures, such as *miraba,* which are widely practised in the area have yielded little success. Field plot experiments were laid down in Majulai and Migambo villages from 2011 - 14 on typical soils of the area (*Acrisols)*. The aim was to single out soil properties developed under the studied soil conservation practices and their impact on crop yields with reference to maize (*Zea mays*) and beans (*Phaseolus vulgaris*). Results showed that total N, OC, available P, Ca^{2+}, Mg^{2+}, K^{+} and pH were powerful ($p < 0.05$) attributes that discriminated conservation measures. Magnitudes of the discriminating attributes followed the trend: *miraba* with *Tughutu* (*Vernonia myriantha*) mulching > *miraba* with Tithonia (*Tithonia diversifolia*) mulching > *miraba* sole > cropland with no 'Soil and Water Conservation' (SWC) measures (control). Contents of micro-nutrients did not differ significantly with SWC measures except for Zn which was significantly ($p < 0.05$) lower in the control. Bulk density and available moisture content (AMC) were also strong discriminators of conservation measures. Maize and bean grain yields differed significantly ($p < 0.05$) with the trend: *miraba* with *Tughutu* > *miraba* with Tithonia > *miraba* sole > control in both villages. Crop yields did not vary within the studied SWC practices except for control where maize yield was significantly ($p < 0.05$) higher in lower segments than the upper segments. Crop yields under *miraba* were a function of AMC and pH (R^2= 0.71); AMC, available P, Ca^{2+} and K^+ (R^2= 0.89) under *miraba* with Tithonia mulching; AMC, available P, Ca^{2+} and K^+ (R^2= 0.90) under *miraba* with *Tughutu* mulching. These findings imply that *miraba* with *Tughutu* mulching had greater potential in improving soil properties and crop yields than *miraba* with Tithonia mulching and *miraba* sole.

Key words: Soil erosion, *miraba,* Tithonia, *Tughutu,* maize yields, bean yields

6.1 INTRODUCTION

The problem of soil erosion is global, and has been reported all over the world to affect agricultural sustainability (Faucette *et al*., 2004; Kimaro *et al*., 2008; Jiao *et al*., 2012). For example the West Usambara Mountains of Tanzania which are characterized by a high population density of about 120.4 persons/km^2, and practise farming on steep slopes of more than 40 % due to land scarcity, suffer from severe soil degradation by water erosion (Vigiak *et al.,* 2005; National Bureau of Statistics, 2012). Soil loss, nutrient depletion and reduced capacity of the soil to retain water are major forms of soil degradation in the area. These have led to deterioration of soil properties and reduced crop productivity (Mowo *et al*., 2006). Population pressure in the area has led to an increased land use intensity and expansion of cultivation of food and cash crops in valleys and sloping land (Vigiak *et al.,* 2005; National Bureau of Statistics, 2012).

There is a growing concern that land use practices in the West Usambara Mountains may not be sustainable because of their detrimental effects on soil properties (Vigiak *et al.,* 2005; Kyaruzi, 2013). To address the problem of soil degradation by water induced soils erosion, West Usambara farmers developed indigenous. Soil and Water Conservation' (SWC) measures such *miraba* (rectangular grass bound strips that do not necessarily follow contour lines), micro-ridges and stone bunds as integral part of their farming systems, while introduced measures *e.g.* terraces have often been rejected or minimally adopted because they were expensive in terms of money and labour (Ellis-Jones and Tengberg, 2000; Tenge, 2005; Msita *et al.,* 2010).

Surprisingly however, the indigenous soil erosion control measures implemented in the area have remained poorly documented (Msita *et al*., 2010). Besides, farmers' efforts to conserve the degraded land have yielded very little success, and deterioration of some soil properties is active even in places where SWC measures are practised (Tenge, 2005; Vigiak *et al*., 2005; Kyaruzi, 2013; Msita, 2013). This is partly due to limited knowledge on the effectiveness of the indigenous SWC practices. Moreover, indigenous SWC measures in the area have been for decades left traditional with little scientific intervention for improvement (Msita, 2013).

Indigenous SWC measures have been documented to play a considerable role in controlling soil erosion and improving crop yield. For example, stone bunds in Ethiopia have been reported by Vancampenhout *et al*. (2006) to be effective in increasing yields from 632 to 683 kg ha^{-1} for cereals, from 501 to 556 kg ha^{-1} for *Eragrostis tef* and from 335 to 351 kg ha^{-1} for *Cicer arietinum* as compared to the situation without stone bunds. Likewise the study by Msita (2013) in the West Usambara Mountains, Tanzania revealed *miraba* to have some contribution in controlling soil erosion and increased maize yield from 0.7 Mg ha^{-1} in cropland with no soil conservation measures to 1.1 Mg ha^{-1} in farms with *miraba*.

Although studies on the effectiveness of some introduced SWC technologies on soil erosion control and agricultural productivity have recently been carried out in the West Usambara Mountains (Tenge, 2005; Kyaruzi, 2013), the contribution of indigenous SWC measures including *miraba,* which is the most preferred in the study areas for sustained crop productivity have not fully been investigated (Vigiak *et al.,* 2005, Msita, 2013). Even when investigated, not a single study has attempted to explain the linkages that exist between soil properties and crop yields associated with SWC technologies. Furthermore, land use planners, agricultural managers and extension officers need sound information to guide implementation of SWC practices within the context of improved soil properties and maximized crop production; yet, at present such information does not exist.

The study reported herein, was therefore aimed at establishing the linkages between identified soil properties associated with soil conservation practices namely *miraba* and *miraba* with various mulching materials with reference to productivity of maize (*Zea maize*) and beans (*Phaseolus vulgaris*) under smallholder farming conditions in the West Usambara Mountains. The objectives of this study were (i) to identify soil properties that discriminate between selected SWC practices (ii) to test whether the identified soil properties correlated with crop yield and (iii) to investigate the relation between the identified soil properties and crop yield.

6.2 MATERIALS AND METHODS

6.2.1 Description of the study sites

Migambo and Majulai villages in the West Usambara Mountains, Lushoto District, Tanzania (Fig. 6.1) are located between 38^0 15’ to 38^0 24’ E and 4^0 34’ to 4^0 48’ S. Migambo is humid cold with mean annual air temperature of 12 ^{0}C - 17 ^{0}C and an annual precipitation ranging from 800 - 2300 mm. Majulai is dry warm with mean annual air temperature between 16 ^{0}C and 21 ^{0}C and annual precipitation of 500 – 1700 mm. The monthly evapo-transpiration (ETo) as estimated by the local climate estimator software (New LocClim) (FAO, 2006) ranges from 100 mm to 145 mm.

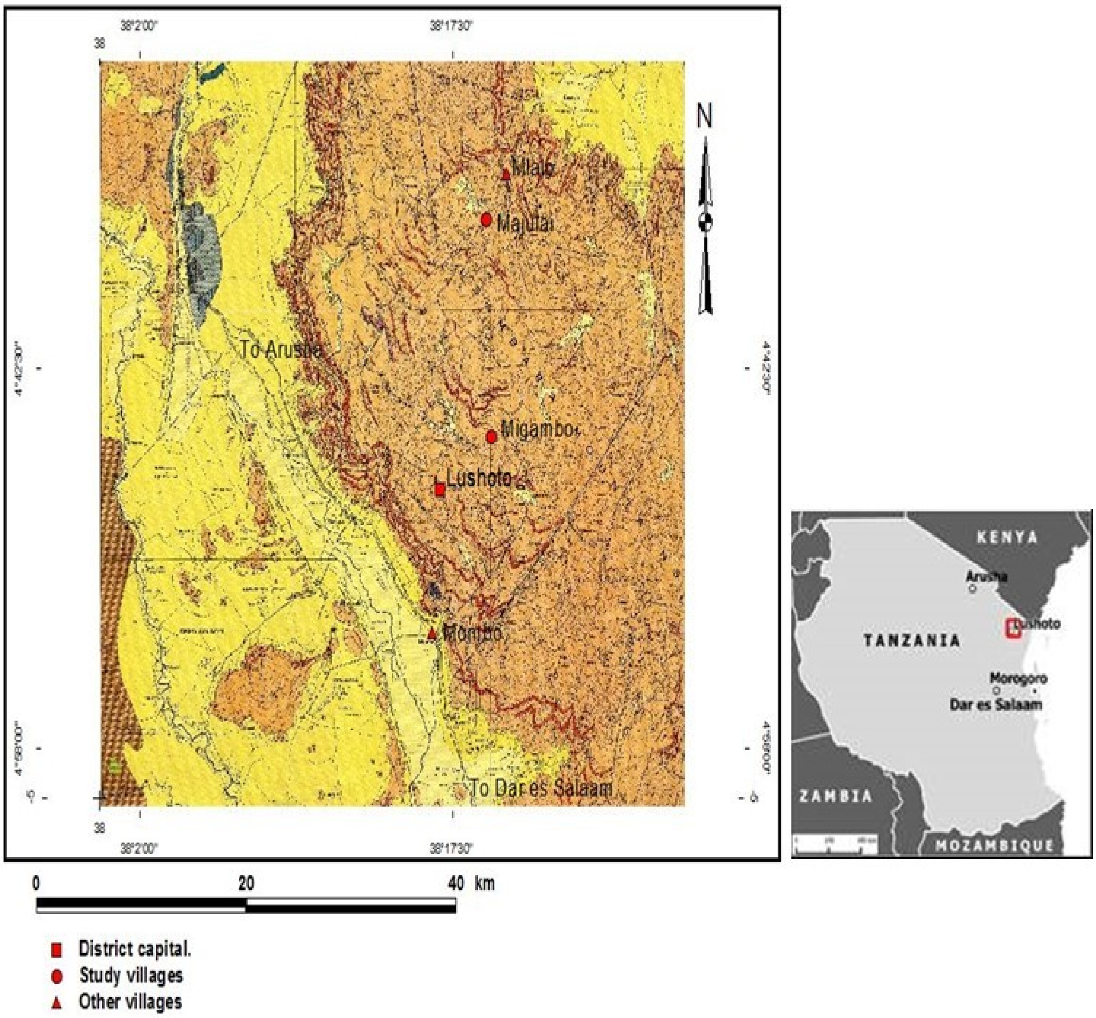

Figure 6.1: Location map of Migambo and Majulai villages, Lushoto District, Tanzania. Source: Terrain image derived from the geological map of Lushoto.

The West Usambara Mountains support a large population density of about 120.4 persons/km^2 (National Bureau of Statistics, 2012).

Soil maps of Majulai and Migambo village are presented in Appendices 1 and 2. According to the World Reference Base for soil resources (WRB) (FAO, 2014) the soil type in Majulai experimental site classified as *Chromic Acrisol* (*Humic, Profondic, Clayic, Cutanic, Colluvic*) whereas in Migambo site the soils are *Haplic Acrisol* (*Humic, Profondic, Clayic, Colluvic*). The main land uses include cultivation on slopes and valley bottoms, settlements on depressions, lower ridge summits and slopes and forest reserves on ridge summits and upper slopes. Vegetables such as carrots, onions, tomatoes, cabbages, and peas are grown as sole crops in valleys under rain fed or traditional irrigation. Beans are grown mainly during long rains and maize in short rains, Irish potatoes and fruits namely peaches, plums, pears, avocado, and banana are grown on ridge slopes under rain fed mixed farming. Irish potatoes are also grown in valleys as sole or intercropped with maize.

6.2.2 Establishment of *miraba*

Miraba were established by using Napier grass (*Pennisetum purpureum*) barriers in field plots in April 2011 about nine months before planting crops and runoff collection. Tillers of Napier grass were planted in single rows at 10 cm spacing (as per farmers' practise) perpendicular to the general slope. The grass barriers were maintained at 50 cm wide strips to avoid reduction of cropland by grass barriers. The grass barriers were cut at about 25 cm above ground (Pfeifer, 1990), the low cutting reduce competition of space and sunlight with crops, while also stimulate tillering that make dense grass barriers for effective control of soil erosion. Napier grass barriers across the slope were spaced 5 m apart to mimic the recommended maximum effective width of hand made bench terraces Sheng (2002). On the other hand, the spacing of Napier grass barriers forming *miraba* along the slope was set at 3 m apart, wider by 1 m from the standard runoff plots to accommodate the space occupied by grass barriers.

It has been documented that soil conservation measures such as *Fanya* Juu (hillside ditches made by throwing excavated soil on the upslope of the ditch, built along contour lines at appropriate intervals depending on slope gradient) and stone bunds tend to progressively form bench terraces when at close spacing (Sheng, 2002; Kaswamila, 2013). Moreover, the closer the grass strips are the more effective they become in controlling soil erosion (Kaswamila, 2013). Progressive bench terrace formation is also possible under *miraba* when adjusted to appropriate spacing of grass strips. Natural bench terrace formation as a result of *miraba* implementation is much less expensive compared to mechanical bench terrace construction which is feared by farmers. Bench terraces are highly recommended for use in the West Usambara Mountains (Shelukindo, 1995; AHI, 2001; Tenge, 2005, Vigiak *et al.,* 2005).

6.2.3 Experimental design

Miraba plots 22 m x 3 m in a Randomized Complete Block Design (RCBD) were set in the lower ridge slopes at 50 % slope in Majulai and 45 % slope in Migambo village (Plate 6.1). Such slopes were chosen because the study area is dominated by steep slopes where maize and beans are mainly grown. Maize and beans were planted in rotation as test crops in 2012/13 and 2013/14 rain seasons, where maize was planted during short rains (*vuli*) and beans during long rains (*masika*) as per farmers' practise. The treatments included plots with (i) *Miraba* (***MI***) (ii) *Miraba* with Tithonia mulching (***MITH***) (iii) *Miraba* with *Tughutu* mulching (***MITG***) (iv) No SWC measures (***CO***) (Control), all replicated three times.

Plate 6.1: Majulai experimental plots left, Migambo experimental plots with maize crop right. Plates by: Mwango, S.B. 25/09/2013 left and 14/11/2013 right

6.2.4 Mulching materials

Mulching materials used included the leaves of *Tithonia diversifolia* (*Alizeti Pori*) and *Vernonia myriantha* (*Tughutu*) in both villages. The mulch was applied under *miraba* two weeks after crops germinated at the rate of 3.6 Mg ha^{-1} dry weight, the amount that ensured complete coverage on the soil. These shrubs were chosen as mulches because the plants are readily available in the area and they have been documented to contain appreciable NPK contents (Wickama and Mowo, 2001; Mowo *et al*., 2006). Samples from each mulching material were collected for the determination of total N, available P, K^+, Mg^+, Ca^{2+} and Na^+.

6.2.5 Determination of soil chemical and physical properties

The impact of SWC measures on soil chemical and physical properties was determined by taking composite topsoil samples (0 - 30 cm depth) from each treatment for the analysis of pH, OC, total N, available P, K^+, Ca^{2+}, Mg^{2+}, Na^+, Fe, Cu, Zn, Mn and soil texture. Undisturbed core soil samples were also collected from 0 – 5 cm depth for bulk density and available moisture content determination. Soil samples were collected after every cropping season i.e. long rains and short rains from 2012/13 to 2013/14. In each runoff experimental site a representative soil profile was excavated and described, and soil samples collected from each horizon for pedological characterization. Undisturbed core soil samples were taken from 0 - 5 cm, 45 - 50 cm and 95 - 100 cm soil depths by Kopecky's core rings (100 cm^3) for bulk density and available moisture determination for further characterization of the representative soil profiles. The soil profiles were classified to tier-2 according to WRB for Soil Resources (FAO, 2014).

6.2.6 Crop yields determination under the selected SWC practices

Maize (*Zea mays*) variety PAN 67 and beans (*Phaseolus vulgaris*) Kilombero variety were planted in runoff plots during the 2012/13 and 2013/14 rainy seasons with maize in short rains and beans during the long rains as per farmers' practise. The crops were planted as per recommended spacing of 75 cm × 30 cm for maize and 50 cm × 25 cm for beans. Beans were always planted one month before maize was harvested in Migambo and two weeks in Majulai village, because in Migambo village maize stay longer in the field due to cold climate. Farmyard manure was basal and spot applied at the rate of 3.6 Mg ha^{-1} air-dry weight, DAP 18: 46: 0 NPK ratio and Urea 46 % N were applied at the rate of 80 kg ha^{-1}, but Urea was not applied for beans as per farmers' practise. At maturity maize and bean grains were harvested and dried to 13 % moisture content. The harvesting was done by dividing the plots into two equal segments i.e. the upper and lower segments for determination of the effect of gradients within plots.

6.2.7 Soil and plant sample analysis

Soil analysis was done following the Moberg's (2001) Laboratory Manual. Organic carbon (OC) was measured using the dichromate oxidation method, total nitrogen (TN) by Kjeldahl method, available phosphorus (Bray-I), exchangeable bases (Ca^{2+} and Mg^{2+}) by atomic absorption spectrophotometer, exchangeable Na^{+} and K^{+} by flame photometer and pH water by normal laboratory pH meter. The available Fe, Mn, Zn and Cu were extracted using buffered DTPA (Diethylene triamine pentaacetic acid) method and the DTPA extract was analysed in an Atomic Absorption Spectrophotometer (AAS). Soil texture was determined by Hydrometer method. Bulk density was determined by oven drying and weighing method. Soil moisture retention characteristics were studied using sand kaolin box for low suction values and pressure plate apparatus for higher suction values (NSS, 1990).

6.2.8 Data analysis

Bartlett's test for homogeneity of variance was conducted to test data normality using the GenStat software (GenStat, 2011). All data were subjected to Analysis of Variance (ANOVA). GenStat statistical analysis software (GenStat, 2011) was used for the analysis and significant differences were tested by the Least Significant Difference ($LSD_{0.05}$). Correlation and multiple linear regressions were performed using Minitab software (Minitab, 2004) to determine the relationship between soil properties and crop yield under the studied SWC measures.

6.3 RESULTS AND DISCUSSIONS

6.3.1 Selected chemical properties of mulching materials

Chemical properties of mulching materials are presented in Table 6.1. It can clearly be seen that *Tughutu* had the higher nutrient contents than Tithonia shrub. The higher nutrient contents in *Tughutu* than in Tithonia shrub could probably be explained by the ability of *Tughutu* shrub to extract nutrients from the soil. Other researchers Wickama and Mowo (2001) also found similar situation where higher NPK contents were observed in *Tughutu* than in Tithonia shrub.

Table 6.1: Chemical properties of mulching materials and farm yard manure applied in Majulai and Migambo villages

	Plant nutrients content %					
Mulching materials	N	P	K	Ca	Mg	Na
Tithonia	3.3	0.3	6.1	1.2	0.7	0.04
Tughutu	3.6	0.3	6.3	1.4	0.9	0.04
Farm yard manure	1.7	0.4	1.9	0.9	0.6	0.07

6.3.2 The influence of SWC measures on selected soil physico-chemical properties

Variability of soil chemical and physical properties between SWC measures are presented in Table 6.2 & 6.3. Considering the soil chemical properties in relation to the SWC measures, most of the properties were significantly ($p < 0.05$) different between treatments. The differences can be explained by the influences of the SWC measures applied. It was revealed in both villages that the contents of all the studied macro nutrients contents followed the trend that: *miraba* with *Tughutu* mulching >

miraba with Tithonia mulching > *miraba* sole > cropland with no SWC measures (Table 6.2) except for Na^+ which did not significantly ($p > 0.05$) differ. Similarly for pH which followed the same trend. It was therefore concluded that total N, OC, P, Ca^{2+}, Mg^{2+}, K^+ and pH were powerful attributes that differentiated between SWC measures. Studies by Tenge (2005) and Kyaruzi (2013) revealed similar observations where terracing such as bench and *Fanya Juu* terraces effectively controlled runoff and soil losses, thus improving soil physical and chemical properties in the West Usambara Mountains.

Table 6.2: The influence of the studied SWC practices on soil chemical properties

Village	SWC	N	pH	OC	TN	P	K^+	Ca^{2+}	Mg^+	Na^+	Fe	Mn	Zn	Cu
				%	%	mg kg^{-1}	cmol (+) kg^{-1}				mg kg^{-1}			
Majulai														
	Control	12	4.5	2.2	0.19	10.6	0.15	1.1	0.72	0.32	36.4	44.4	1.5	3.2
	Miraba sole	12	4.5	2.4	0.22	14.4	0.17	1.5	0.95	0.33	41.2	42.0	2.1	3.6
	Miraba with Tithonia	12	4.5	2.6	0.26	23.1	0.31	1.4	1.17	0.32	42.5	47.2	1.7	3.1
	Miraba with *Tughutu*	12	4.9	2.9	0.28	26.7	0.45	2.2	1.93	0.34	41.6	51.7	2.2	3.9
Migambo														
	Control	12	5.2	3.4	0.33	5.6	0.13	4.3	1.22	0.31	42.3	157.6	3.5	2.6
	Miraba sole	12	5.5	3.7	0.36	7.5	0.19	6.1	1.79	0.32	41.7	187.6	4.7	3.5
	Miraba with Tithonia	12	5.7	4.1	0.38	10.1	0.42	6.4	2.38	0.34	44.6	155.0	4.4	3.2
	Miraba with *Tughutu*	12	5.7	4.4	0.42	13.0	0.46	7.3	2.78	0.35	47.9	164.4	5.1	3.5
	LSD ($p \leq 0.05$)		0.3	0.5	0.03	4.0	0.13	1.3	0.6	0.09	6.5	30.9	1.1	1.5
	SE		0.1	0.2	0.01	1.4	0.05	0.5	0.2	0.01	2.3	11.0	0.4	0.5

LSD: least significant difference; SE: standard error of means

The higher pH and macronutrient status under *miraba* with *Tughutu* mulching than under *miraba* with Tithonia mulching can be explained by the higher nutrient contents of *Tughutu* as compared with Tithonia mulching material (Table 6.1). The higher NPK contents in *Tughutu* than in Tithonia shrub was also reported by Wickama and Mowo (2001). It is also well known that exchangeable bases have strong positive correlation with soil pH (Mwango, 2000; Msanya *et al*., 2001). In the case of micro-nutrients, it was found that there were no significant ($p > 0.05$) different between SWC measures except for Zn which was significantly low under cropland with no SWC measures. Therefore Zn was spotted as the best micronutrient differentiating SWC measures.

These differences can be explained by the influences of the tested SWC measures. In the West Usambara Mountains, Kyaruzi, (2013) also reported bench terraces and grass strips to have an influence on soil chemical properties such as pH, total N, OC, CEC, Ca^{2+} and Mg^{2+} when compared to control. Other researches by Tenge, (2005) and Wickama *et al*. (2014) in the West Usambara Mountains reported soil conservations measures such as bench terraces, *Fanya Juu* terraces and grass strips were found to have a big influence on soil chemical and physical properties as compared with cropland with no SWC measures.

On the other hand soil physical properties were significantly ($p < 0.05$) different between SWC measures except for soil texture which did not differ (Table 6.3). The available moisture contents (AMC) were higher under *miraba* with mulching than under *miraba* sole and cropland with no SWC measures. Bulk density (BD) values were significantly lower under *miraba* with mulching than under *miraba* sole and cropland with no SWC measures. Thus AMC and BD were powerful soil physical properties that discriminated between SWC measures. The higher AMC and lower bulk density under *miraba* with mulching can be explained by the increased organic

Table 6.3: The influence of the studied SWC practices on soil physical properties.

Village	SWC practises	N	AMC %	BD g/cc	Sand %	Silt %	Clay %
Majulai							
	Control	12	23.2	0.98	34	9	56
	Miraba sole	12	29.2	0.97	33	9	58
	Miraba with Tithonia	12	32.9	0.93	34	9	57
	Miraba with *Tughutu*	12	32.9	0.91	33	12	55
Migambo							
	Control	12	17.6	0.95	35	13	52
	Miraba sole	12	22.7	0.89	35	15	51
	Miraba with Tithonia	12	25.9	0.88	35	16	50
	Miraba with *Tughutu*	12	29.3	0.83	35	13	52
	LSD (P = .05)		3.6	0.06	5.1	3.0	4.6
	SE		1.3	0.02	1.8	1.1	1.6

LSD: least significant difference; SE: standard error of means

carbon contents due to the application of mulches. It has been established that the higher the organic carbon contents in the soil the lower the bulk density while also the higher the capacity of the soil to retain moisture available to plants (Aticho, 2013). The improvements of the aforementioned soil physical and chemical properties under *miraba* can also be explained by the fact that; apart from the ability of grass barriers forming *miraba* of retaining soil sediments and nutrients, *miraba* were also progressively forming bench terraces such that the terrace height was raised to about 1 m in Migambo and 0.7 m in Majulai village after about three years of experimentation.

The terraces so formed cut down the slope steepness resulting in reduced runoff velocity and increased rate of infiltration which in turn reduced runoff volume thus reducing soil and nutrient losses. Observations by Gilley *et al*. (2011) reported grass hedge to effectively reduce runoff and nutrient loads following manure application as compared with cropland with no grass hedge. Wanyama *et al*. (2012) also reported elephant grass, lemon grass, paspalum and sugarcane to effectively trap sediments and reduce runoff from cropland in Uganda.

6.3.3 The influence of selected SWC practices on crops yield in Majulai and Migambo villages

Maize and beans yield under the studied SWC practices in the Majulai and Migambo villages are presented in Table 6.4. Significant ($p < 0.05$) differences in crop yield between SWC practices were observed. Maize and bean grain yield followed the trend: *miraba* with *Tughutu* > *miraba* with Tithonia > *miraba* sole > control in both villages. Maize grain yield were significantly ($p < 0.05$) higher in 2013 than in 2012, but there were no significant ($p > 0.05$) differences in bean grain yield between the two years of study. It was clearly observed that the crop yield differences between treatments are highly influenced by the SWC practices intervention (Table 6.4), while the higher crop yields under *miraba* with Tithonia and *miraba* with *Tughutu* mulches could be explained by the improved soil properties especially of AMC, OC, N, P, K, Ca^{2+}, Mg^{2+}, pH and BD.

Similar observations were reported by Tenge (2005) where *Fanya Juu* terraces had significantly higher maize and beans yields than under bench terraces and grass strips while control had the least, likewise the study by Msita (2013) found that *miraba* with farm yard manure and mulching have higher maize and bean yields than under *miraba* sole and control had the least. The higher yields were associated with improved soil fertility. The observed crop yields under the studied SWC practices

Table 6.4: Crop yields under selected SWC practices in Majulai and Migambo villages

Village	SWC measures	Segments within SWC measures	N	Mean crop grains yield Mg ha^{-1} in 2012 Maize	Mean crop grains yield Mg ha^{-1} in 2012 Beans	Mean crop grains yield Mg ha^{-1} in 2013 Maize	Mean crop grains yield Mg ha^{-1} in 2013 Beans
Majulai							
	Plots with no SWC	Upper segment		0.51	0.56		0.57
		Lower segment		0.91	0.62		0.61
		Mean	**3**	**0.71**	**0.59**	0.0	**0.59**
	Miraba sole	Upper segment		1.24	0.80		0.85
		Lower segment		1.28	0.82		0.85
		Mean	**3**	**1.26**	**0.81**	0.0	**0.85**
	Miraba with Tithonia	Upper segment		1.61	0.89		1.04
		Lower segment		1.63	0.89		1.04
		Mean	**3**	**1.62**	**0.89**	0.0	**1.04**
	Miraba with *Tughutu*	Upper segment		1.96	0.93		1.09
		Lower segment		1.98	0.93		1.09
		Mean	**3**	**1.97**	**0.93**	0.0	**1.09**
	LSD ($P \leq 0.05$)			0.15	0.15	0.0	0.15
	SE.			0.05	0.05		0.05
Migambo							
	Plots with no SWC	Upper segment		1.07	0.62	1.33	0.65
		Lower segment		1.97	0.66	1.95	0.69
		Mean	**3**	**1.57**	**0.64**	**1.64**	**0.67**
	Miraba sole	Upper segment		2.53	0.81	3.10	0.92
		Lower segment		2.63	0.81	3.14	0.92
		Mean	**3**	**2.58**	**0.81**	**3.12**	**0.92**
	Miraba with Tithonia	Upper segment		3.14	0.90	4.00	1.06
		Lower segment		3.22	0.90	4.10	1.06
		Mean	**3**	**3.18**	**0.90**	**4.05**	**1.06**
	Miraba with *Tughutu*	Upper segment		3.75	0.95	4.82	1.14
		Lower segment		3.83	0.95	4.84	1.14
		Mean	**3**	**3.79**	**0.95**	**4.83**	**1.14**
	LSD ($P \leq 0.05$)			0.41	0.41	0.41	0.41
	SE.			0.14	0.14	0.14	0.14

LSD: least significant difference; SE: standard error of means

(Table 6.4) were higher than the average yields according to (FAO, 2010) of 1.5 Mg ha^{-1} for maize and of 0.7 Mg ha^{-1} for beans in Tanzania. When considering variability of crop yields within the studied SWC practices, it can be seen from Table 6.4 that, crop grain yields did not significantly ($p < 0.05$) varied within SWC measures except under cropland with no SWC measures where lower segments had higher maize grain yields than the upper segments. It can easily be noted that maize crop is more sensitive to the effect of gradients than bean crop; this is probably due to the ability of beans to fix nitrogen for its consumption as opposed to maize crop. Tenge (2005) reported similar observations where bean crop performance was found not sensitive to slope gradients as opposed to maize.

The evenly distributed crop yields within the studied SWC practices can partly be explained by the effect of reducing spacing of grass barriers that form *miraba* from the traditionally very wide to 5 m apart. This spacing was close enough to limit runoff velocity and thus reduced soil nutrients that could move with it down the slope to the lower segments. Besides, with this spacing, *miraba* were progressively forming bench terraces which cut down the slope and thus reduce translocation of soil nutrients by runoff. On the other hand mulching was also contributing to the reduced soil nutrient movement from the upper to the lower segments, allowing crops to respond evenly within the studied SWC practices.

6.3.4 Relation between soil properties and crop yields under the different SWC measures

Correlation between soil chemical properties (that discriminated SWC measures) and crop yields are presented in Table 6.5. It can be seen that all the discriminator soil properties were positively correlated with crop yield except for bulk density which was negatively correlated. The negative correlation of bulk density with crop yields can be explained by the fact that, bulk density is greatly influenced by soil organic carbon contents such that low the OC contents high the bulk density of the soils and vice versa, similar relationship was also reported by (Aticho, 2013). Soil OC has been acknowledged to be an important cushion for many soil nutrients thus the higher the OC content the higher the soil nutrients in the soil (Mwango, 2000; Msanya *et al*., 2001).

Table 6.5: Soil properties that correlated with crop yield under the studied SWC measures

Crop	SWC measure	Soil chemical properties										n
Maize												
	Control	Ca*	Mg**	Zn*								24
	Miraba	Ca***	Mg***	TN***	OC**	pH***	Zn***	Mn***				24
	Miraba with Tithonia	Ca***	Mg***	TN***	OC***	K***	pH***	Zn*	Mn*			24
	Miraba with *Tughutu*	Ca***	Mg***	TN***	OC***	K***	pH***	Zn*	Mn*	AMC**		24
Beans												
	Control	Ca*	Mg*	Mn*								24
	Miraba	Ca*	Mg*	pH*	K*	AMC**						24
	Miraba with Tithonia	Ca*	Mg***	K***	P*	pH*	AMC***	-BD*				24
	Miraba with Tughutu	Ca**	Mg***	K***	P*	pH***	TN**	OC*	Zn**	AMC**	-BD*	24

Key: *** =significant at p<0.001, ** =significant at p<0.01 and * =significant at p<0.05

A multiple linear regression model was fitted through the discriminator soil properties that were correlated with crop yields under SWC measures (Table 6.6). It was found that maize grain yields under *miraba* were significantly ($p < 0.05$) a function of Ca^{2+} and Mg^{2+} with (R^2 = 0.85) for cropland with no soil and water conservation measures and (R^2 = 0.79) for cropland with *miraba*. However, under *miraba* with Tithonia mulching maize grain yields were mainly a function of K^+ and Mg^{2+} (R^2 = 0.89) whereas under *miraba* with *Tughutu* mulching maize grain yields were greatly a function of available moisture content (AMC), K^+ and Mg^{2+} (R^2 = 0.97).

On the other hand bean grain yields was significantly ($p < 0.05$) a function of Mg^{2+} and Mn (R^2 = 0.68) under control; available moisture content (AMC) and pH (R^2 = 0.71) under *miraba*; AMC, available P, Ca^{2+} and K^+ (R^2 = 0.89) under *miraba* with Tithonia mulching; while under *miraba* with *Tughutu* mulching beans grain yields were strongly a function of AMC, available P, Ca^{2+} and K^+ (R^2 = 0.90). These observations imply that AMC and pH had greater potential of influencing maize and beans grain yields under *miraba*, while AMC, available P and K^+ had greater potential of influencing maize and beans grain yields under *miraba* with Tithonia and *miraba* with *Tughutu* mulching.

The enhanced ability of *miraba* to avail soil water to plants and increase soil pH can be explained by the improved soil OC and exchangeable bases under *miraba*. Similar positive correlations of exchangeable bases with pH and AMC with OC were also reported by other scholars (*e.g.* Mwango, 2000; Msanya *et al.*, 2001; Shelukindo *et al.,* 2014). The improved P and K^+ under *miraba* were greatly due to the influences of mulching materials applied which have high contents of available P and K^+ (Table6.1). This is strongly supported by the findings that applications of organic materials in soils reduce P sorption capacities and increase P availability (Ikerra,

Table 6.6: Relation between soil properties and crop yield (Mg ha^{-1}) (Y) under the studied SWC measures

Crop	SWC measure	Regression equations	R^2	P	n
Maize	Control	Y = 0.152 + 0.104 Ca^{2+} cmol/kg + 0.793 Mg^{2+} cmol/kg^{-1}	0.85	0.003	24
	Miraba				
		Y = 0.314 + 0.139 Ca^{2+} cmol/kg + 0.038 OC% + 0.716 Mg^{2+} cmol/kg	0.80	0.000	24
		Y = 0.376 + 0.03 TN% + 0.141 Ca^{2+} cmol/kg + 0.752 Mg^{2+} cmol/kg	0.80	0.000	24
		Y = 0.381 + 0.142 Ca^{2+} cmol/kg + 0.754 Mg^{2+} cmol/kg	0.79	0.000	24
	Miraba with Tithonia				
		Y = - 0.70 + 5.67 K^+ cmol/kg + 0.703 Mg^{2+} cmol/kg + 0.191 pH	0.90	0.000	24
		Y = - 0.040 + 5.62 K^+ cmol/kg + 0.732 Mg^{2+} cmol/kg + 0.85 TN%	0.90	0.000	24
		Y = 0.004 + 5.71 K^+ cmol/kg + 0.714 Mg^{2+} cmol/kg + 0.069 OC%	0.90	0.000	24
		Y = 0.134 + 5.96 K^+ cmol/kg + 0.762 Mg^{2+} cmol/kg	0.89	0.000	24
	Miraba with Tughutu				
		Y = - 1.98 + 0.0319 AMC% vol + 0.848 Mg^{2+} cmol/kg + 3.04 K^+ cmol/kg + 1.63 TN%	0.98	0.000	24
		Y = - 2.70 + 0.0238 AMC % vol + 0.313 pH + 0.886 Mg^{2+} cmol/kg + 3.35 K^+ cmol/kg	0.98	0.000	24
		Y = - 1.37 + 0.0259 AMC% vol + 0.970 Mg^{2+} cmol/kg + 3.51 K^+ cmol/kg	0.97	0.000	24
Beans	Control	Y = 0.456 + 0.000629 Mn mg/kg + 0.0872 Mg^{2+} cmol/kg	0.68	0.006	24
	Miraba				
		Y = - 1.18 + 0.0197 AMC% vol + 0.156 pH	0.71	0.000	24
	Miraba with Tithonia				
		Y = - 0.496 + 0.0175 AMC% vol + 0.00569 P mg/kg + 0.0470 Ca^{2+} cmol/kg + 0.242 K^+ cmol/kg	0.89	0.000	24
	Miraba with Tughutu				
		Y = - 0.224 + 0.0123 AMC% vol + 0.00839 P mg/kg + 0.0474 Ca^{2+} cmol/kg + 0.219 K^+ cmol/kg	0.90	0.000	24

2004), while also application of high quality organic materials with P content equal to or greater than 3.0 g P kg^{-1} in the soil decreases P adsorption (Lyamuremye and Dick, 1996), a tendency that improves P availability in the soil.

6.4 CONCLUSIONS AND RECOMMENDATIONS

Most of the studied chemical and physical soil properties were significantly ($p < 0.05$) influenced by the studied SWC measures. The trend for total N, OC, available P, Ca^{2+}, Mg^{2+}, K^{+} and pH was: *miraba* with *Tughutu* > *miraba* with Tithonia > *miraba* sole > cropland with no SWC measures (Control), while Na^{+} did not differ significantly across the SWC measures. Micro nutrients Fe and Cu did not differ between SWC measures except for Zn and Mn which were significantly ($p < 0.05$) low in cropland with no SWC measures. Likewise, *miraba* with *Tughutu* mulching had the highest AMC and lowest BD, whereas cropland with no SWC measures had the lowest AMC and highest BD.

Maize and bean grain yields differed significantly ($p < 0.05$) in the following trend: *miraba* with *Tughutu* > *miraba* with Tithonia > *miraba* sole > control in both villages. Crop grain yields did not significantly ($p > 0.05$) varied within SWC measures except for control which had higher crop grain yields in the lower parts than the upper parts. AMC and pH had the greatest potential in influencing maize and bean grain yields under *miraba*, while AMC, available P and K^{+} had the greatest potential in influencing maize and bean grain yields under *miraba* with Tithonia or *miraba* with *Tughutu* mulching. Further researches are recommended to investigate the potentials of these mulching materials to influence the production of vegetables such as cabbage, tomatoes, onions and carrots which are widely cultivated in the West Usambara Mountains.

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CHAPTER SEVEN

7.0 SOIL LOSS DUE TO CROP HARVESTING UNDER *MIRABA* IN THE WEST USAMBARA MOUNTAINS, TANZANIA: THE CASE OF CARROT, ONION AND POTATO

ABSTRACT

Among the various soil erosion processes threatening sustainable agriculture, soil losses due to root, tuber and bulb harvesting are poorly documented, particularly in tropical environments. A study was thus conducted in two villages with contrasting agro-ecological conditions on *Acrisols* and *Fluvisols* in the West Usambara Mountains, Tanzania. The aim was to investigate soil and nutrients loss and the factors influencing variation of Soil Loss due to Crop Harvesting (SLCH) under *miraba* for Carrot (*Daucus carrota*), Onion (*Allium cepa* L.) and Potato (*Solanum tuberosum* L.) under low input agriculture. A total of 108 farm plots under *miraba* were sampled from the two villages. The mean SLCH values were significantly ($p < 0.05$) higher for carrot (7.1 Mg ha^{-1} $harvest^{-1}$) than (3.8 Mg ha^{-1} $harvest^{-1}$) for onion than (0.7 Mg ha^{-1} $harvest^{-1}$) for potatoes. Soil nutrient losses in kg ha^{-1} $harvest^{-1}$ were higher for carrot than for onion and potatoes (*e.g.* 30 N, 0.1 P, 1.5 K for carrot Vs. 6.3 N, 0.04 P, and 0.2 K for onion) in Majulai village. SLCH was greater in Migambo (humid cold) than in Majulai (dry warm) for all the studied crops. Soil water content at harvest time played a significant role at 5 % level in inducing SLCH for onion crop whereas carrot and potato crops were not significantly influenced by soil water content. Bulk density and soil texture played only a minor role to SLCH of the studied crops. The observed soil and nutrient losses under *miraba* are substantial

and pose a challenge that calls for immediate attention to the harvesting practices in the study area.

Keywords*;* Soil erosion; *miraba*; soil texture; soil water content; bulk density

7.1 INTRODUCTION

Efforts to arrest soil erosion in Sub-Saharan countries including Tanzania have progressed very slowly for lack of adequate data and a link between specific soil erosion processes and the corresponding control measures (Kimaro, 2003). Most of these efforts focus on water and tillage soil erosion, whereas significant soil masses that are lost from arable land during harvesting of root, tuber and bulb crops such as carrot (*Daucus carrota*), onion (*Allium cepa* L.), potato (*Solanum tuberosum* L.) and cassava (*Manihot esculenta*) are overlooked (Ruysschaert *et al*., 2005; Ruysschaert *et al*., 2007). Soil sticking to the harvested crops that is exported from the field and that is rarely returned to the field is referred to as soil loss due to crop harvesting (SLCH) (Ruysschaert *et al*., 2004; Isabirye *et al*., 2007).

While some studies on SLCH have been done under highly mechanized agriculture (Poesen *et al*., 2001), only a single research by Isabirye *et al*. (2007) in Uganda was conducted under low input agriculture. In their study, Isabirye *et al*. (2007) investigated SLCH for cassava (*Mannihot esculenta*) and sweet potato (*Ipomoea batatas*) and the results showed considerable soil losses for cassava (3.4 Mg ha^{-1} y^{-1}). *Miraba* is an indigenous SWC measure mostly preferred and widely practiced in the West Usambara Mountains, it is a rectangular bound grass strips that do not necessarily follow contour lines (Msita, 2013). It was thus innovative to investigate the magnitude of soil and nutrient losses due to harvesting of crops under *miraba* because the process could be hypothesised significant to upset the soil conservation efforts that have been achieved in the area.

Therefore, the present study investigated the magnitude of soil and nutrient losses under *miraba* due to harvesting of carrot (*Daucus carrota*), onion (*Allium cepa* L.) and potato (*Solanum tuberosum* L.) under traditional low-input agriculture in two contrasting agro-ecological settings in the West Usambara Mountains, Tanzania on *Acrisols* and *Fluvisols*. The objectives of this study were: (1) to determine the magnitude of SLCH under *miraba*, (2) to investigate the factors that influence the soil loss rate and (3) to gauge the magnitude of soil nutrient loss from SLCH.

7.2 MATERIALS AND METHODS

7.2.1 Study area

This study was conducted in Migambo and Majulai villages, West Usambara Mountains, Lushoto District, Tanzania (Fig. 7.1) located between coordinates 38^0 15' E to 38^0 24' E and 4^0 34' S to 4^0 48' S. Migambo is humid cold with mean annual air temperature of 12 ^{0}C − 17 ^{0}C and annual precipitation is 800 – 2300 mm (Msita, 2013). Majulai is dry warm with mean annual air temperature between 16 ^{0}C and 21 ^{0}C and annual precipitation of 500 – 1700 mm. The West Usambara Mountains support a large population density more than 120.4 persons/km^2 (National Bureau of Statistics, 2012). The dominant soils of the study area were mainly *Acrisols* on slopes and *Fluvisols* in valley bottoms. The main land uses include agriculture and settlements. Vegetables such as carrots, onions, tomatoes, cabbages and peas are grown as sole crops in valleys (Table 7.1) under rain-fed or under traditional

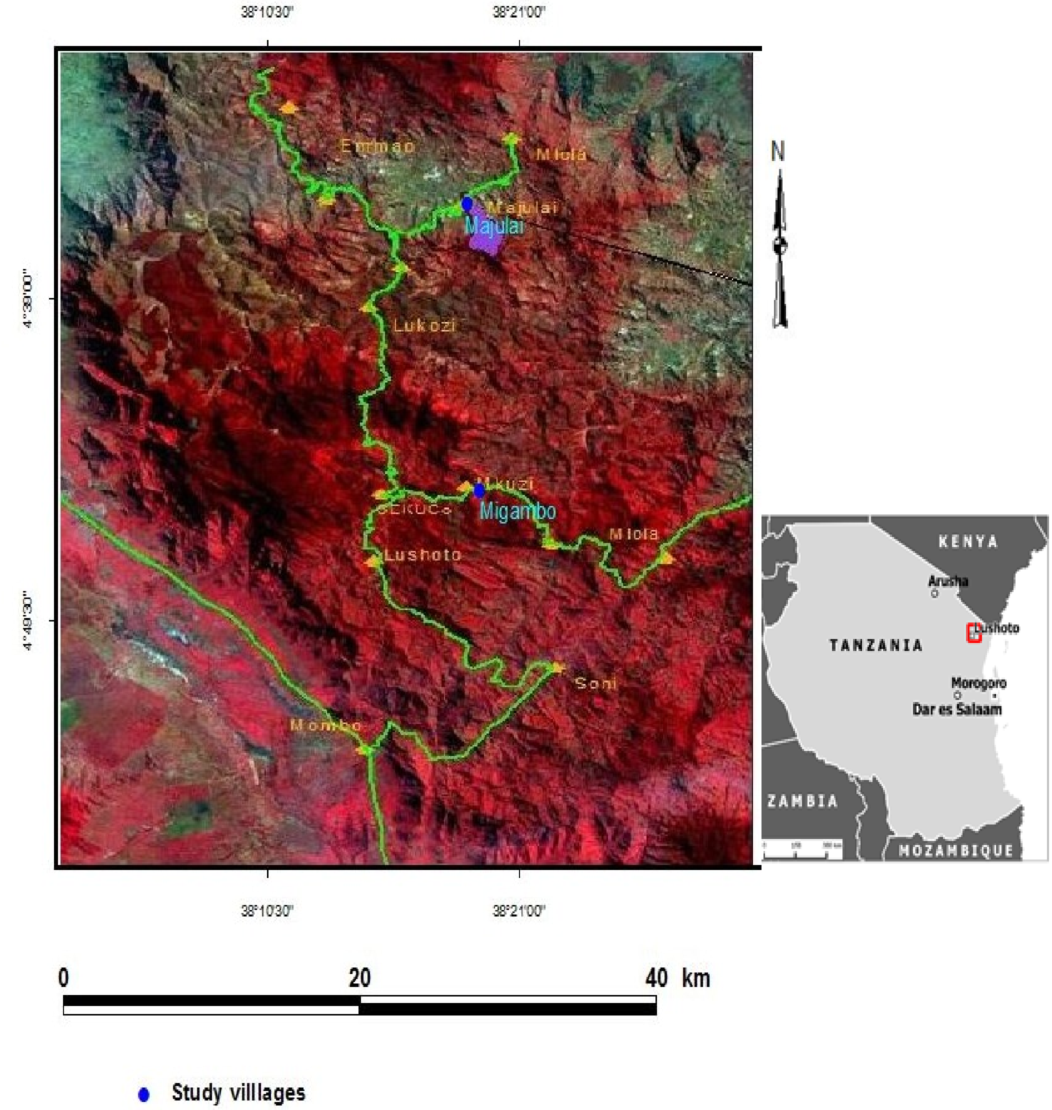

Figure 7.1: Location map of Migambo and Majulai villages, Lushoto District, Tanzania. Source: Terrain image derived from SRTM data available at http://srtm.csi.cgiair.org/

irrigation. Beans, maize, potatoes and fruits namely peaches, plums, pears, avocados and bananas are grown on ridge slopes under rain-fed mixed farming. Potatoes are also grown in valleys as sole or intercropped with maize. Maize crop is mainly grown during short rain season while beans are grown during the long rain season. Potatoes, carrots, onions, cabbages, tomatoes and sweet peppers are crops usually grown twice a year during both long rain season (*masika*) and short rain season (*vuli*), but some vegetable crops such as cabbages, tomatoes and sweet peppers are also grown during offseason by traditional irrigation in few areas with water sources. Potatoes are harvested by hand hoe while carrots and onions are simply uprooted by hand pulling. Crops grown in the Western Usambara Mountains are sold in the local markets but are also exported outside the area to major towns and/or cities in the East African Countries *e.g*. Dar es Salaam, Tanga, Arusha, Morogoro, Mombasa, Nairobi and Southern Sudan; thus the pressure on the fertile cropland for horticultural crops is high.

Table 7.1: Characteristics of the studied villages and the selected farm plots

Village/ Crop	AEZ	Altitude (m a.s.l)	Slope %	Land form	SWC (%)	BD (g cm^{-3})	% clay	% silt	% sand	Soil texture	Soil type (FAO WRB)
Majulai	Dry warm zone										
Onion		1 355-1 401	0.5-1	Valley and toe slopes	30	1.3	32 (27-41)	5 (3–7)	63 (5-70)	Sand clay loam	*Haplic* and *Gleyic Fluvisols & Stagnic Acrisols*
Carrot		1 530-1 719	1-2	Valley and toe slopes	32	1.1	36 (31-45)	10 (8-11)	54 (46-58)	Sand clay loam & Clay	
Potato		1 383-1 633	30-55	Lower slopes	38	1.3	41 (29-57)	9 (7-11)	50 (36-62)	Clay, Sand clay & Sand clay loam	*Chromic Acrisols*
Migambo	Humid cold zone										
Onion		1 572-1 620	1-3	Valley and toe slopes	83	1.3	30 (29-31)	8 (5-11)	63 (60-62)	Sand clay loam	*Mollic Fluvisols*
Carrot		1 603-1 654	0.5-1	Valley	58	0.9	25 (21-32)	15 (9-19)	60 (59-60)	Sandy loam & Sand clay loam	*Mollic Fluvisols*
Potato		1 552-1 576	20-25	Mid and lower slopes	85	1.2	44 (43-45)	10 (9-11)	47 (46-48)	Clay & Sand clay loam	*Haplic Acrisols*

AEZ is agro-ecological zone; SWC is gravimetric soil water content at harvest time; BD is bulk density of the 0 - 5 cm thick top layer

7.2.2 Data collection

In each village 18 farms under *miraba* were selected per crop type. At each farm harvesting was done in a quadrant of 1 m^2 plot which was randomly selected (Plate 7.1). In each village crop samples from 54 quadrants were collected making a total of

108 quadrants from the two villages. Clinging soil particles were removed from roots, bulbs and tubers by washing with clean water. The total dry soil mass was determined after evaporation of the wash water at 75 – 80 ^{0}C and oven-drying overnight at 105 ^{0}C (Isabirye *et al*., 2007). At each sampling quadrants one undisturbed topsoil sample was collected by Kopeck's core rings (100 cm^3) for determination of gravimetric moisture content and bulk density (using oven dry method at 105 ^{0}C).

Plate 7.1: Setting a 1 m x 1 m sampling grid and harvesting of onion from the sampling grid in Majulai village, Lushoto District, Tanzania. Plates by: Mwango, S.B. 05/01/2013

Composite topsoil samples (from 10 subsamples randomly sampled at the farmers' plots at a depth between 0 and 30 cm) were collected for soil fertility analysis. At each sampling point, land use, slope gradient and altitude were recorded and geo-referenced. Soil loss due to crop harvesting was calculated as SLCH per unit of net fresh crop mass i.e. mass-specific SLCH (SLCHspec) and SLCH on an area-unit basis i.e. crop-specific SLCH (SLCHcrop) as defined by Ruysschaert *et al.* (2004).

$$\text{SLCHspec (kg kg}^{-1}) = \frac{M_{ds} + M_{rf}}{M_{crop}} \text{ ……………………………………………………… (1)}$$

Where; M_{ds} is the mass of oven-dry soil (kg), M_{rf} is the mass of rock fragments (kg) = 0, M_{crop} is the net crop mass (kg).

SLCHcrop (Mg ha^{-1} harvest^{-1}) = $SLCH_{spec}$ x M_{cy}.. (2)

Where, M_{cy} (Mg ha^{-1} harvest^{-1}) is the crop yield. Nutrient loss (kg ha^{-1} harvest^{-1}) = Nutrient content (g kg^{-1} soil) x SLCHcrop (Mg ha^{-1} harvest^{-1}) ……......…....… (3)

The nutrient content is expressed on oven-dry soil.

7.2.3 Soil analysis

Soil analysis was done following the laboratory manual of Moberg (2001). Organic carbon was measured using the dichromate oxidation method; total nitrogen by Kjeldahl method; available phosphorus, Ca^{2+} and Mg^{2+} by atomic absorption spectrophotometer, Na^{+} and K^{+} by Flame photometer; pH_{water} was determined by normal laboratory pH meter; bulk density and moisture content by gravimetric method and soil texture by the hydrometer method.

7.2.4 Data analysis

Descriptive statistics of the data was conducted and homogeneity of variances was tested, skewed data were log-normally transformed. Regressions analysis was performed using Minitab 14 software (Minitab, 2004) to detect the relationships between SLCHspec and soil texture, soil water content and bulk density. SLCH variables were subjected to ANOVA using GenStat 14 software (GenStat, 2011) to compare between crops. Least Significant Difference ($LSD_{0.05}$) was used to detect mean differences.

7.3 RESULTS AND DISCUSSION

7.3.1 Characteristics of the selected farm plots in the studied villages

The physiographic properties of farmlands and soil characteristics including the range of soil texture, bulk density, soil types and SWC at the farms during the survey in Majulai and Migambo villages are presented in Table 7.1. It can be seen that in both villages the survey was conducted under *Acrisols* and *Fluvisols* the dominat soil types on slopes and valley bottoms respectively. The higher soil moisture content in Migambo village than in Majulai village was due to heavy rainfall during the survey in Migambo while it was relatively dry in Majulai village. Soil texture did not vary between the two villages but there were slight differences with respect to landform ranging from sandy clay and clay on slopes to sandy clay loam and sandy loam on valley bottoms.

7.3.2 Effect of soil water content, bulk density (BD) and soil texture on SLCH variability

7.3.2.1 Onion

Mean SLCHspec for onion was 0.1 kg kg^{-1} ranging from 0.02 to 0.3 kg kg^{-1} with a median of 0.1 kg kg^{-1} in Majulai. The mean SLCHspec in Migambo was 0.4 kg kg^{-1} ranging from 0.2 to 0.6 kg kg^{-1} and a median of 0.5 kg kg^{-1}. SLCHcrop ranged from 1.0 to 4.0 Mg ha^{-1} $harvest^{-1}$ with average of 2.8 Mg ha^{-1} $harvest^{-1}$ and had a median of 3.0 Mg ha^{-1} $harvest^{-1}$ in Majulai; and ranged from 2.2 to 12.2 Mg ha^{-1} $harvest^{-1}$ with average of 5.2 Mg ha^{-1} $harvest^{-1}$ and a median of 5.1 Mg ha^{-1} $harvest^{-1}$ in Migambo. Bulk density (BD) had positive influence at 5 % level (R^2 = 0.53, $p < 0.03$) on SLCHspec for onion in Majulai whereas in Migambo it had no influence (Table 7.2). Soil texture and soil water content (SWC) at harvest played only a minor role on the variability of SLCH for onion in both villages. The low correlation between SLCHspec with SWC and soil texture is partly due to the small variations of SWC at harvest, sand, clay and silt contents of the farms sampled (Table 7.1).

Table 7.2: Relationship between SLCHspec (Y, kg kg^{-1}) and gravimetric soil water content (SWC, % g g^{-1}) at harvesting time, BD (g cm^{-3}), % clay, % silt and % sand for the studied crops in Majulai and Migambo villages

		Majulai			Migambo		
Measured variable	n	lnY	R^2	p	lnY	R^2	p
Onion							
Clay (%)	18	-0.12-0.64lnX1	0.028	0.67	-1.4 + 0.16lnX1	0.000	0.98
Sand (%)	18	-3.53+0.0189X2	0.043	0.59	-24.8+5.77lnX2	0.224	0.20
Silt (%)	18	-0.82-0.993lnX3	0.249	0.17	0.491-0.709lnX3	0.232	0.19
SWC (%)	18	-1.36-0.0325X4	0.152	0.30	3.0- 0.89lnX4	0.003	0.89
BD (g cc^{-1})	18	-4.75+0.858lnX5	0.526	0.03	-0.073-3.14lnX5	0.156	0.29
Carrot							
Clay (%)	18	3.71-1.36lnX1	0.328	0.11	-9.66+2.69lnX1	0.840	0.001
Sand (%)	18	-3.41+0.0424lnX2	0.329	0.11	205 -50.3lnX2	0.829	0.001
Silt (%)	18	-7.37 + 2.68lnX3	0.435	0.05	2.97-1.5lnX3	0.844	0.000
SWC (%)	18	-1.34+0.0063X4	0.009	0.81	-13.2+3.0lnX4	0.710	0.004
BD (g cm^{-3})	18	-0.963-1.98lnX5	0.174	0.26	-0.656+3.0lnX5	0.844	0.000
Round potato							
Clay (%)	18	-0.80-0.453lnX1	0.148	0.31	3.7-1.66lnX1	0.004	0.87
Sand (%)	18	-3.10+0.0125X2	0.165	0.28	-17.6+3.9lnX2	0.021	0.71
Silt (%)	18	-1.19-0.588lnX3	0.110	0.38	-1.53-0.45lnX3	0.006	0.84
SWC (%)	18	-3.34+0.0232X4	0.107	0.39	-3.4+0.19lnX4	0.000	0.97
BD (g cc^{-1})	18	-1.96-1.80lnX5	0.020	0.72	-2.49-0.29lnX5	0.001	0.93

Where X1, X2, X3, X4 and X5 are % clay, % sand, % silt, % SWC and BD respectively, n is the number of sampled plots in each village

A similar observation was reported by Isabirye *et al*. (2007) and Ruysschaert *et al.* (2004) where small variations in sand and clay contents and SWC that characterized most farms sampled (Table 7.1) were the reason for the poor correlations between SLCH with texture and SWC. When the results from the two villages were combined, the following variations of SLCHspec for onion with respect to SWC, soil texture and bulk density were observed. Soil water content at harvest had positive influence (R^2 = 0.39, p < 0.006) on SLCHspec (Table 7.3), whereas sand, silt, clay and BD had weak correlations with SLCHspec for onion. However, when these factors were combined in multiple regressions they could explain about 79 % of the variations of SLCHspec for onion (Table 7.3).

7.3.2.2 Carrot

Mean SLCHspec for carrot was 0.3 kg kg^{-1} ranging from 0.2 to 0.6 kg kg^{-1} and a median of 0.3 Mg ha^{-1} $harvest^{-1}$ in Majulai, while in Migambo the mean SLCHspec was 0.4 kg kg^{-1} and ranged from 0.2 to 0.8 kg kg^{-1} and a median of 0.3 kg kg^{-1}. SLCHcrop ranged from 4.0 to 13.0 Mg ha^{-1} $harvest^{-1}$ with a mean of 7.0 Mg ha^{-1} $harvest^{-1}$ and a median of 7.0 Mg ha^{-1} $harvest^{-1}$ in Majulai and ranged from 2.8 to 23.0 Mg ha^{-1} $harvest^{-1}$ with a mean of 7.1 Mg ha^{-1} $harvest^{-1}$ and a median of 5.5 Mg ha^{-1} $harvest^{-1}$ in Migambo. Bulk density (R^2 = 0.84, p < 0.001) SWC at (R^2 = 0.71, p < 0.004) and % clay at (R^2 = 0.84, p < 0.001) had positive influences on SLCHspec for carrot whereas % sand at (R^2 = 0.83, p < 0.001) and % silt at (R^2 = 0.84, p < 0.001) had a negative influence in Migambo (Table 7.3); this agreed with studies by Ruysschaert *et al*. (2006) and Ruysschaert *et al*. (2007) where gravimetric soil moisture content and % clay were positively related to SLCHspec.

On the other hand, in Majulai % silt had a positive influence (R^2 = 0.44, p < 0.05) on SLCH while BD, SWC, % clay and % sand had a minor influence. This situation can be explained by the higher SWC at harvesting time in Migambo than in Majulai village (Table 7.1) which facilitated soil to stick on the surface of carrot roots.

Similarly the correlation between SLCHspec and SWC was explained by Isabirye *et al*. (2007) to be influenced by the tendency of moist soil to stick on roots more than dry soil. When results from the two villages were combined. Soil texture SWC and BD revealed weak correlations with SLCHspec for carrot. However, when these factors were combined in multiple regressions they could explain about 79 % of the variations of SLCHspec for carrot (Table 7.3).

Table 7.3: Relationship between SLCHspec (Y, kg kg^{-1}) and gravimetric soil water content (SWC, % g g^{-1}) at harvesting time, BD (g cm^{-3}), % clay, (%) silt and % sand as X variables for the studied villages when combined

Measured variable	n	lnY (*)	R^2	p
Onion				
Clay (%)	36	4.98 – 1.93lnX1	0.079	0.26
Sand (%)	36	-8.9+ 1.73lnX2	0.031	0.49
Silt (%)	36	-2.24 + 0.35lnX3	0.023	0.55
SWC (%)	36	-5.67 + 1.04lnX4	0.390	0.006
BD (g cc^{-1})	36	-1.92+ 1.1lnX5	0.005	0.78
lnY = -1239+115lnX1+193lnX2+14.6lnX3+2.26lnX4+50.7lnX5			0.786	0.001
Carrot				
Clay (%)	36	-1.92 + 0.248lnX1	0.017	0.60
Sand (%)	36	-7.13 + 1.5lnX2	0.085	0.24
Silt (%)	36	0.634 - 0.689lnX3	0.181	0.08
SWC (%)	36	-2.94 + 0.496lnX4	0.129	0.14
BD (g cc^{-1})	36	-1.07 + 0.983lnX5	0.121	0.16
lnY = -122+9.1lnX1+14.7lnX2+9.96lnX3+1.74lnX4+12.2lnX5			0.793	0.001
Round potato				
Clay (%)	36	-0.73– 0.475lnX1	0.047	0.39
Sand (%)	36	-4.67+ 0.561lnX2	0.040	0.42
Silt (%)	36	-1.22 – 0.58lnX3	0.039	0.43
SWC (%)	36	-2.34 - 0.04lnX4	0.001	0.88
BD (g cc^{-1})	36	-2.54 + 0.16lnX5	0.001	0.91
lnY = 23-3.37lnX1-2.6lnX2-1.53lnX3+0.19lnX4-1.09lnX5			0.237	0.61

Where X1, X2, X3, X4 and X5 are % clay, % sand, % silt, % SWC and BD respectively, n is the number of sampled plots in the two villages

7.3.2.3 Potato

Mean SLCHspec for potato was 0.1 kg kg^{-1} and ranged from 0.05 to 0.14 kg kg^{-1} with a median of 0.1 kg kg^{-1} in Majulai; the mean SLCHspec in Migambo was 0.1 kg kg^{-1} and ranged from 0.05 to 0.20 kg kg^{-1} with a median of 0.06 kg kg^{-1}. SLCHcrop ranged from 0.7 to 2.0 Mg ha^{-1} $harvest^{-1}$ with a mean of 1.1 Mg ha^{-1} $harvest^{-1}$ and a median of 1.1 Mg ha^{-1} $harvest^{-1}$ in Majulai and ranged from 0.23 to 1.20 Mg ha^{-1} $harvest^{-1}$ with a mean of 0.5 Mg ha^{-1} $harvest^{-1}$ and a median of 0.5 Mg ha^{-1} $harvest^{-1}$ in Migambo. SLCHspec for potato was not significantly influenced by SWC, BD and soil texture at harvesting time.

7.3.3 Differences in SLCH between crops in Majulai and Migambo villages

From Table 7.4 it can be seen that SLCHspec and SLCHcrop for carrot were significantly ($p < 0.05$) higher for onion and potato. Similarly for crop yields, this followed the same trend. When considering the effect of villages, it is clear that the SLCHspec and SLCHcrop values per harvest for carrot were significantly ($p < 0.05$) higher than for onion and potato in Majulai village, likewise for Migambo village the trend was the same.

The higher values of SLCH variable for carrot can be explained by its rough and kinked morphology, thus more soil is expected to stick on the rougher root skin of carrots compared to the smoother potato tubers and onion bulbs. On the other hand, yield for onion was significantly ($p < 0.05$) higher than for carrot and potato in Majulai village, while in Migambo village yield for carrot was higher than for onion and potato. These differences in trends between the two villages could partly be explained by the variations in crop yields and moisture content at harvesting. It is worth to note that the studied crops are usually cultivated twice a year during long rain season and short rain season.

Table 7.4: Impact of the studied crops on mean crop yield, SLCHspec and SLCHcrop in Majulai and Migambo villages

Treatments	Crops	n	SLCHspec (kg kg^{-1})	SLCHcrop (Mg ha^{-1} $harvest^{-1}$)	Crop yield (Mg ha^{-1}.$harvest^{-1}$)
Crop					
	Onion	36	0.2	3.8	19.2
	Carrot	36	0.3	7.1	20.8
	Potato	36	0.1	0.7	8.7
	LSD ($P \leq 0.05$)		0.1	1.4	1.3
	SE		0.1	1.1	1.1
Crop*Village					
Majulai	Onion	18	0.1	2.8	28.7
	Carrot	18	0.3	7.0	22.1
	Potato	18	0.1	1.1	12.5
	LSD ($P \leq 0.05$)		0.2	1.6	1.5
	SE		0.1	1.2	1.2
Migambo	Onion	18	0.4	5.2	12.9
	Carrot	18	0.4	7.1	19.6
	Potato	18	0.1	0.5	6.1
	LSD ($P \leq 0.05$)		0.2	1.6	1.5
	SE		0.1	1.6	1.5

LSD is least significant difference; SE is the standard error of means; n is the number of sampled plots in each village

7.3.4 Soil nutrient losses associated with SLCH of the studied crops

Soil nutrient losses due to crop harvesting are presented in Table 7.5. Differences in soil nutrient loss between crops and villages can be attributed to the differences in average crop yield (Table 7.4) and the inherent nutrient status of the topsoil (Table 7.6). Generally, nutrient losses were higher in Migambo (humid cold) than in Majulai (dry warm) with the order of magnitude such that OC > Total N > Ca > Mg > K > Na > P. Carrot harvesting had the highest soil nutrient losses (Table 5) where the OC, N, P, K, Ca, Mg and Na losses were respectively 365, 30, 0.1, 2, 19, 4 and 0.7 kg ha^{-1} $harvest^{-1}$ in Majulai and 423, 32, 0.1, 0.8, 16, 3 and 0.4 kg ha^{-1} $harvest^{-1}$ in Migambo village.

Table 7.5: Estimates of soil nutrient loss (kg ha^{-1} harvest^{-1}) and STDEV in brackets for each crop in two villages

Village	Crop	n	OC	Total N	P	K^+	Ca^{2+}	Mg^+	Na^+
Majulai									
	Onion	18	21	6	0.04	0.3	4	1.1	0.2
			(20)	(4)	(0.03)	(0.1)	(1.5)	(0.4)	(0.1)
	Carrot	18	365	30	0.09	1.5	19	3.9	0.7
			(191)	(16)	(0.07)	(0.8)	(12)	(2.2)	(0.3)
	Potato	18	29	3	0.01	0.3	2	0.5	0.1
			(12)	(1)	(0.004)	(0.3)	(0.8)	(0.2)	(0.07)
Migambo									
	Onion	18	134	14	0.06	1.3	10	3.0	0.4
			(101)	(11)	(0.02)	(1.1)	(6.5)	(1.5)	(0.3)
	Carrot	18	423	32	0.07	0.8	16	2.8	0.4
			(113)	(11)	(0.06)	(0.6)	(14)	(2.7)	(0.3)
	Potato	18	21	2	0.003	0.1	1	0.2	0.01
			(11)	(0.9)	(0.002)	(0.8)	(0.6)	(0.1)	(0.007)

n is the number of sampled plots in each villages

Table 7.6: Average topsoil (0 – 30 cm) nutrients status (g kg^{-1}) with STDEV in brackets for the farm plots surveyed

Village	Crop	n	OC	Total N	P	K^+	Ca^{2+}	Mg^+	Na^+
Majulai									
	Onion	18	22	3	0.01	0.1	1.9	0.6	0.03
			(18)	(2)	(0.007)	(0.6)	(1.0)	(0.3)	(0.01)
	Carrot	18	33	3	0.01	0.1	1.6	0.4	0.03
			(17)	(1.5)	(0.007)	(0.06)	(0.9)	(0.2)	(0.01)
	Potato	18	26	2	0.003	0.1	0.9	0.3	0.03
			(12)	(0.5)	(0.001)	(0.05)	(0.7)	(0.1)	(0.01)
Migambo	Onion	18	17.1	2	0.07	0.6	2.9	0.6	0.3
			(7.5)	(1.6)	(0.03)	(0.4)	(1.1)	(0.4)	(0.1)
	Carrot	18	52.3	4	0.004	0.1	1.9	0.4	0.04
			(24.5)	(2)	(0.001)	(0.08)	(1.0)	(0.1)	(0.02)
	Potato	18	31.8	3	0.003	0.2	2.2	0.3	0.02
			(14.3)	(1.4)	(0.001)	(0.1)	(1.0)	(0.2)	(0.01)

n is the number of sampled plots in each village

A study by Msita (2013) in Migambo village West Usambara Mountains reported respectively total N, P and K losses due to interill and rill erosion of about 248, 31 and 3 kg ha^{-1} yr^{-1}. In absolute terms the reported losses in this study particularly of OC, Total N, Ca, Mg and K are alarming. Usually crop residues are left on fields and some farmers replenish their farm plots by adding small doses of urea and di-ammonium phosphate (DAP) (about 10 to 50 kg ha^{-1}) and yet others do not use any fertilizer. However, the magnitude of nutrient losses observed (Table 7.5) is considerable compared to what is being returned to the soil such that with time soils will be depleted and this will pose severe nutrient imbalances.

7.3.5 Soil losses observed in this study as compared to the reported losses due to other soil erosion processes

The observed soil losses in this study when compared to soil losses by other soil erosion processes such as interill, rill and tillage (Table 7.7), it is obvious that the reported losses in the current study should not be underrated. According to severity classes for interill and rill erosion as reported by Turkelboom *et al*. (1999), the soil losses observed in this study i.e. 5.2 for onion and 7.1 Mg ha^{-1} $harvest^{-1}$ for carrot fall under moderate erosion and 1.1 Mg ha^{-1} $harvest^{-1}$ for potato is classified as mild erosion, taking into consideration the two cropping cycles in a year. The current study had relatively low SLCH values when compared with the works by Van Esch (2003) and Ruysschaert *et al*. (2006) in Belgium who reported the mean SLCH of 15.8 Mg ha^{-1} $harvest^{-1}$ for carrot and 3.2 Mg ha^{-1} $harvest^{-1}$ for potato respectively, while in Uganda, Isabirye *et al*. (2007) reported a SLCH of 3.4 Mg ha^{-1} $harvest^{-1}$ for cassava.

Table 7.7: Reported soil losses due to crop harvesting, water and tillage erosion as compared to SLCH in the West Usambara Mountains obtained in this study

Data type	Country	Soil loss $tha^{-1}year^{-1}$	SLCHcrop (Mg ha^{-1} $harvest^{-1}$) (min–max)	Measurement period	Source
SLCH under high-input mechanized agriculture					
Carrot	Belgium		15.8 (0.5–65.5)	2001–2002,	Van Esch (2003)
Carrot	Russia		2.5 (1.8–3.4)	1985	Belotserkovsky and Larionov (1988)
Potato	Belgium		3.2 (0.2–21.4)	2002–2003	Ruysschaert *et al*. (2006)
Potato	Germany		6.7 (1.0–13.4)	1996–2002	Auerswald *et al*. (2006)
SLCH under low-input agriculture					
Cassava	Uganda		3.4 (0.4–25.8)	2002–2003	Isabirye *et al*. (2007)
Sweet potato	Uganda		0.1 (0.0–0.2)	2002	Isabirye *et al*. (2007)
Onion	Tanzania		5.94 (2.2-12.18)	2013	This study
Carrot	Tanzania		9.3 (2.75-22.86)		This study
Potato	Tanzania		1.12 (0.7-2.0)		This study
Water and tillage erosion					
Rill erosion	Tanzania	91 to 258		2000- 2002	Kimaro, *et al*. (2008)
Interill erosion	Tanzania	41 to 115		2000- 2002	Kimaro, *et al*. (2008)
Rill and interill erosion	Tanzania	132		2010- 2012	Msita (2013)
Rill and Interrill erosion	Tanzania	28 to 72		1972	Temple (1972)
Tillage erosion	Tanzania	42 to148 kg m^{-1} y^{-1}		2000-2001	Kimaro *et al.* (2005)
Sheet and rill	Belgium	6.9		1999	Poesen *et al.* (2001)
Tillage	Belgium	8.7		1999	Poesen *et al.* (2001)

Farmers in the West Usambara Mountains usually clean their harvested crops in river streams and transport them to the local and markets in Dar es Salaam, Tanga, Arusha, Morogoro, Mombasa, Nairobi, Southern Sudan and other nearby towns or sometimes harvested crops are stored in farmers' compounds before transportation. Still some farmers do not clean their harvested crops i.e. soon after harvesting the crops with soil particles are packed and transported to the aforementioned markets, thus most of SLCH are dumped in these markets and in river streams when crops are cleaned and some are lost during storage and transportation. Therefore soil and nutrient lost as a result of these kinds of harvesting practices are rarely returned back to the cropland where the crop was grown. On the other hand cleaning of harvested crops in river streams contributes to extra sediment load, and hence pollution of the river water which may cause negative down-stream effects (*e.g*. flooding, siltation in channels and reservoirs).

7.4 CONCLUSIONS AND RECOMMENDATIONS

Significant rates of soil and nutrient losses due to crop harvesting under *miraba* in the West Usambara Mountains were revealed. This calls for the need to include SLCH in soil erosion assessment and mitigation strategies to reduce overall soil loss rates. Soil water content played a significant role on variability of SLCH for onion with minor influence for carrot and potato. Bulk density and soil texture played a minor role in SLCH of the studied crops. Higher SLCH was observed in carrot harvesting followed by onion and potato being the least. Soil losses due to crop harvesting under *miraba* can be reduced by avoiding harvesting of crops when soils are wet and sticky.

Furthermore, farmers should remove as much as possible soil stuck on the harvested crops at their farm plots instead of cleaning them at their homes and river streams as is usually practised in the West Usambara Mountains to avoid losses of soil and nutrients from farm lands and protecting river streams from sedimentation. An easy way to do this is to let the roots or tubers dry for a couple of days in the field prior to transporting them, as when the soil dries most of it will drop out and remain in the field.

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CHAPTER EIGHT

8.0 GENERAL CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

Integration of indigenous SWC technologies with scientific adjustments and improvements provide appropriate solutions for combating the escalating problem of soil degradation and low crop productivity. Previous studies on soil degradation and, in particular, soil erosion control and maintenance of soil fertility did not adequately consider the contribution of indigenous SWC measures which resulted into rejection or minimal adoption of the promoted SWC technologies. The current study was carried out to investigate the potentials and constraints of indigenous SWC measures that are preferred and widely used by smallholder farmers in the West Usambara Mountains, Lushoto District, Tanzania. The main purpose was to enhance knowledge on indigenous SWC measures under smallholder farming conditions for improved crop productivity in the area and other areas with similar agro-ecological conditions. Based on the findings from this study the following conclusions are pertinent:

a) Low soil fertility and spatial variability of soil fertility and crop performance under traditional *miraba* and micro ridges are the major constraints to high crop yields in smallholder farmlands of the West Usambara Mountains.

b) The results also indicate that the roots of Guatemala grass has a higher potential to reduce soil erosion rates by concentrated flow as compared to the roots of Napier grass or Tithonia shrub in the 0 - 0.4 m soil depth. Thus selection and use of appropriate plants for soil erosion control is essential.

c) Even if improved *miraba* were effective in reducing runoff, soil and nutrient losses, but improved *miraba* with either *Tughutu* or Tithonia mulching were by far more effective. Likewise, both improved *miraba* sole and improved *miraba* with Tithonia mulching showed great potential in increasing crop yields, but improved *miraba* with *Tughutu* mulching had better performance. Whereas *Tughutu* mulches had higher potential in soil fertility restoration than Tithonia mulches; and thus improved *miraba* with *Tughutu* mulching was the best SWC measure for improving soil fertility and crop yields.

d) The effectiveness and performance of improved *miraba* was a function of climate. Thus improved *miraba* were more effective in Migambo village which is humid with high and good rainfall distribution than in Majulai village which is dry with low rainfall and long dry spell periods. During dry spells Napier grasses forming *miraba* die out and rejuvenate during rainy seasons thus the formed Napier grass strips become weaker and less effective when compared to Migambo village.

e) Despite the fact that the soils of the West Usambara Mountains are susceptible to erosion as indicated by their very low values of *K* factors and very high rates of soil degradation by water erosion, the *C* and *P* factors indicate that these soils are responsive to soil conservation measures including mulching.

f) Although *miraba* and *miraba* with mulching were effective in reducing soil and nutrient losses, significant rates of soil and nutrient losses under *miraba* that were revealed due to harvesting of root, tuber and bulb crops could frustrate the success of soil conservation efforts that have been achieved. Higher soil loss due to crop harvest (SLCH) was observed in carrot harvesting followed by onion and potato being the least. Soil losses due to crop harvesting can be reduced by avoiding harvesting of crops when soils are wet and sticky.

8.2 Recommendations

The following recommendations are made in the light of gaps revealed from the findings of this study.

a) It is recommended that the spacing of grass bound strips that form *miraba* under smallholder farming condition be reduced to 5 m apart to allow *miraba* form progressive bench terraces and minimise the speed and intensity of runoff and reduce soil and nutrient losses which in turn will also minimise the magnitude of soil fertility and crop performance variability for improved crop yields under *miraba*.

b) The use of *Tughutu* shrub should be strongly promoted for use as mulching materials under *miraba* as the shrub has demonstrated its effectiveness in controlling soil erosion and at the same time improving soil fertility and crop yields. It is strongly recommended also that *Tughutu* shrubs be planted in the borders of the farm plots along the slope for easier their availability. Further research is recommended to investigate the potentials of the mulching materials used in this study and their influence on the production of vegetables such as cabbage, tomatoes, onions and carrots which are widely cultivated in the West Usambara Mountains

c) It is also recommended in dry areas like Majulai village that drought resistant grasses such Guatemala be used for establishing *miraba* since Napier grass which is mostly preferred is sensitive to drought the thing that reduce the effectiveness of *miraba* .

d) Based on the analysis of the root properties of the studied plants, Guatemala grass is strongly recommended for use in controlling the concentrated flow erosion in the study area. Studies are needed to evaluate more plants growing in various habitats for selection of plant species that can effectively control concentrated flow erosion rates.

e) Due to the vulnerability of the West Usambara Mountains to soil degradation, it is recommended not to cultivate in these areas without the use of appropriate SWC measures.

f) Further research is recommended to investigate effectiveness of the studied soil conservation practices at watershed or landscape scale to mitigate river streams flow and sedimentation. Further studies should also be carried out on the scaling up of the application of improved *miraba* in the West Usambara Mountains and in other areas of the country with similar socio-economic and environmental conditions for reduced soil degradation and improved crop productivity

g) Farmers are advised to remove as much as possible within their farmlands soil stuck on the harvested crops instead of cleaning them at their homes and river streams as is usually practiced in the West Usambara Mountains to avoid soil and nutrients losses from farmlands and protecting river streams from pollution and sedimentation. More researches should be carried out to investigate SLCH for other crops in different climatic conditions and soil types to validate further this process under low input farming.

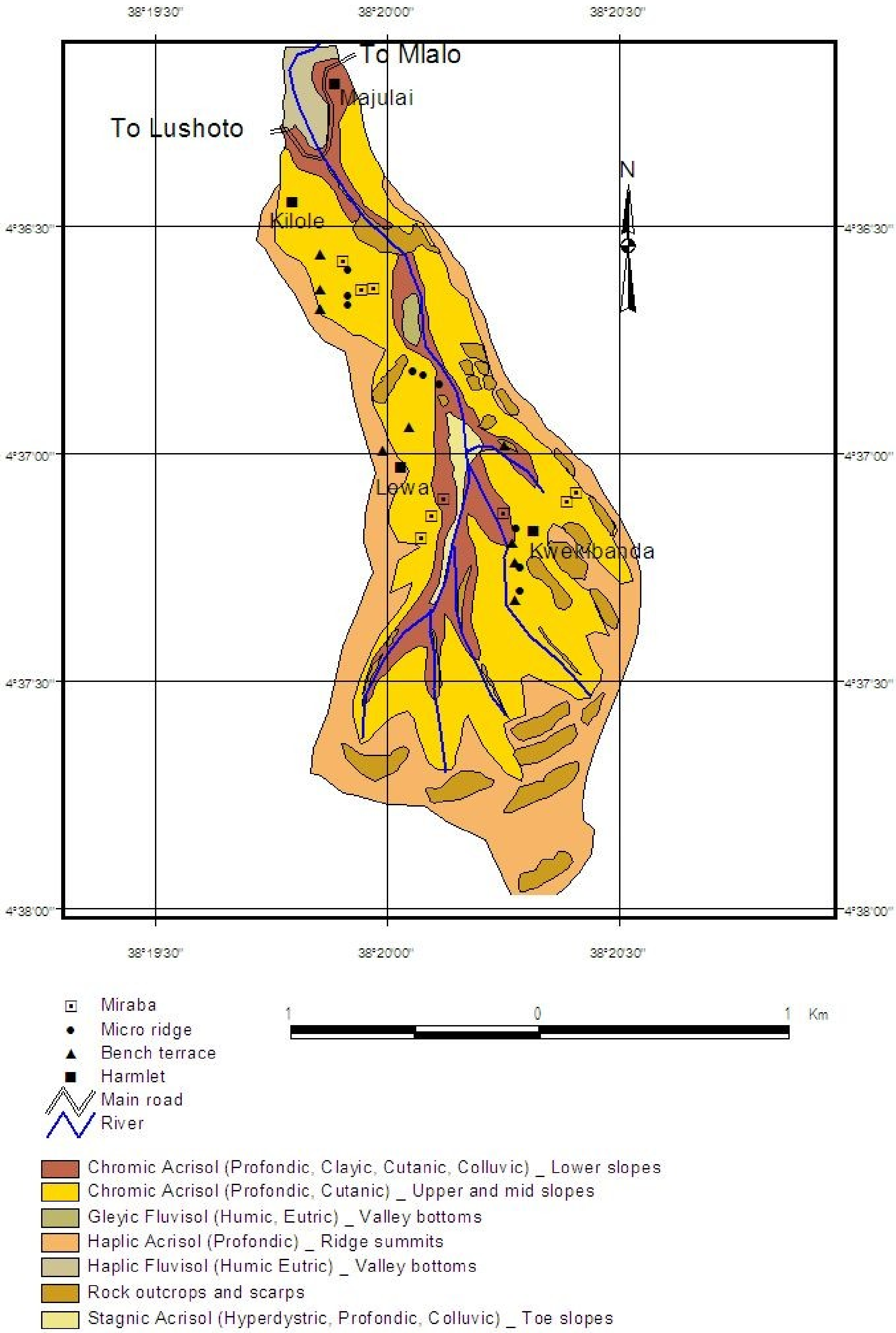
APPENDICES

Appendix 1: Soil and topographical properties at the runoff experimental sites

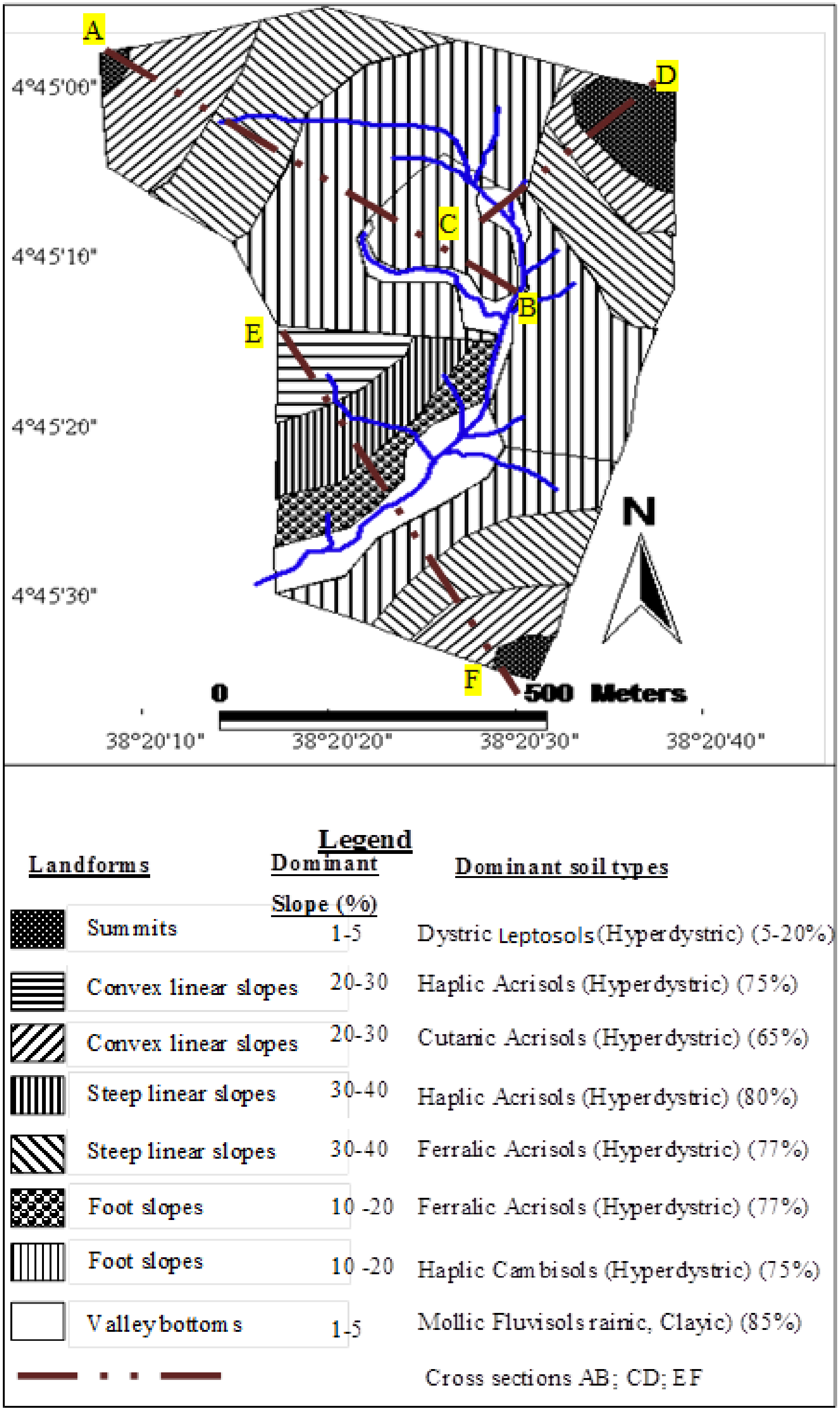
Village	Altitude (m a.s.l.)	Slope (%)	Soil horizon	BD g cm^{-3}	Sand %	Silt %	Clay %	Textural class	AMC %	GMC %
Majulai village	1402	50	Ap	1.14	45	7	48	C	20	52
			Bt1	1.26	31	7	62	C	17	60
			Bt2	1.30	21	15	64	C	16	62
Migambo village	1682	45								
			Ap	1.15	33	14	53	C	19	53
			Bt1	1.28	22	10	66	C	16	61
			Bt2	1.33	12	16	72	C	15	64

BD = Bulk density, AMC = available moisture content, GMC = gravimetric moisture content, m a.s.l. =metres above sea level, C = Clay

Appendix 2: Soil map of Majulai watershed



Appendix 3: Soil map of Migambo watershed



Soil map of Migambo watershed with Migambo River in blue colour. Source: Kyaruzi (2013).