MAKERERE UNIVERSITY

SOIL, RUNOFF AND NUTRIENT LOSSES UNDER MAIZE AND BANANA CROPPING SYSTEMS IN THE LWIRO MICROCATCHMENT, DRC

BY

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DECLARATION

I **ADIDJA MATABARO**, hereby declare that this is my original research work and it has never been submitted to any institution for any award.

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DEDICATION

I would like to dedicate this work to my parents; Bihinda Matabaro Francois and Nabarungu Ganywamululu Euphrasie.

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LIST OF ABBREVIATIONS AND ACRONYMS

D.R.C: Democratic Republic of Congo

FAO: Food and Agriculture Organization of the United Nations

FGDs: Focused Group Discussions

GPS: Global Positioning System

HH: Households

NGOs: Non-Governmental Organizations

%: Percentage

PRA: Participatory Rural Appraisal

SPSS: Statistical Package for Social Scientists

CRSN: Centre de Recherche en Sciences Naturelles

ABSTRACT

This study was carried out with the following objectives i) to characterise the cropping systems; ii) to identify existing soil and water conservation practices in the Lake Kivu basin and iii) to determine the magnitude of soil, runoff and nutrient losses from Maize and Banana based cropping systems in Lwiro micro catchment in the Lake Kivu basin. Characterisation of the cropping systems and the identification of existing soil and water conservation in the Lake Kivu were done using households and key-informants interviews and focus group discussion. Soil, runoff and nutrient losses were determined using runoff plot approach. Instrumentalised runoff plots of 2X15m were installed on maize intercropped with beans and banana gardens. Two soil erosion management practices, namely; *Tithonia* and contour bunds were tested on Maize intercrop with Beans and mulch for Banana. The experiment included a control practice for each crop. Each treatment and control was replicated four times. Runoff and soil loss were estimated for each rainfall event and aggregated on seasonal basis. Nutrient (N, P and K) losses were estimated per season. The major cropping systems included the banana, maize and cassava based cropping systems. The dominant features are small holding, rainfed and limited inputs. The major soil and water conservation practices used in the Lake Kivu included: mulch under banana; agroforestry, contour bunds, *Tithonia* and *tripsacum* under annuals. Results of the long and short rains of the first year of experimentation show that soil and runoff losses did not significantly change with practices and seasons ($P>0.05$) for both banana and maize based systems. Soil and runoff losses ranged from 15.73 to 32.93 t/ha, and from 168.14 to 322.17 m^3; respectively. Nutrient losses varied with practices and seasons ($P<0.05$) and ranged from 54.68 to 112.34 Kg/ha, 87.7 to 409.4 Kg/ha; 24.5 to 94.22 Kg/ha for K, N and P; respectively. Soil and runoff losses ranged from 8.99 to 20.6 t/ha, and from 85 to 152 m^3; respectively. Only K losses changed significantly with season ($P<0.05$) and ranged from 17.8 to 53.9 Kg/ha under Banana cropping system.

Key words: Land degradation, Lake Kivu Basin, pollution loading, Bukavu, D.R. Congo

CHAPTER ONE: INTRODUCTION

1.1 Background

Soil erosion is widespread and varies in magnitude from place to place depending on the land-use system, population pressure, community wealth, management, relief, and vulnerability of the soil to climate aggressivity (Majaliwa *et al.*, 2009). In DRC, and particularly in Kivu mountain areas, soil erosion is believed to be one of the major processes of soil degradation (Majaliwa *et al.*, 2009). The latter is reported to have reached catastrophic proportions on agricultural lands in the Kivu mountainous region (Majaliwa *et al.*, 2009; Tenywa *et al.*, 2010).

Subsequently, the region is threatened by famine and food insecurity, it is reported that 70% of the population is affected by food insecurity (Leonce, 2004). Yet, the region has a great agricultural potential. Under rain-fed conditions, DRC can feed more than two billion people and 50% of its agricultural potential is located in the great Kivu region (Sud-Kivu, Maniema and Nord-Kivu). This situation is likely to exacerbate and reinforce the cycle of poverty-poor management- natural resources degradation (GTZ, 1995). On the other hand, soil erosion in the Kivu mountain region contribute to increased pollution loading into Lake Kivu, one of the deadly Lakes in the world. The Lake has reached critical concentration of CH_4 and CO_2 which can lead to an increased instability of the Lake which can trigger an explosion if any action is not taken to control the flow of carbon into the water bodies (Cohen *et al.*, 1993; Cohen, 1995; Donohue, Verheyen & Irvine, 2003). Lake Kivu is critical for the survival of millions of people around its basin and beyond (Alin *et al.*, 2002). It is a biodiversity hotspot area (Halbwachs *et al.*, 2002), and a source of protein and income for communities around it.

Although soil erosion is considered to be a major cause of land degradation in Kivu mountain region, very few studies have been conducted in the region to determine its magnitude and evaluate practices currently used for its control. Limited studies were conducted during the colonial time and in the 80s (Ischebeck *et al.*, 1984), and in Rwanda (Lewis, 1988; Moeyerson *et al.*, 1989; 2004).

1.2 Problem statement

Farmers in Lake Kivu basin complain about reduction of crop productivity leading to reduced income, increased famine and poverty at the household level (Vlassenroot *et al.*, 2003; Ulimwengu *et al.*, 2009). Crop productivity decline is attributed to decreased soil fertility, use of low yielding and low stress tolerance crop varieties, increasing pests and diseases, inappropriate farming practices and increased soil erosion. There are increasing indicators of soil erosion the Lake Kivu basin, and it is believed to be the most important cause of the reduction of productivity in the basin (Majaliwa *et al*., 2009). Indeed, several studies in the basin have observed an increment in sediment concentration in the major rivers connected to agricultural land (Muvundja *et al.*, 2012; Zirirane, 2012). In addition to the on-site agricultural losses, sediment and other pollutants loading into the surface waters could contribute to reduced biodiversity and decreased water quality, transport disruption on the lake, increase in the treatment cost of water, fish and human intoxication, change in livelihood activities and $C0_2$ increase in the Lake. The increased $C0_2$ and CH_4 amount in the lake lead to its instability and risk of explosion of the accumulated methane gas explosion.

Soil erosion has been observed in the past decade in most part of the agriculture area in the Kivu Mountain where approximately 85 % of the people rely on agriculture as their principal livelihood activity (Ischebeck *et al*,, 1984). In quasi-similar environmental conditions Moeyerson *et al.* (2004) observed soil erosion of the magnitude of 1 to 143 t/ha (Lewis, 1988) in Rwanda. However, very few soil erosion measurements have been done in the Kivu region. This information is necessary for designing appropriate on-farm to Lake basin wide soil erosion and pollution control strategy.

1.3 Objectives of the study

The main objective of this study was to determine soil, runoff and nutrient losses under maize and banana cropping systems in the Lake Kivu basin in Eastern DRC and contribute to pollution loading abatement in the Lake Kivu basin. Two specific objectives were stated, notably:

(i) To characterize the cropping system in the Lake Kivu basin

(ii) To identify the existing soil erosion management practices under maize and banana cropping systems in the Lake Kivu basin;

(iii) To determine the magnitude of soil, runoff and nutrient losses under these cropping systems in Lwiro micro-catchment.

1.4 Hypothesis

- There is no significant difference in the performance of the existing soil erosion management practices in Lake Kivu basin.

1.5 Significance and justification of the study

Information generated in this study can be included in the Lake Kivu and Lake Tanganyika database. This information can be used also to calibrate and validate soil erosion, hydrological and sedimentation models within the both lakes basins. It is a key in designing appropriate soil erosion and water pollution reduction strategy at all levels (on-farm to Lake Basin level). It can be used as baseline to assess the efficiency of studied soil and water conservation practices in the region, hence help policy makers to take good decisions on the type of practices to promote and farmers to be aware and able to choose good management practices.

1.6 Conceptual framework

Soil, runoff and nutrient losses are influenced by soil type, slope steepness, land use management and climate (rainfall). The selection of best practices will lead to improved crop productivity and people livelihood and protection of the Lake Kivu waters.

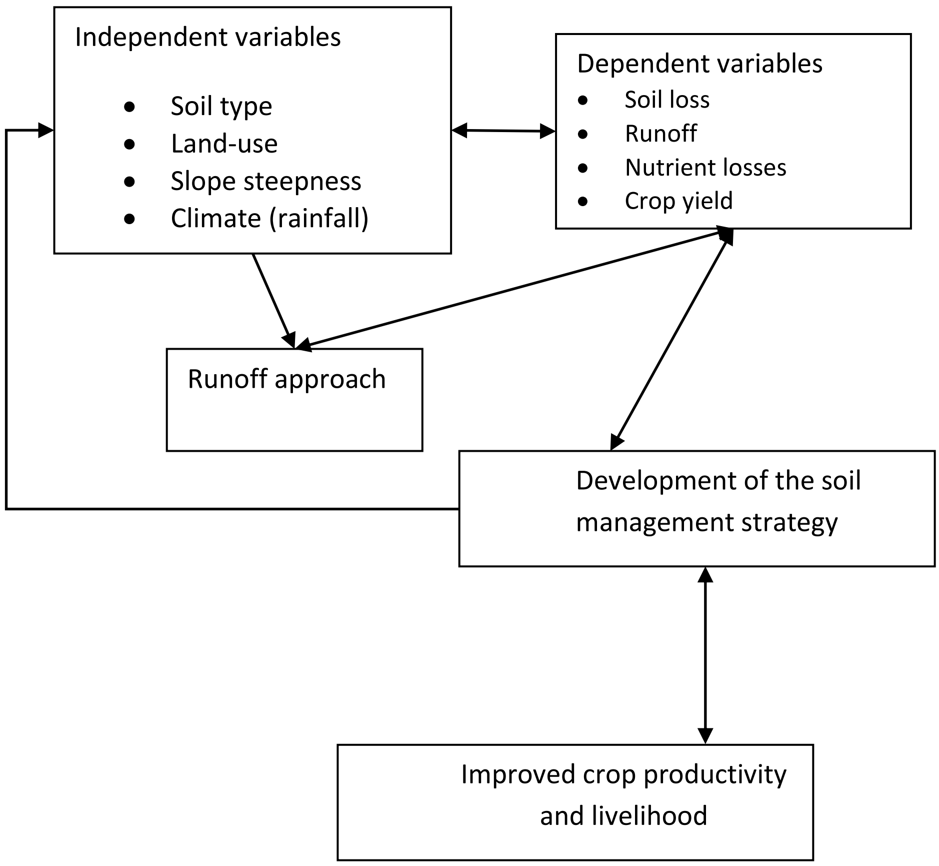

Figure 1: Conceptual framework used in this study. Where are the operational terms?

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The literature on soil loss/ erosion is scarce and the available one is often limited in terms of regional coverage, scale, land use types, as well as its onsite and offsite impacts (Bagoora, 1988; Magunda *et al.,* 1999; Gobin *et al.,* 2004). The reason for the paucity of data on soil loss/erosion and related aspects is attributed to several factors including lack of technical know-how, equipment and resources (Morgan, 1986; Duma and Monde, 2000). Much of the literature in Africa is from Eastern and Western Africa (Tenywa, 1994; Majaliwa, 1998; Rose, 1998; Magunda and Majaliwa, 2002; Lufafa *et al.,* 2002; Majaliwa, 2004; Mulebeke, 2003).

In Eastern DRC, much of available literature on soil loss/erosion is on gullies in the Bukavu region (Moyersons et al., 2004), few focuses on the causes of soil erosion and its control. The little work involving soil erosion measurement was done at the catchment outlet without plot measurements (Azanga, 2013). No study was conducted to assess soil erosion from different land uses, soil type and slope position. However, soil erosion by water remains one of the major environmental problems in Eastern DRC in general and Lake Kivu in particular (Majaliwa, 2008). A better understanding of soil erosion processes, factors governing them, and its relationship with on site and off site degradative processes is a key to its control and sustainability of both land and water resources (Majaliwa, 2004).

2.2 Soil erosion processes

Water erosion starts with detachment of soil particles by the impact of raindrop on the soil surface. The proportion of detached sediment, which will be eroded, depends on the availability of overland flow with sufficient momentum for its transport. Overland flow or runoff is that excess water accumulating on the soil surface, and fill the soil surface depressions, when rainfall intensity exceeds the infiltration rate into the soil or the soil has been saturated (Horton, 1933; Dunne, 1978; Levy *et al.*, 1994). According to the way soil particles are removed and the source of the sediment soil erosion is classified as sheet, interrill, rill or gully erosion (Toy et al., 2002).

Due to spatial variability in soil resistance to water movement, accumulation of overland flow may create small rivulet called rills. Detachment and transport of soil material in between two rills is called interrill erosion (Foster and Meyer, 1975). Interrill areas are defined such that all detachment that occurs on these areas is by raindrop impact. The process and rate of interrill erosion are complex and vary with rainfall intensity, raindrop size and soil properties (Bryan, 1987), however the detachment capacity of interrill flow is small because of its low velocity.

Rill erosion occurs when the soil particles are removed from the bottom and/or the side very small intermittent channels (50-200 mm wide) where there is accumulation of overland flow (Foster, 1990). The latter is the dominant detaching and transporting agent. Erosion processes in rills depend on the runoff and sediment delivered to them from the interrill areas (Foster, 1990). Rills develop when the scouring power of the overland flow exceeds the shear resistance of the soil. Styczen and Nielsen (1989) distinguish five main phases in the rill erosion process: rill initiation/development of protorills, headcut erosion, addition of interrill materials, tail erosion, and wall collapse. As interrill erosion, numerous empirical and physical based models are used to quantify rill erosion. It is worthwhile to note that on a garden soil is lost through rill, interrill or sheet erosion. At a bigger scale, mass movement, creep or landslide can also lose soil.

Gully erosion is often an advanced stage of rill erosion. The rate of gully erosion on the overland flow producing characteristics of the slope, the drainage area, soil characteristics, the alignment, size and shape of the gully, the slope in the channel, and the vegetation (Desta and Adugna, 2010; Adugna; 2012). Four stages of gully development are generally recognized (Glenn et al., 1981): channel erosion, headward growth, gradation of the channel, and stabilisation. As ephemeral gully erosion processes are similar to those in rills except the magnitude. In Lake Kivu basin around Bukavu area accelerated landsliding and sudden gully development also occur (Moeyersons et al., 2004). In many districts, houses have to be constantly rebuilt, roads are generally in poor condition, and waterworks and the sewerage systems are frequently disrupted. Many landscapes are shaped in such a way that runoff is collected in a few major natural waterways, called ephemeral gullies, before leaving the watershed (Foster and Lane, 1983).

2.3 Factors controlling erosion by water

The factors controlling soil erosion are of two orders: the state of biophysical environment and man action or factor controlling his action.

2.3.1 State of the biophysical environment

Biophysical factors controlling soil erosion by water are well documented and have been inspired by the historical report from Wischmeier experiments in USA (Wischmeier *et al.*, 1958; Thornes, 1990; Rickson and Morgan, 1995). They include rainfall regime, vegetation cover, soil type and topography.

a) Rainfall regime: Soil loss is related to the rainfall regime through the energy of drops and the contribution of runoff in soil detachment. The rainfall type, amount and intensity are the major important factors affecting the erosivity of rains (Laws and Parsons, 1943; Mason and Andrews, 1960; Braud and Flyod, 1974). Erosivity of rainfall is a function of rainfall intensity and duration, and the mass, diameter, and velocity of raindrops (Mohamed et al., 2011; Ghosh and Tithi Maji, 2011).

Acording to Morgan (1986) and Thomas (1997) erosivity of runoff is a function of its volume and rate. They are influenced by rainfall, infiltration, ground cover and surface roughness. High intensity and long duration- low intensity rainfall cause infiltration to exceed capacity, leading to increase in volume and velocity of run-off (Thomas, 1997). Foster *et al.* (1982) found that the average soil loss rate per unit of rainfall is directly proportional to the intensity of the storm. Different land uses have different thresholds for surface runoff and sediment transport (Rydgren, 1992). Cultivated land and grazing land have rainfall intensity threshold of 15 mmh^{-1} and 3-5 mmh^{-1}; respectively.

b) Vegetation cover: The most important role played by vegetation cover is to reduce on the energy of raindrop through raindrop size fragmentation (Morgan, 1986). Vegetation may also provide mechanical protection against overland flow detachment (Franti *et al.*, 1996). The effect of vegetation cover on erosion processes by water is well illustrated by the mosquito gauze experiment in Zimbabwe (Hudson, 1981) and confirmed latter by Zanchi (1983). The effectiveness of cover depends on type, extent, quality of cover as well as its seasonal variability (Dilshad et al,. 1994; Silbum *et al.* 1992). Several others (Lufafa *et al.*, 2002; Majaliwa, 2004; Mulebeke, Kizza et al, 2013; Gabiri, 2013) have demonstrated that different cover types have different responses to rainfall amount and intensity in the Lake Victoria.

They also observed that long rainy season tended to have high soil and runoff losses than short rains. Kizza *et al.* (2013) observed that different forest recovery gradient responded differently to rainfall in Mabira forest reserve in central Uganda. Similar observations were made earlier by Stocking (1984). A study by Nakileza (1992) on the slopes of Mt. Elgon reports a high correlation (r = 0.64) between soil loss and change in crop cover, while Frielinghaus *et al.* (2001) observed sufficient soil protection with 2 tha-1 ground cover and 30-50% canopy cover. This efficiency depends on the stage of crop growth (Morgan, 1995) and the proportion of exposed bare ground (Wischmeier and Smith, 1978; Hudson, 1981; Torri and Poesen, 1994).

c) Soil type: Different soil types exhibit different inherent soil properties; which infer different erodibility (Wischmeier and Mannering, 1967; Le Bissonnais and Singer, 1993). According to Lal (1985), soil erodibility refers to the degree of resistance of soil material to be detached and transported. It depends on texture, aggregate stability, shear strength, infiltration capacity, organic matter content, chemical content (Morgan, 1986; Kinnell, 2002); type of clay minerals and depth of impervious layer (Thomas, 1997; Barrow, 1991; Troeh *et al.*, 1999).

d) Topography: The effects of topography on the rate of erosion increase with steepness and the length of the slope as a result of increasing runoff momentum (Hudson, 1981). The relationship between slope length and soil loss has been studied from field or laboratory for a long time (Wischmeier and Smith, 1958). Many studies show that soil loss is proportional to the product of power functions of slope steepness and length (Zingg, 1940; Kirkby, 1969). Tukahirwa’s work (1996) in Kabale soil losses of 1.4 and 30-t ha-1 yr-1 were recorded on slopes of 10% and 20% ; respectively. For tropical regions, the effect of slope length seems to be strong due to the nature of rains which are heavy (Lattanzi *et al.*, 1974; Hudson 1981; Tukahirwa, 1996; and Tenywa *et al.*, 1999). Slope gradient is another topographical factor affecting soil loss. Most studies have shown that the relationship between soil losses to gradient may be expressed as some exponential function or quadratic polynomial (Zingg, 1940; Musgrave, 1947; Wischmeier and Smith, 1965; McCool *et al.*, 1987). In soil erosion studies, these factors are considered as very independent. However, it seems to be evident that the interaction between these factors may have short to long-term effects on soil erosion.

2.3.2 Factors controlling human action

The current acceleration of soil erosion is due to the disturbance of the land-vegetation-climate equilibrium mainly because of the human activities (Cooke and Doornkamp, 1990). It is this form of induced erosion, which is one of the major environmental problems facing the humankind today (Lal, 1988).

Many interrelated factors are responsible for the human-induced erosion on agricultural and grazing land. In the tropics, where most of the developing countries are located, underlying factors are socio-economic, policy and political in nature (Lal, 1990; Rubahaiyo, 1991; Hudson and Rodney, 1993; Hudson, 1996; Nill *et al.*, 1996; Sanchez *et al.*, 1997; Odongo and Wasiko, 1999). They include poverty (income), population pressure, poor conservation policy and laws, land tenure, limited access to the markets and credit, and limited farmer knowledge of appropriate technologies (Pender *et al.*, 1998). Lack of capital undermines farmers' ability to invest in soil erosion conservation techniques. Poverty coupled with population pressure can also push people to cultivate on marginal land (Magunda and Majaliwa, 2002), which are steeper and shallow, more drought-prone, or extremely subjected to waterlogging and salinity (Pereira, 1981). Apart from the above horizontal expansion of agricultural land, which occurs where there is enough land available, population pressure may lead to overexploitation of land, land fragmentation, decline fallow and extension of farming or grazing activities (Magunda and Majaliwa, 2002).

Poor conservation policy and laws regulating the use of land may prevent farmers from applying soil conservation practices (UNEP, 2012). In several of sub-saharan Africa countries SWC was perceived as a symbol of colonial oppression and was rejected as part of a colonial legacy (Erickson, 1992; SIDA, 1993; Moeyersons, 2004). In Uganda, conservation policies were weakened after break down in administrative structures due to political turmoil (Zake, 1992). In addition, other statutory laws and formal and informal community rules, norms, or ideas can facilitate or impeding adoption of conservation technology (IFPRI, 1998). IFPRI cites from example Erenstein and Cadena (1997), partially attributed the adoption of conservation tillage in Chiapas to a law prohibiting the burning of crop residues.

Insecure land rights create little incentive to farmers to invest in land improvement. In Uganda, there are mixed reports on the impact of land tenure on land management. Land in DRC belongs to the state. Although the formal law applies to all land in DRC, it is more applicable to urban areas and large holdings of productive land in rural areas. In most rural areas, customary law governs. Under customary law, groups and clans hold land collectively, and traditional leaders allocate user rights to parcels. Community members have the authority to loan, lease for cash, or sharecrop of their individualized plots of communal land, but in most areas they cannot sell or permanently alienate the communal land to people outside the community. As areas have become commercialized, the prohibition against the sale of land to outsiders has relaxed (GODRC Constitution 2005; Musafiri 2008; Leisz 1998; Vlassenroot and Huggins 2005). Mugerwa (1995) and Roth et al. (1994) reported low farmers' incentives to invest due to land tenure insecurity; while Bashaara (2001) found the actual law was protective enough and no investment on the land could be more associated with lack of funds. Bashaara findings corroborate earlier observations by MISR/LTC (1989) showing that land tenure insecure farmers did more investment than their counterparts.

2.4. Soil erosion in the Lake Kivu basin

Many researchers believe that soil erosion is a widespread and the most important form of soil degradation in Eastern of DRC (Majaliwa, 2008; Azanga, 2013). From the few surveys and observations, in different parts of Eastern DRC soil loss varied from place to place, and depends on climate, soils, land-use and management, and topography (Ischebeck *et al.*, 1984; Mwadi, 2008; Adidja, 2009; Biragi, 2010).

Highlands are the most vulnerable regions in Eastern DRC. Studies in Uganda also show that soil loss ranges from 10 to 129 t/ha/yr on highlands (Sperow and Keefer, 1975; Tukahirwa, 1996; Bagoora, 1997; Majaliwa, 2004). These include Kabale, Kisoro, Bundibugyo, Mbale and Kapchorwa. Semi-arid areas such as Rakai district, Soroti, North Luwero are not the least affected areas because of their fragile vegetation cover, extensive grazing, and unusual heavy rains (Zake, 1993; Majaliwa, 2004).

Banana and coffee land uses suffer moderate soil loss while annuals are subjected to severe to high soil loss (Tukahirwa, 1996; Bagoora, 1997; Majaliwa, 1998; Lufafa et al., 2002). Precipitation losses through runoff are also high (Majaliwa *et al.*, 2002). Sperow and Keefer (1975) recorded soil losses and runoff losses of 34.0 t/ha/season and 23.4 % under maize, 26.6 t/ha/season and 19.9% under cowpea, 26.6 t/ha/season and 5.3% under Rhodes grass, and 0.1 t/ha/season and 0.5% for undisturbed veld. Majaliwa *et al*. (2002) observed runoff losses from maize and maize-beans intercropped ranging between 45 to 90 t/ha. Cropping and management practices were found to have a significant effect on reducing soil loss in Mount Elgon slopes (Nakileza, 1992).

2.5. Impact of soil erosion

The impacts of soil erosion are categorised as on-site and off-site. On-site erosion includes soil, runoff and nutrient losses, and yield decline; while off-site impacts of soil erosion are lowland siltation and pollution loading of watercourses.

2.5.1. On-site impact of soil erosion

Soil and associated nutrient losses

Several studies have shown that soil erosion removes alarming quantities of nutrients, especially in sub-saharan Africa (Lal 1976; 1995; Kowal, 1972; Sanchez *et al.*, 1995; Majaliwa, 2004; Mulebeke, 2003; Kizza et al., 2013; Gabiri et al., 2013). The magnitude of nutrient losses depends on the type of nutrient, land use and management, soil type, topography and climate. Lal (1976) reported K losses ranging from 0.1 to 13.4 Kg.ha $^{-1}$. season $^{-1}$, Ca from 0 to 4.2 Kg.ha $^{-1}$. season $^{-1}$. P measured from runoff plots in tropical regions may be as low as 0 to 2.0 Kg.ha $^{-1}$. season $^{-1}$. Roose (cited in FAO, 1994) reported losses of 98 Kg/ha/yr of nitrogen, 29 Kg/ha/yr for phosphorus, 39 Kg/ha/yr of lime and 39 Kg/ha/yr of magnesium from soils of Ivory Coast as a result of erosion. Majaliwa (2004) reported nitrogen losses ranging from 76 to 312 Kg/ha/season; while phosphorus losses ranged from 2 to 27 Kg/ha/season with the highest under annuals and the lowest under coffee in the Lake Victoria Basin. Kizza *et al* (2013) found nitrogen losses ranging from 0.11 to 5.36; phosphorus losses ranging from 0.01 to 0.3 and K losses ranging from 0.33 to 39.81 Kg/ha/season under different forests recovery gradient in Uganda. In Ugandan highlands, the estimated rate of nutrient losses have reached 85 kg of N, P2O5, and K2O per hectare of arable land per year (Storvoogel and Smaling, 1997) and is basically due to inappropriate or poor farming practices (Zake *et al.*, 1997; Walaga *et al.*, 1999). Soil erosion also contributes to loss of organic matter affecting several soil properties including aggregate stability, infiltration and aeration rates, soil tilth, microbial activity, and it is part of the cation exchange complex. Soil carbon content is closely correlated with soil shear strength and cohesion (Lal, 1991; Kaihura *et* al., 1998; Troeh *et al.*, 1999; Boye and Albrecht, 2001), properties which are vital in the soils ability to resist erosion. Soil loss amounting to 50 t $ha^{-1}yr^{-1}$ may cause up to 1 t ha-1 carbon loss and it is predicted to reduce carbon content by 1/3 in 10 years (Young, 1997). Several scholars (e.g. Norse and Saigal, 1993; Gachene, *et al.*, 1997) reported that eroded sediment are relatively enriched compared to soils left behind.

In addition, more nutrients can also be lost through runoff losses. Zobisch *et al.* (1995) reported 52 kg/ha combined phosphorus and potassium loss in runoff in a bare fallow at the Kabete Steep Lands Research Station, Nairobi, Kenya.

Soil productivity decline

The magnitude of soil and nutrient losses, soil organic matter decline and selective removal of clay particles contribute significantly to soil productivity decline (Larson, 1986; Heimlich, 1991; Zake and Nkwiine, 1995; Tenywa *et al.*, 1999). The effect of soil loss/depth reduction and nutrient losses to crop production is illustrated by artificial erosion experiment (Lal, 1976; Rehm, 1978; Mbagwu, 1984; Gollany *et al.*, 1992). Maize yield reduction of 73% was observed on Alfisols in Africa after removing the 10 cm topsoil (Lal, 1987). Marsh (1971) reported yield declines of 3 to 7.5 % after 1 mm of soil loss and declines of 10 to 25% after 8 mm of soil loss. Mbagwu *et al.* (1984) observed that a 5, 10 and 20 cm top soil depth reduction translated to 95, 95, 100% maize yield reduction on Ultisols and 31, 74 , 94% yield reduction, respectively, on Alfisols in Nigeria. Gollany *et al.* (1992) observed exponential yield decline after removal of 0 to 45 cm of soil in Dehra Dun, India. Fulipovic (1983) reported that erosion rates of 77 to 216 t/ha/yr resulted in yield decline of 50 to 70%. It is important to note that the type of soil, topography and climate can contribute significantly to the loss of productivity. For certain volcanic and loessial soils, there is uniformity of soil properties up to great depths in the profile. In such soils, several cm of topsoil loss will have little or no effect on crop yield (Lal, 1987). But on shallow and infertile tropical soils, productivity may decline more rapidly than in similar temperate soils (Lal, 1983; Lal, 1987).

2.5.2. Off-site impact of soil erosion

Off-site impacts of soil erosion have been documented by several authors (Rose and Dalal, 1988; Rose *et al.*, 1991; Lehman and Branstrator, 1993). These include deterioration in the quality of freshwaters (rivers and Lakes water) due to the suspended load from terrestrial catchment. Suspended load includes organic matter (a threat to the oxygen essential to river fauna), as well as nitrogen and phosphorus (from mineral fertilizers used by farmers), which can accelerate the eutrophication of the freshwaters including proliferation of algae which will in turn asphyxiate the fish. Peak flood sediment loads also cause damage, leaving torrential mud flows at the bottom of fields, in ditches, on roads and in cellars. Once the peak flood is over, considerable amounts of sediment are deposited in lakes, rivers, canals and harbours.

2.6. Existing soil and water conservation practices in eastern region

Land use management is recognised as a key indicator of actual erosion risk (Frielinghaus et al, 2001; Magunda and Tenywa, 2001). Farmers often apply management practices irrespective of soil and landscape characteristics, resulting in inappropriate and inadequate erosion control. A variety of soil and water management have been identified in the east African region including mechanical and biological technologies (Magunda and Tenywa, 2001; Mati, 2005). These include mulch, contour bunds, terraces, trash stones and agroforestry. The importance of mulches in reducing surface runoff, soil erosion and evaporation losses cannot be overstated (Liniger, 1991; Okwach, 2000). However, the type and amount of vegetation cover, which is a function of management, determine soil loss rates. Throuw *et al.* (1988) noted significant decreases in erosion as grasses in the rangeland changed from short-medium-tall. A 50 to 75% cover is known to sufficiently protect soil from erosion. Cover levels of 20% were reported to be efficient in controlling soil loss in Kenya (Moore, 1979). Majaliwa (2004) observed that contour bunds only significantly reduced soil loss from annuals, banana, rangelands, and coffee after 3 years. Results from studies have shown substantial increases in yield on land with "fanya juu" terraces compared to non-terraced land (Ngigi, 2003)

Agroforestry trees provide nutrient inputs to crops by capturing nutrients from atmospheric deposition, biological nitrogen fixation, tapping nutrients from deep in the subsoil and storing them in the bio-mass (Sanchez *et al.* 1997). Trees also enhance nutrient cycling through conversion of soil organic matter into available nutrients (especially nitrogen and phosphorus) (Biamah and Rockström 2000; Muzzora et al, 2011).

CHAPTER THREE: METHODOLOGY

3.1 Description of the study site

This study was conducted in the River Lwiro micro-catchment within Lake Kivu Basin. The River Lwiro is located on the eastern flank of Lake Kivu between latitudes 2°15' and 2°30' S and longitudes 28°45' and 28°85' E. Its headwaters are in the Kahuzi-Biega National Park mountain region; at an altitude of 2000 m. The 84 km^2 river basin is bordered on the east by Lake Kivu and on the west by the Kahuzi mountain forest (Figure 2). This watershed of Lwiro river, the principal tributary of the Lake Kivu, covered 4 localities namely Irhambi/Katana, Bugorhe, Luhihi and Bushumba in the territory of Kabare, province of South-Kivu, Democratic Republic of Congo. Annual rainfall varies between 1134 mm and 1689 mm with an average of 1411 mm (Figure 3). The rainfall is bimodal with a dry season from June and July (Figure 4). The soil comprises of clay and rich volcanic soil, which is easily eroded. The geological composition is of Precambrian metamorphoses sediments (metamorphic rocks) and Preterozoic platform sediments (Cahen and Lepersonne, 1967). Verhaeghe (1964) describes metamorphic limestone and numerous travertines along Lake Kivu and Lake Edward. Carbonates for the production of cement are also found north and north-west of Lake Kivu.

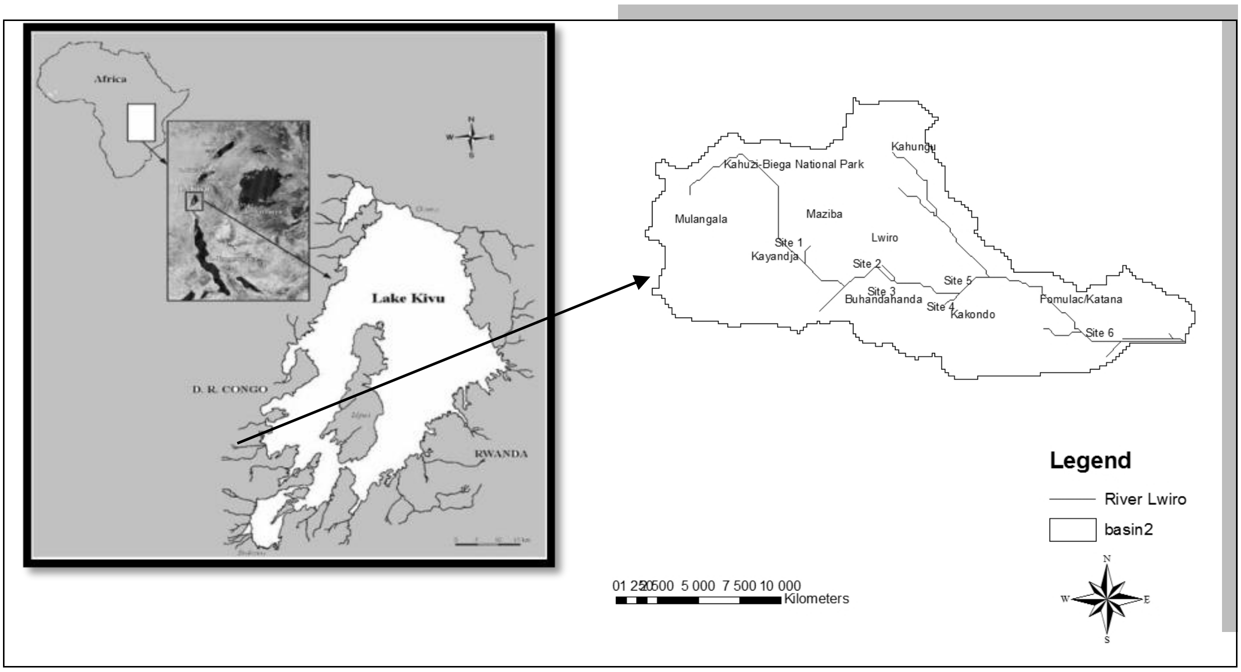

Figure 2: Lwiro micro-catchment and the main rivers, Lake Kivu basin

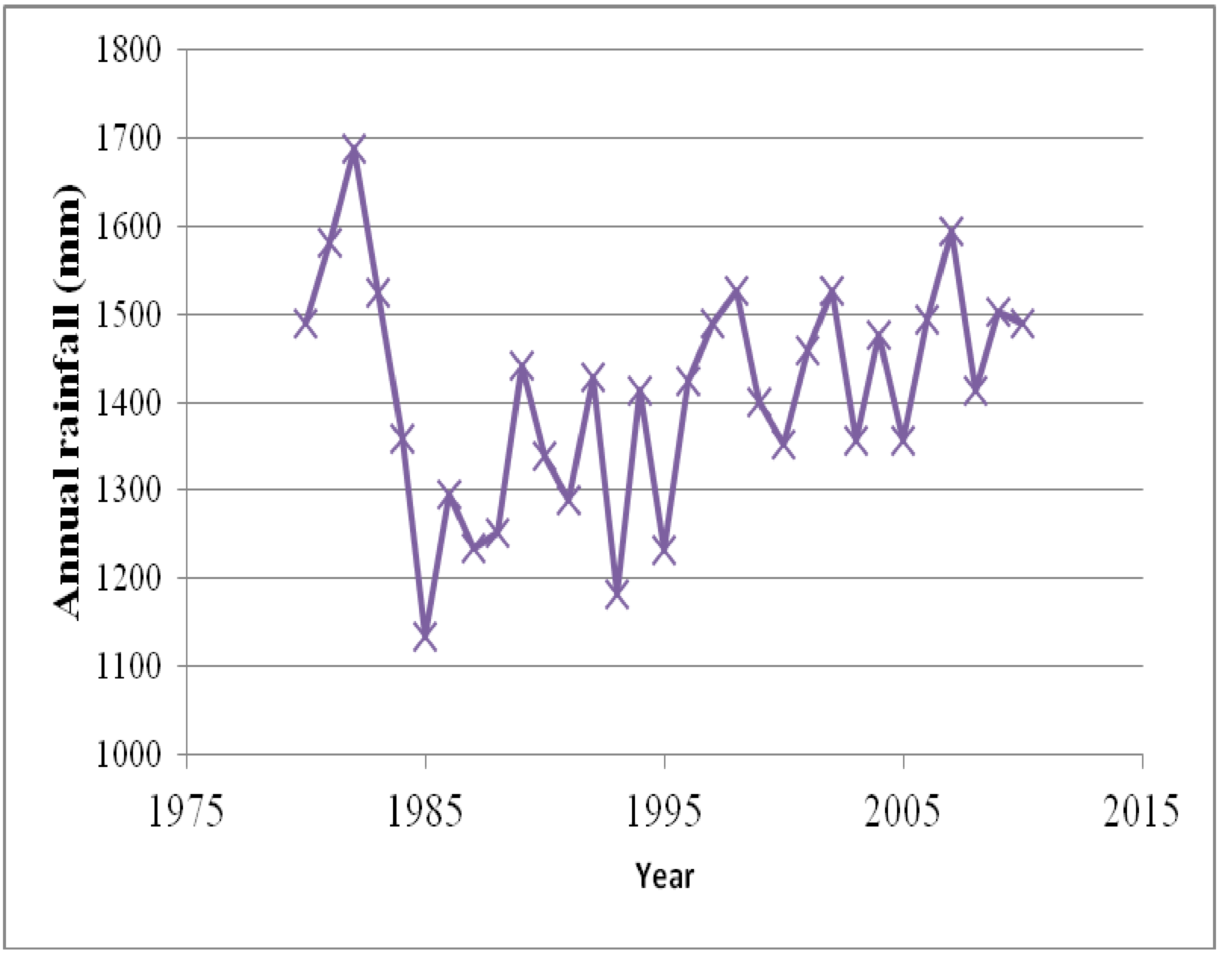

Figure 3: Annual rainfall in the Lwiro micro-catchment (Source Merra Data)

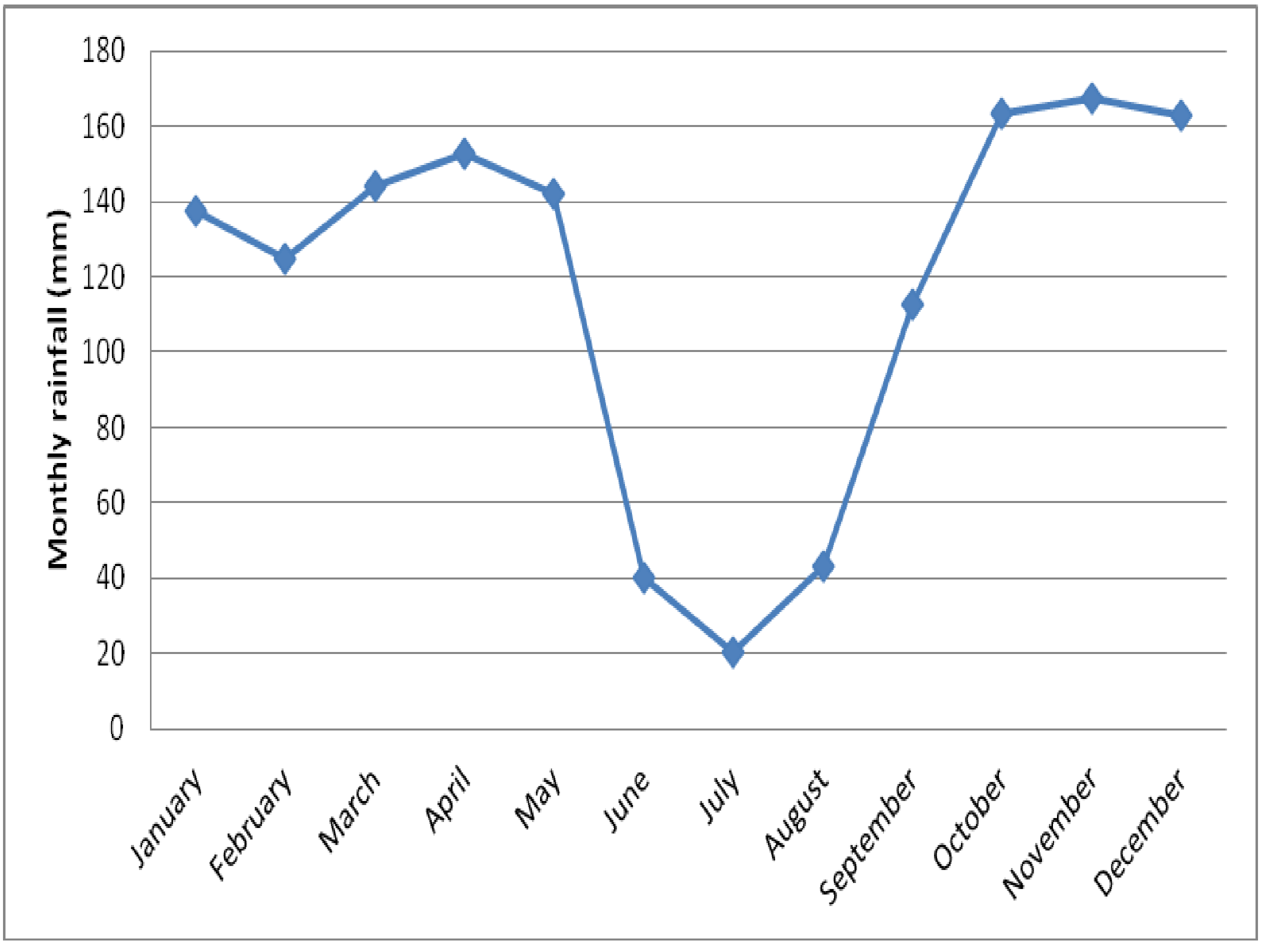

Figure 4: Monthly rainfall in Lwriro micro-catchment (Source Merra data)

The micro-catchment is dominated b y small scale farming, forest and built-up area. Forest cover is more located in the mountainous area and is part of the Kahuzi Biega National Park (Figure 5).

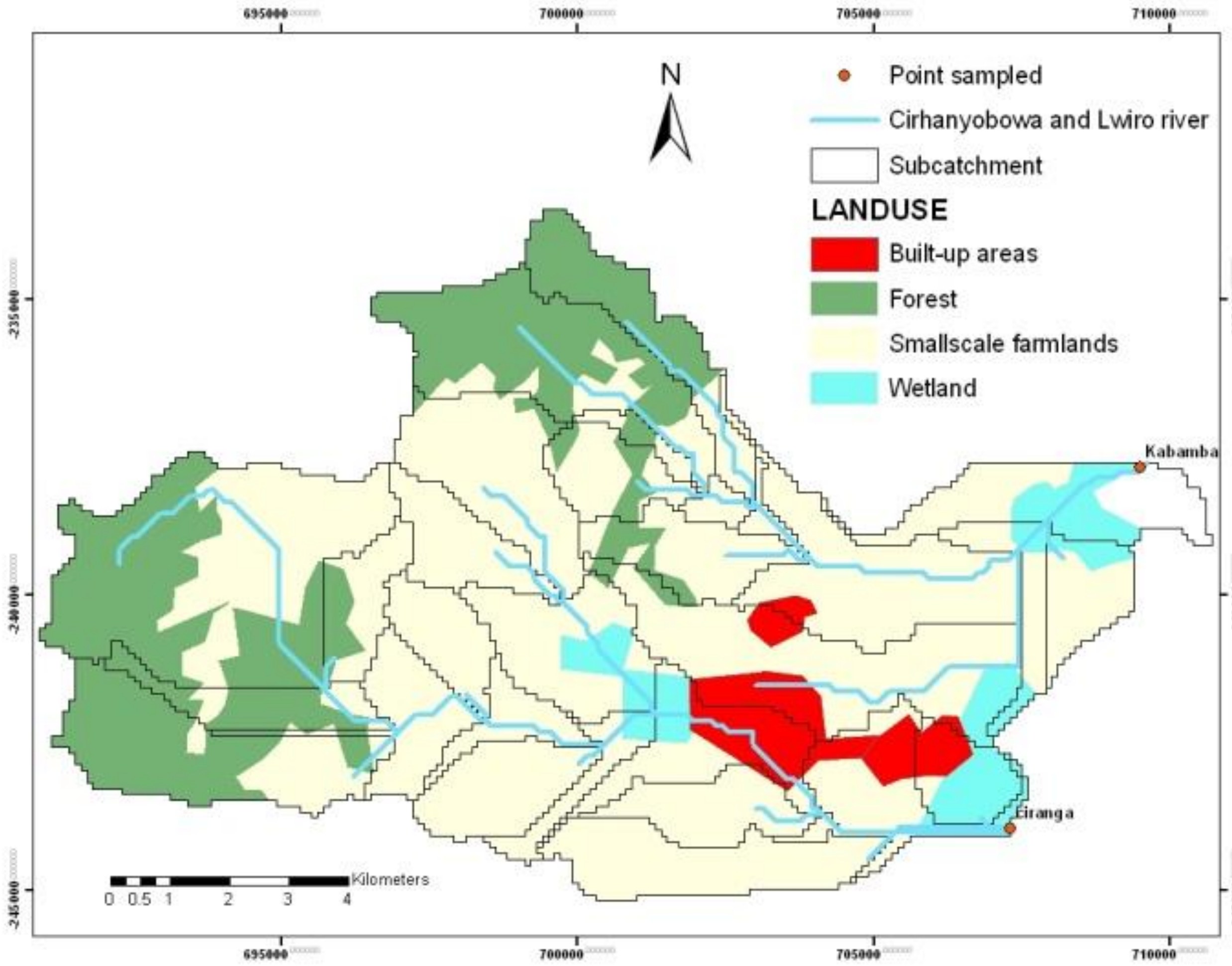

Figure 5: Land-use/cover in Lwiro micro-catchment

The geology of Lake Kivu has been described by Ilunga (1991) and Moeyersons *et al.* (2004). It is a rolling landscape of convex and elongated hills, developed on the weathered lavas. In the Bukavu area, folded and faulted Precambrian strata are covered by thick Tertiary and Quaternary lava flows. The oldest series, not present at Bukavu itself, predates local rifting and is dated between 7 and 10 millions of years (Pasteels *et al.*, 1989). The middle and upper series are present at Bukavu. The middle series, of Mio-Pliocene age (Kampunzu *et al.*, 1983; Pasteels *et al.*, 1989), is intimately related to the rift faults. The upper series started during the Pleistocene and continued to the last century. The chemical composition of these three series evolves from sub-alkaline over moderately alkaline to strongly alkaline (Pouclet, 1980). Every lava series consists of many individual flows, separated in time (UNESCO, 2002). The complex geometry of the present lava layers resulted from successive rifting and eruptive episodes. Weathering and erosion, as well as normal faulting, occurred between successive lava flow series, explaining the occurrence of palaeo-relief, contact metamorphism, smectite layers, probably Vertic palaeosoils, and clastic deposits having an alluvial and colluvial origin.

3.2 Research approach

Qualitative, quantitative and experimental approaches were used in this study.

3.2.1 Characterization of the cropping systems and identification of existing soil erosion management practices in the Lake Kivu basin.

Characterisation of the cropping systems and identification of existing soil erosion management practices in the Lake Kivu basin were achieved using a semi-structured questionnaire, key informants, and focus group discussions. The number of household that were interviewed was estimated using Bryan (1992) equation:

$$n = \frac{Z^2 PQ}{d^2}$$

Z (1.96) is the score at 0.95 level of significance from the normal curve. P is the proportion of household involved in agricultural activities (85%), Q = 1- P=15%, d (0.05) is the precision desired or the tolerated maximum value of relative sampling error. The number of household to be interviewed according to the Bryan's formulae is 196. These households were randomly selected from ten (10) villages namely: Ntane/Bidagari, Busandwe, Bushuramwambi, Chegera, Kayandja, Cirhundu, Cirhambi, Maziba, Kayandja and Kavuha in the Lake Kivu basin. The Ten (10) villages were selected based on accessibility and security criteria. In addition Ten (10) key informants' interviews and Ten (10) focus group discussions were conducted. At least on key informants was randomly selected among the NGOs staff (both local and international) and public extension service operating in each village. For each focus group 20 people were invited. The socioeconomic characteristics of the interviewed household heads are summarised in the Table 1. The majority of them were females (57.18%); most of the household members had never been to school (68.13%) followed by those with primary level education (21.43%). Only 10.43% had a secondary level of education. The interviewed household heads' age varied between 51 and 89 year old.

Table 1: Characteristics of the interviewed household heads

Characteristics		**Percentage**
Gender	Female	57.2
	Male	42.8
Education	Primary	21.4
	Secondary	10.4
	None	68.1
Age (yr)	51-60	45.0
	60-69	33.7
	70-79	13.3
	80-89	8.2

3.2.2 Determination of soil, runoff and nutrient losses from maize and banana cropping systems

a) Treatments and control

Soil, runoff and nutrient losses were determined using runoff plot approach. Plots of 2X15 m were demarcated on farmers' gardens at "Centre de Recherche en Science Naturelles" (CRSN-Lwiro) and equipped with dividers and collecting tanks. The runoff transfer coefficients were estimated in the field using water and an accurate balance. Local varieties of maize, beans and banana were used for the experiment. Maize and beans were intercropped but banana was cultivated in monoculture. Two soil erosion management practices, namely; *Tithonia* and contour bunds were tested on maize intercrop with beans and mulch for banana (Plate 2). The experiment includes a control practice for each crop. Each treatment and control was replicated four times.

Plate 1: Runoff plots established at CRSN-Lwiro, maize block

 

Plate 2: Contour bund on top of one of the runoff plot (a) ; Tithonia on top of one of the runoff plot (b)

b) Measured parameters

The measured parameters included soil loss, runoff, nutrient losses and the crop yield. Runoff and soil loss were estimated for each rainfall event. Samples of collected runoffs were measured using a graduated cylinder and total runoff for the rainfall events were estimated by multiplying the collected runoff by the deviser's transfer coefficient. The collected runoff was thoroughly mixed and a 100 ml sample was collected for sediment concentration determination in the lab. In the lab, sediment concentration was determined by filtration. The total soil loss for the rainfall event was determined by multiplying the total runoff volume by the associated sediment concentration. For a given season, the total runoff was computed as the sum of the different event runoff. The same was done for soil loss.

Seasonal nutrient (N,P and K) losses were estimated for the short rainy season of year 2012 and the long rainy season of the year 2013. Plot composite soil samples were obtained by putting together sediment collected after each rainfall event for a given season. The composite samples were taken to the laboratory for N, P and K analysis. N, P and K were analysed using standard procedures (Okalebo *et al.*, 2002). Total N were analysed using Kjeldahl digestion method. Available P was extracted by Bray II method (Bray and Kurtz, 1945). The exchangeable K+ cation was determined by a flame photometer. Total N and total available P was determined by multiplying their respective concentration with the total season soil loss.

In addition, crop yield parameters were determined for each plot. For maize intercropped with beans biomass and grain yield were determined on two 1x1m quadrats randomly placed in the plots. For banana, mature bunch weights were determined in each plot during the period of study.

c) Data analysis

The survey questionnaires were coded and entered in PASW statistics version 18 for analysis. Frequencies, tables and graphs were obtained using descriptive statistics and cross tabulation.

For the experiment, Analysis of Variance was used for mean separation at $p \leq 0.05$ in GenStat 13th edition.

CHAPTER FOUR: RESULTS

4.1. Major cropping systems in the Lake Kivu basin

The major crops grown in the Lwiro micro-catchment include banana, cassava, maize, beans and sorghum, and sweet potatoes (Figure 6). Banana, cassava and maize are the dominant crops in the area, and are generally intercropped with other crops such a beans. Generally maize and cassava are grown in all types of soils while banana are grown around homestead located on backslopes and footslopes.

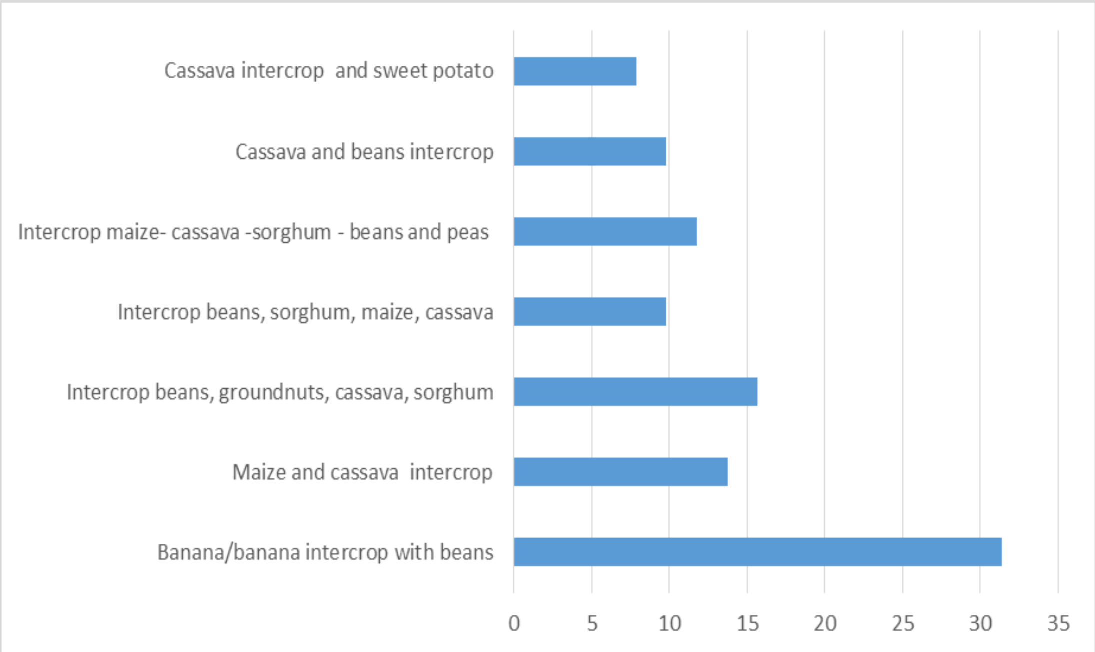

Figure 6: Major cropping system of the Lake Kivu

About 76% of the respondents grown maize in both season without rotation and only 25% do rotate maize with other crops. About 60% the respondents did not see their land increased in the last 10 years, and only 40% of the respondents have expanded their land. For the latter, land is used more intensively, the soils get more and more exhausted. The average crop yield has declined compared from the last 10 years yield. Some of the maize-based cropping system is turned into a maize-cassava, then a sorghum-based cropping system. Mineral fertilizers are not used and manure is seldom used in the banana cropping system. The majority of the respondents (90.7%) own land and about 7.41% of them hire land for cultivation (Figure 7). The farms are generally small in size, ranging from 0.01 to 0.24 ha, with limited input. Soil cultivation practices entailed gathering the little organic matter left around crop roots (ridging), preserving and recycling hoed weeds, waste products and refuse.

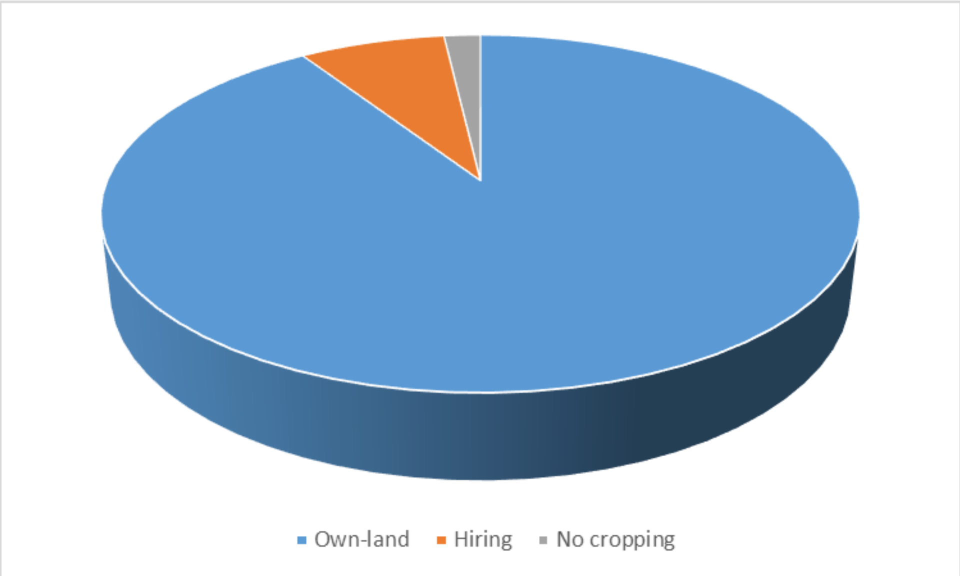

Figure 7: The respondents land ownership

Majority farmers (85%) reported that lack of technical support from government, shortage of labour (11%) and lack of quality inputs like seed, fertilizer, pesticides were also constraints of crop production in the Lake Kivu basin. Nature-related problems like, erratic rains, and heavy soil erosion were also mentioned as the causes for reducing the crop yield. Input-related production constraints mentioned were unavailability of improved seeds, fertilizers, pesticides in place and time, high prices of inputs, and labour shortages. Further on, insect-pest damage and epidemic problems of some diseases were important biotic constraints.

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4.2. Existing soil and water conservation practices in the Lake Kivu basin

4.2.1. Commonly used soil erosion practices in the Lake Kivu basin

The commonly used practices in the region include mulch under banana; agroforestry, contour bunds, *Tithonia* and *Tripsacum laxum* under annual crops (Figure 8). However, only a minimum number of people have adopted and use these practices in the region.

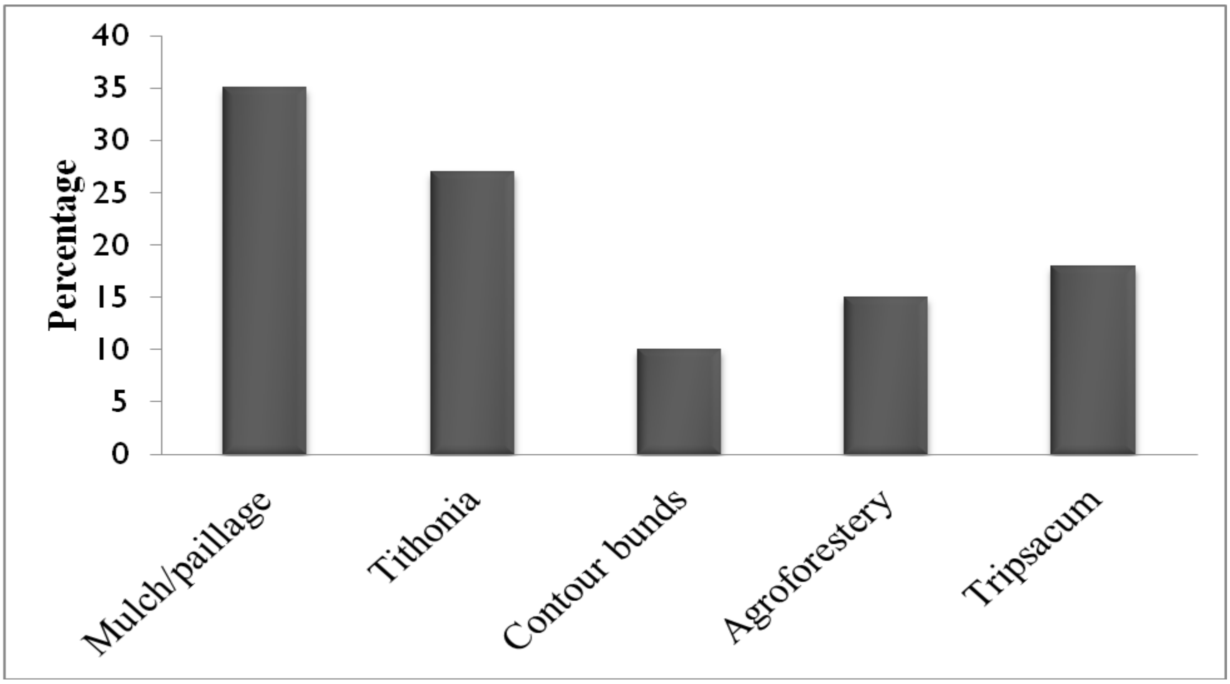

Figure 8: List of soil erosion practices in Lwiro micro-catchment

4.2.2 Causes of non-adoption of soil erosion practices in Lake Kivu basin

The different causes of non use or adoption of erosion practices in the Lake Kivu as mentioned above include lack of extension services, lack of awareness/ limited information, poverty of farmers, insecurity, livelihood change and land tenure (Figure 9).

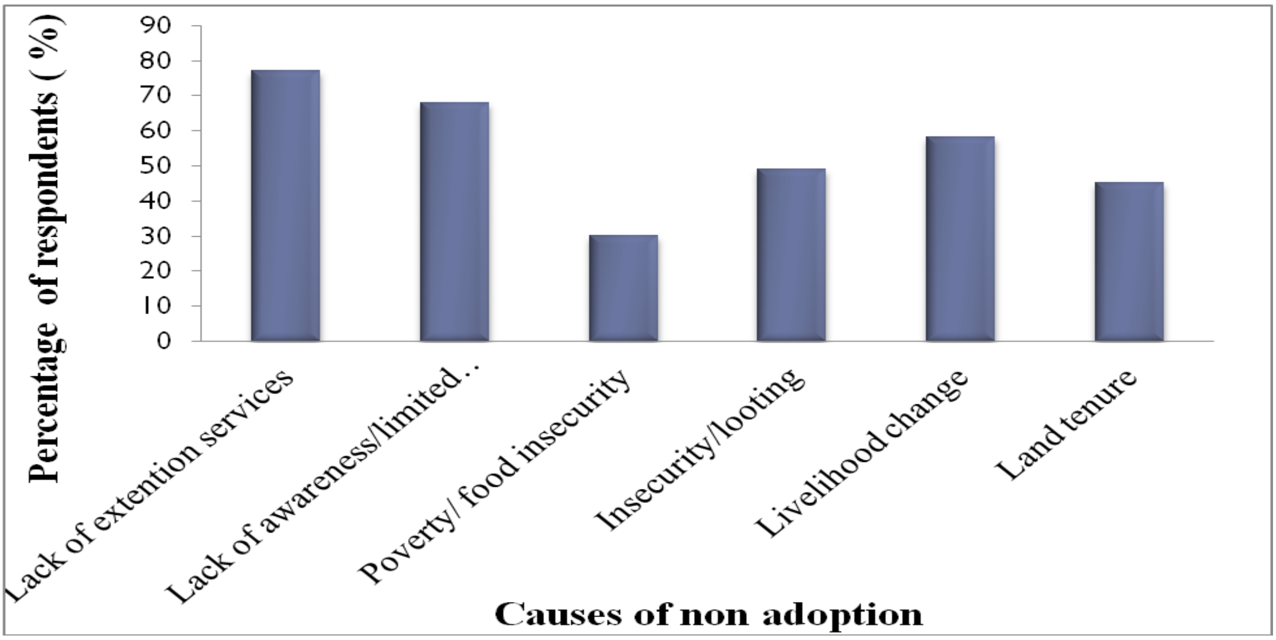

Figure 9: Causes of non-adoption of soil erosion practices

4.2. Soil loss, nutrient loss and runoff from maize and banana based cropping systems

4.2.1 Maize based cropping system

4.2.1.1. Soil and Runoff losses under maize based cropping system

Soil and runoff losses for both season I (long rainy) and season II (short rainy) are presented in figure 10 and 11; respectively. Soil loss and runoff losses did not significantly depend on soil erosion practices and rain seasons (P>0.05). However, soil loss under contour bunds was relatively the lowest followed by *Tithonia* and control for both seasons. A similar trend to that of soil loss was observed for runoff. The long rains season tended to have relatively higher value of soil loss and runoff for all practices. Soil loss under contour bunds varied between 15.73 t/ha and 20.49 t/ha, 19.29 t/ha and 23.33 t/ha under *Tithonia* and 30.91 and 32.93 t/ha/season under control depending on seasons. Runoff under contour bunds was also the lowest followed by *Tithonia* and control for both seasons. Runoff ranged between 168.14

and 203.22 under contour bunds, 206.60 and 240.13 under *Tithonia* and 264.29 and 322.17 t/ha/season under control.

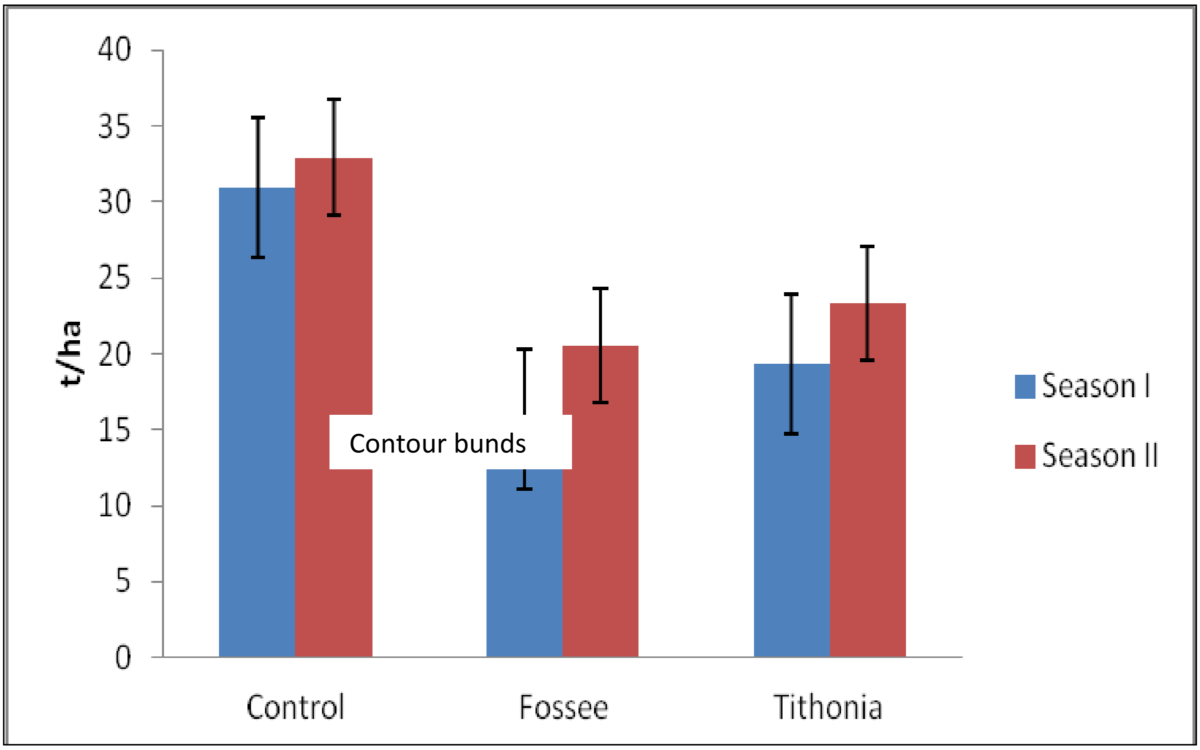

Figure 10: Soil losses under Maize cropping system

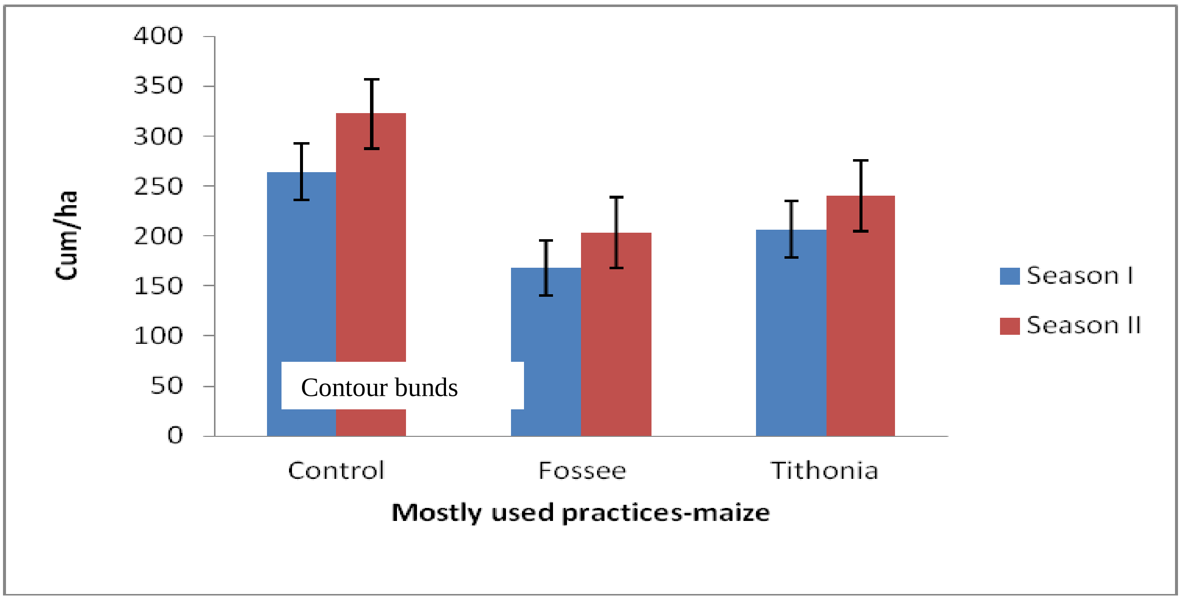

Figure 11: Runoff under Maize cropping system

Table 2 below shows nutrient concentration under different practices and across seasons. Different nutrients were affected differently by practices and seasons. Practices effects was observed only on K while seasons affected N and P concentration in the sediment lost (P $\leq$0.05). The interaction between seasons and practices was significant for K an P concentration in sediment lost (P $\leq$0.05). Contour bunds tended to have a relativly high concentration of N and K and lower value of P compared to other technologies for the short rain season. All technologies had less variation in concentration of nutrients during the long rain season. Nitrogen concentration in sediments was relatively higher during the first season compared to the second season for all practices. Phosphorous concentration was relatively constant under *Tithonia* and control during the two seasons. It is important to observe that P concentration increased during the second season for contour bunds. K concentration increased under *Tithonia* and control during the second season. It is also important to note that K concentration decreased under contour bunds during the season.

Table 2: Nutrient concentration under different practices and across seasons

Land use practices	Short rainy 2012			Long rainy 2013		
	N	P	K	N	P	K
	%					
Control	0.87	0.23	0.19*	0.36	0.28	0.34*
Contour bunds	1.94	0.16*	0.58	0.38	0.28*	0.36
Tithonia	0.75	0.24	0.20*	0.4	0.26	0.36*
LSD-*landuse*	NS	0.06	0.34	NS	NS	NS
LSD *Season*	0.56					
LSD Landuse.season	NS	0.06	0.23			

*: Seasonal effects at P<0.05

Table 3 below shows nutrient losses under different practices and across seasons. Nutrient losses from different land-use varied with practices and seasons ($p \leq 0.05$). Practices effects was observed on K, while N loss was only affected by season ($P \leq 0.05$) . K loss and P loss was also affected by season ($P<0.05$). The interaction between seasons and practices was significant for K and P losses ($P<0.05$). Contour bunds tended to have a relativly high amount of K and N losses and lower value of P loss compared to other technologies for the short rainy season ($P <0.05$). Contour bunds had also relativlely low amount of K loss, N loss and P loss compared to other technologies in the long rain season ($p<0.05$). The amount of K and N losses decreased for plots with contour bunds during the long rain season while it increased for P loss. The amount of K loss and P loss increased for control and *Tithonia* during the long rain season while N loss decreased.

Table 3: Nutrient losses under different practices and across seasons

Land use practices	Short rainy 2012			Long rainy 2013		
	N	P	K	N	P	K
	Kg/ha/season					
Control	291.8	68.01	54.68	125.9	94.22	112.34
Contour bunds	409.4*	24.5	103.74	71.5*	55.5	72.92

Tithonia	131.1	45.47	35.96	87.7	59.68	83.06
LSD- *landuse*	NS	25.26	28.81	NS	NS	NS
LSD Season	178.3	20.45	23.32			
LSD landuse*season	311.2	NS	40.72			

* Seasonal effects at P<0.05

4.2.1.2 Selected soil physical and chemical properties of soils under maize cropping system

The Saturated hydraulic conductivity (Ksat) of the soil under Maize is shown in the Figure 12. Ksat varied with soil depth (P=0.002) and was higher in the top soil (0-15 cm). It was very rapid in the top soil under contour bunds (52.14 cm/h) and *Tithonia* (33.69 cm/h) and rapid under control (23.37 cm/h). For the sub-soil (15-30 cm) it was low for all practices.

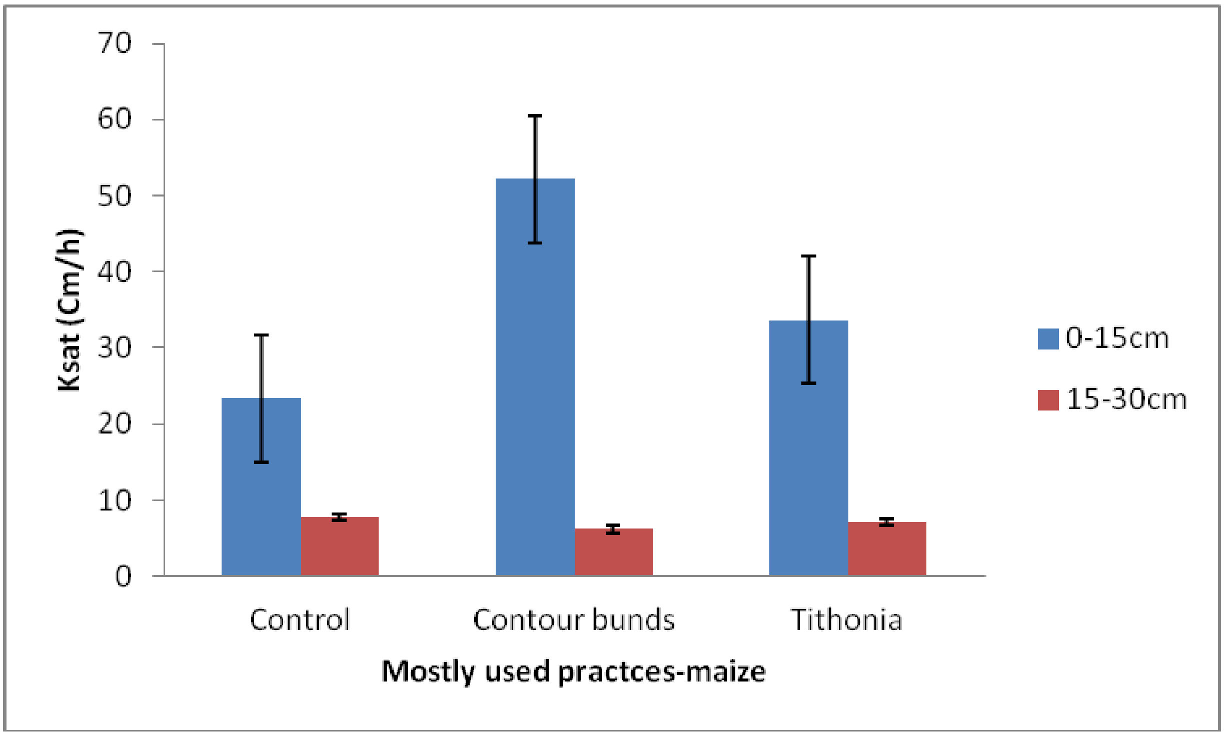

Figure 12: Saturated hydraulic conductivity under maize

Soil physical and chemical properties under maize based copping system are presented in Tables 4 and 5 for soil depths 0-15 cm and 15-30 cm, respectively. Soil properties were not significantly different under all practices tested for maize (P> 0.05). The soil is acidic with a pH ranging from 5.08 to 5.27. Nitrogen (N) was high with values ranging from 0.29 to 0.31

%. The organic carbon was high with values ranging from 3.68 to 4.82 %. Phosphorus (P) was below the critical value of ppm (15 ppm) ranging from 1.7 to 3 ppm. Potassium (K) , Calcium (Ca) and Magnesium (Mg) values were higher than the critical values of 0.2 ; 4 and 0.5 Cmol/Kg. Sodium (Na) values were within the range required for plant growth of < 1.

Table 4: Selected Soil chemical and physical parameters under Maize (0-15 cm)

Practices	pH	N	OC	P	K	Ca	Mg	Na	Sand	Clay	Texture
		%	%	Cmol/Kg					%	%	
Contour bund	5.17	0.304	4.37	3	0.24	6.25	1.14	0.2	63.2	21.25	SaCL
Control	5.27	0.286	3.68	1.7	0.21	7.81	1.59	0.13	59.5	25.75	SaCL
Tithonia	5.08	0.305	4.78	2.63	0.22	5.94	1.12	0.18	60.2	24.75	SaCL
Critical value	5.50	0.22	3.00	15.00	2-5	65-85	6-12	<1			

Table 5: Selected Soil chemical and physical parameters under Maize (15-30 cm)

Practices	PH	N	OC	P	K	Ca	Mg	Na	Sand	Clay	Texture
		%	%	Cmol/Kg					%	%	
Contour bund	5.15	0.303	4.82	2.25	0.23	8.44	1.73	0.16	54.8	29	SaCL
Control	5.27	0.286	4.71	1.97	0.19	6.88	1.28	0.11	59.2	26.25	SaCL
Tithonia	5.08	0.305	4.3	2.08	0.2	5.62	1.07	0.1	60	26.25	SaCL
Critical value	5.50	0.22	3.00	15.00	2-5	65-85	6-12	<1			

4.2.2. Banana based cropping system

4.2.2.1. Soil and Runoff losses under maize based cropping system

Soil and runoff losses for both season I (long rainy) and season II (short rainy) are presented in figures 13 and 14; respectively. Soil loss and runoff losses did not significantly depend on land-use practices and rainy seasons (P>0.05). However soil loss on mulched banana was relatively the lowest compared to the control (banana unmulched) for both seasons. A similar trend to that of soil loss was observed for runoff. The long rainy season tended to have relatively higher value of soil loss and runoff for both practices. Soil loss under mulched banana varied between 89.93 and 15.77 t/ha/season and between 13.88 and 20.61 t/ha/season under un mulched (banana). Runoff under mulched banana was also the lowest compared to the unmulched banana. Runoff varied also between 85 and 134 under mulched banana and between 118 and 152 t/ha/season under unmulched banana.

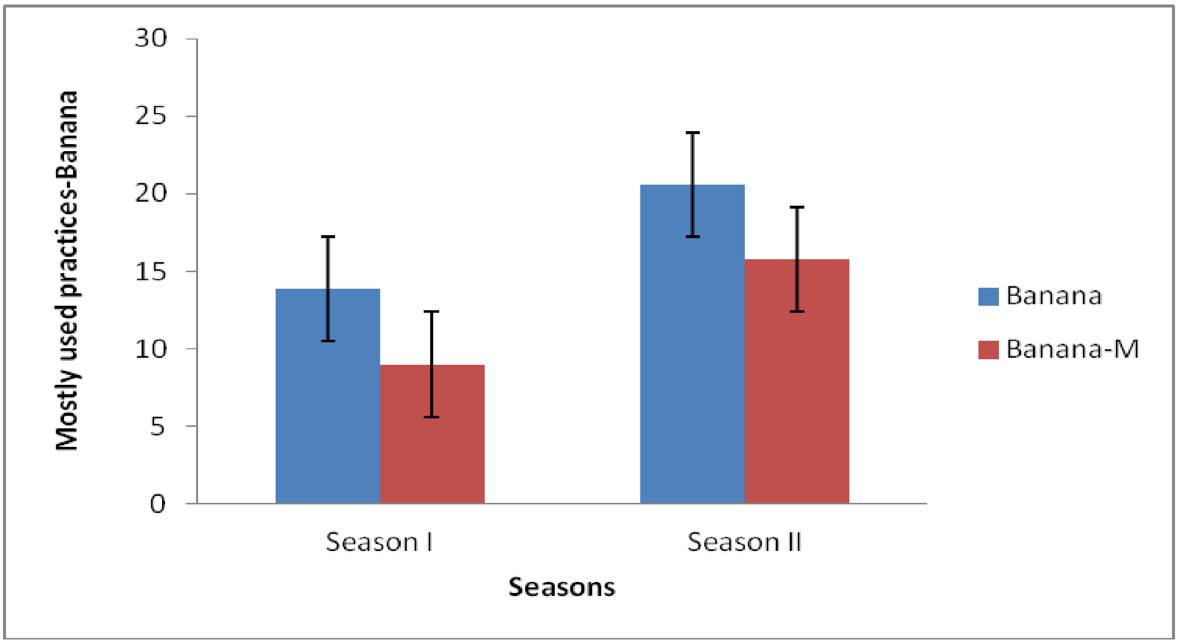

Figure 13: Soil losses under banana cropping system

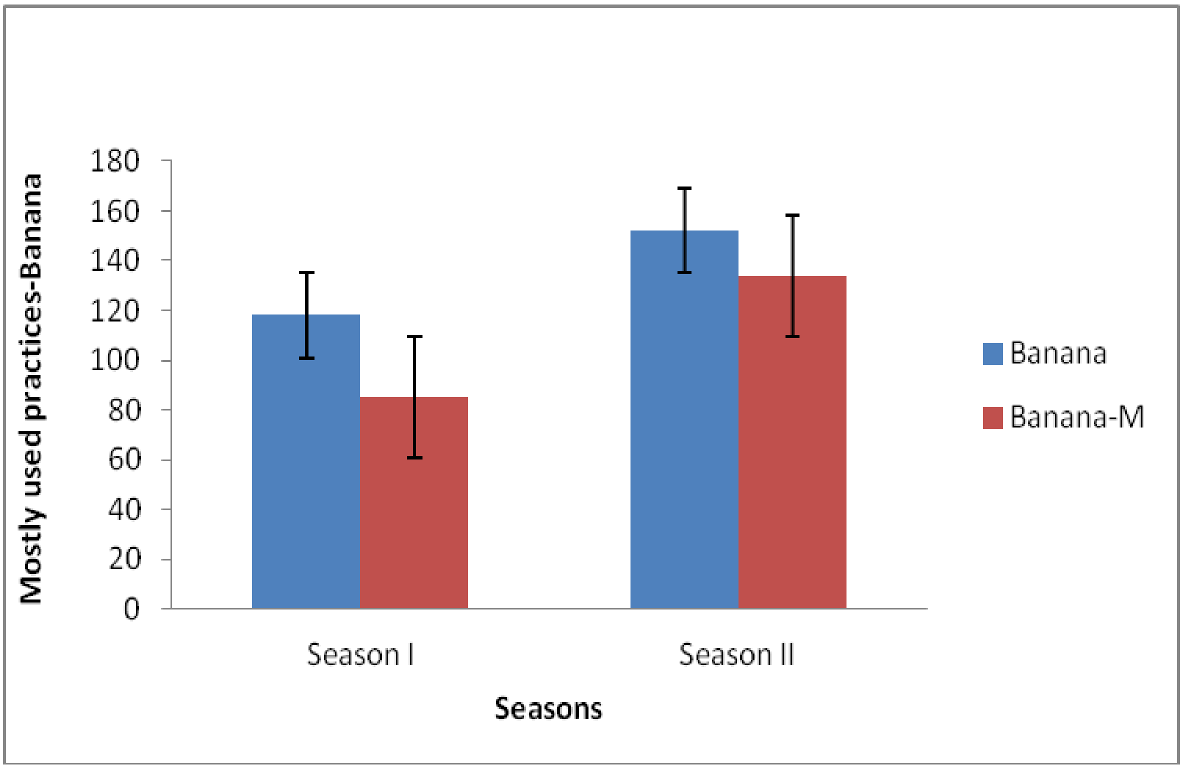

Figure 14: Runoff under banana cropping system

Table 6: Nutrient concentration under different practices and across seasons for Banana

Land use practices	%					
	Short rainy 2012			Long rainy 2013		
	N	P	K	N	P	K
Banana unmulched	0.74	0.24	0.19	0.39	0.23	0.28
Banana mulched	0.55	0.26	0.21	0.42	0.24	0.32
LSD- landuse	0.08	NS	NS			
LSD-season	0.07	NS	0.04			
LSD landuse.season	0.11	NS	NS			

Table 6 shows nutrient concentration under different practices and across seasons. N and P were not signicantly affected by different practices and seasons (P>0.05). Only K was affected by the season (P<0.05). All the nutrients tended to have relatively the same concentration during the long rainy season for the different practices except the N concentration which decreased under control (banana unmulched) during the long rain season.

Table 7 below shows nutrient losses under different practices and across seasons. Most of the nutrient losses were not affected signicantly by practices and seasons(P>0.05). Only K losses were significantly affected by the season(P<0.05). Mulched banana plots tended to have a relatively low nutrient losses in both seasons. K and P losses increased during the long rainy season for all practices while N losses decreased during the long rainy season for the unmulched banana.

Table 7: Nutrient losses under different practices and across season for Banana

Practices	Kg/ha/season					
	Short rainy 2012			Long rainy 2013		
	N	P	K	N	P	K
Banana unmulched	107	35.2	25.7	79	48.1	53.9
Banana-mulched	46	23.6	17.8	69	37.6	51.6
LSD-landuse	NS	NS	NS			
LSD Season	NS	NS	11.3			
LSD Landuse.Season	NS	NS	NS			

4.2.2.2 Selected soil physical and chemical properties of soils under banana cropping system

The Saturated hydraulic conductivity of the soil under banana is shown in the figure 15. It did not depend on both land use practices and soil depth (P>0.05) and was higher in the top soil. It was very rapid in both the top soil and sub-soil under all land use practices.

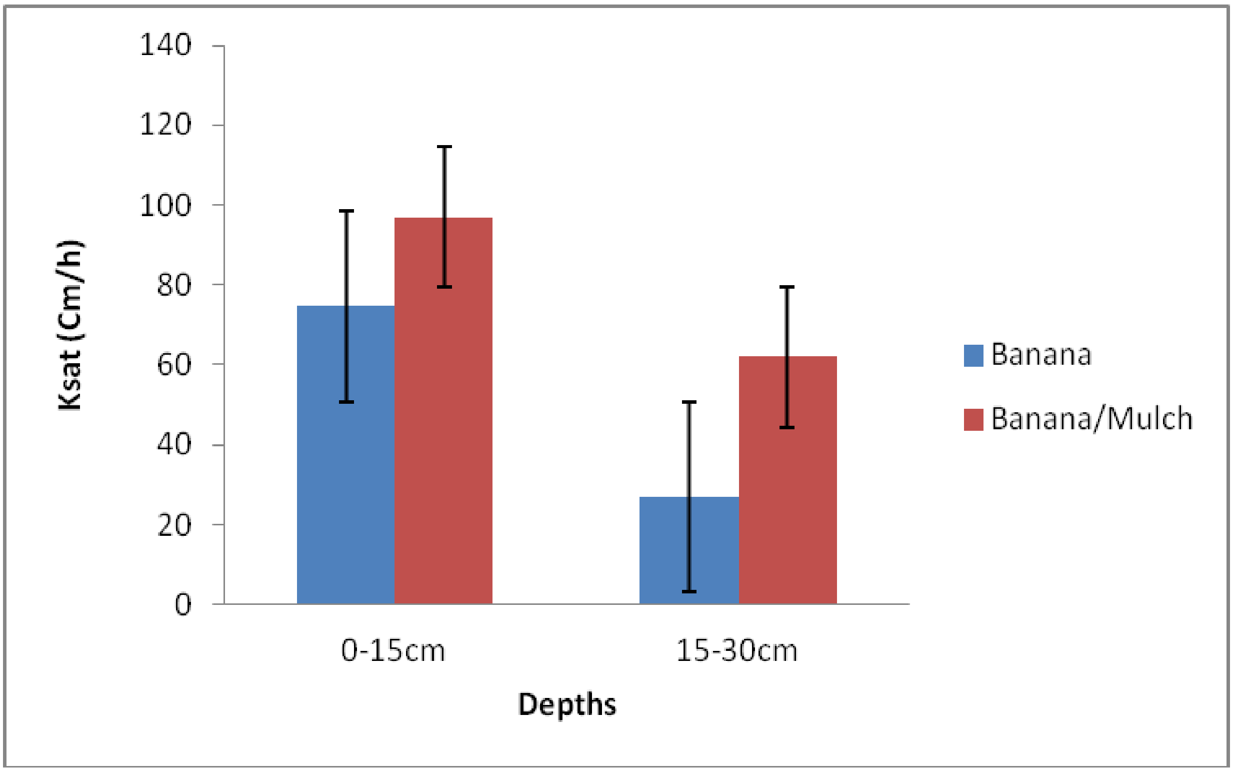

Figure 15: Saturated hydraulic conductivity under banana

Soil physical and chemical properties under banana based cropping system are presented in Tables 8 and 9 for soil depths 0-15 cm and 15-30 cm, respectively. In general, soil properties were not significantly different under all practices tested for banana (P> 0.05). Only Na (p=0.01), OC (p=0.03) and K (p=0.059) varied the practices.The soil is slightly acidic with a pH ranging from 5.93 to 6.19. Nitrogen (N) was high with values ranging from 0.37 to 0.41 %. The organic carbon was high with values ranging from 4.56 to 5.7 %. Phosphorus was below the critical value of ppm (15 ppm) ranging from 9.8 to 12.6 ppm. Potassium (K) , Calcium (Ca) and Magnesium (Mg) values were higher than the critical values of 0.2; 4 and 0.5 Cmol/Kg. Sodium (Na) values were within the range required for plant growth of < 1.

Table 8: Selected Soil chemical and physical parameters under Banana (0-15 cm)

Practices	PH	N	OC	P	K	Ca	Mg	Na	Sand	Clay	Texture
		%	%	Cmol/Kg					%	%	
Banana unmulched	6.14	0.391	4.89	9.8	0.405	13.75	3.04	0.13	60	23	SaCL
Banana mulched	6.19	0.399	5.7	12.6	0.775	13.75	2.99	0.32	63	21.8	SaCL

Table 9: Selected Soil chemical and physical parameters under Banana (15-30 cm)

Practices	PH	N	OC	P	K	Ca	Mg	Na	Sand	Clay	Texture
		%	%	Cmol/Kg					%	%	
Banana unmulched	5.93	0.37	4.56	10.8	0.416	17.19	3.82	0.2	53	24.2	SaCL
Banana mulched	6.14	0.41	4.74	12.4	0.527	13.44	3	0.26	57	23.5	SaCL

4.3. Yield of maize, beans and banana

4.3.1. Maize yield

Figure 16 presents the maize yield for both seasons. Only seasons had a significant effect on the yield for the two seasons (P=0.001). All practices had higher yield in the first season while lower values in the second season. However, contour bunds and *Tithonia* had a relatively higher yield compared to control for the first season while *Tithonia* had relatively higher yield than all the other practices in the second season.

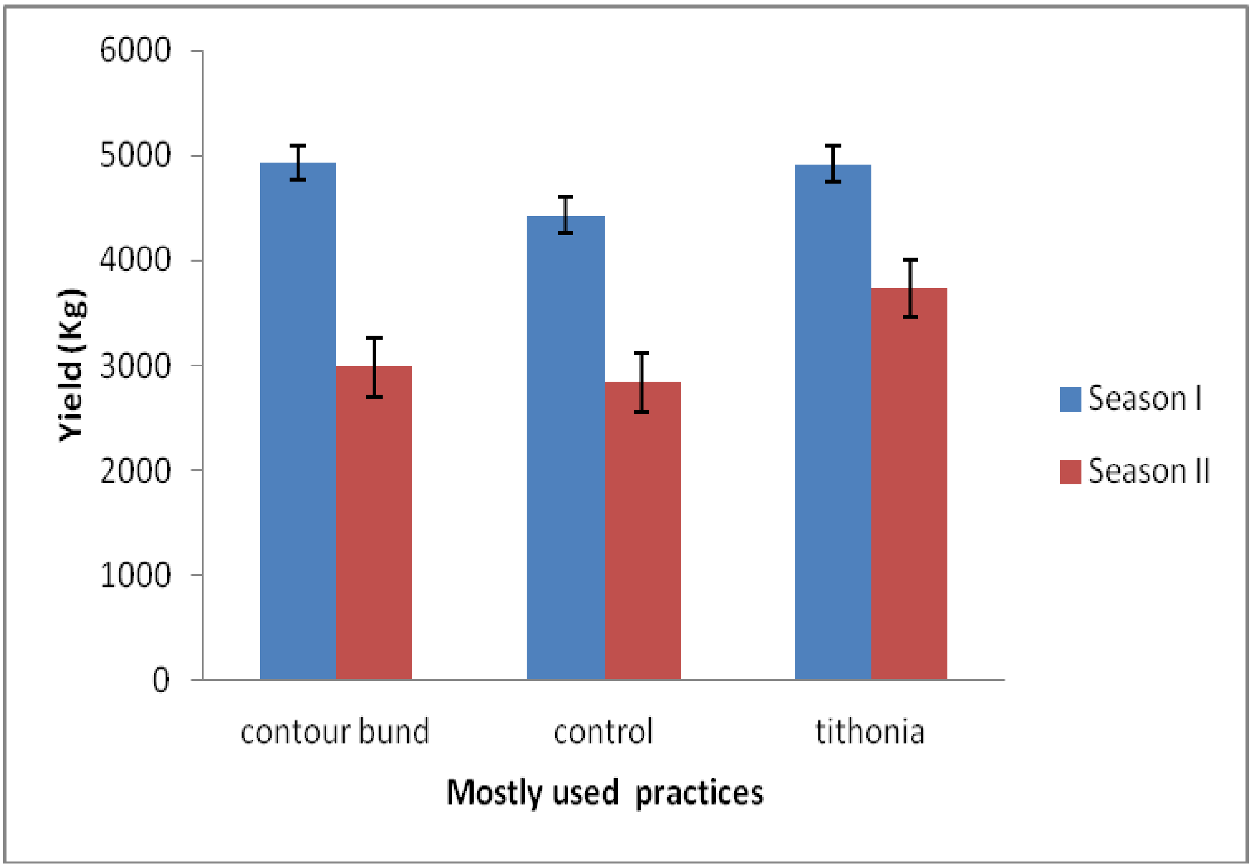

Figure 16: Maize yield (Kg/ha) for both long and short rainy seasons

4.3.2. Beans yield

Figure 17 presents the beans yield for both seasons. As for maize, bean yield was also signifiantly varied with season (P=0.004). All practices had higher yield in the first season while lower values in the second season. However, contour bunds and *Tithonia* had a relatively higher yield compared to control for the short rainy season while *Tithonia* had relatively higher yield than all the other practices in the long rainy season.

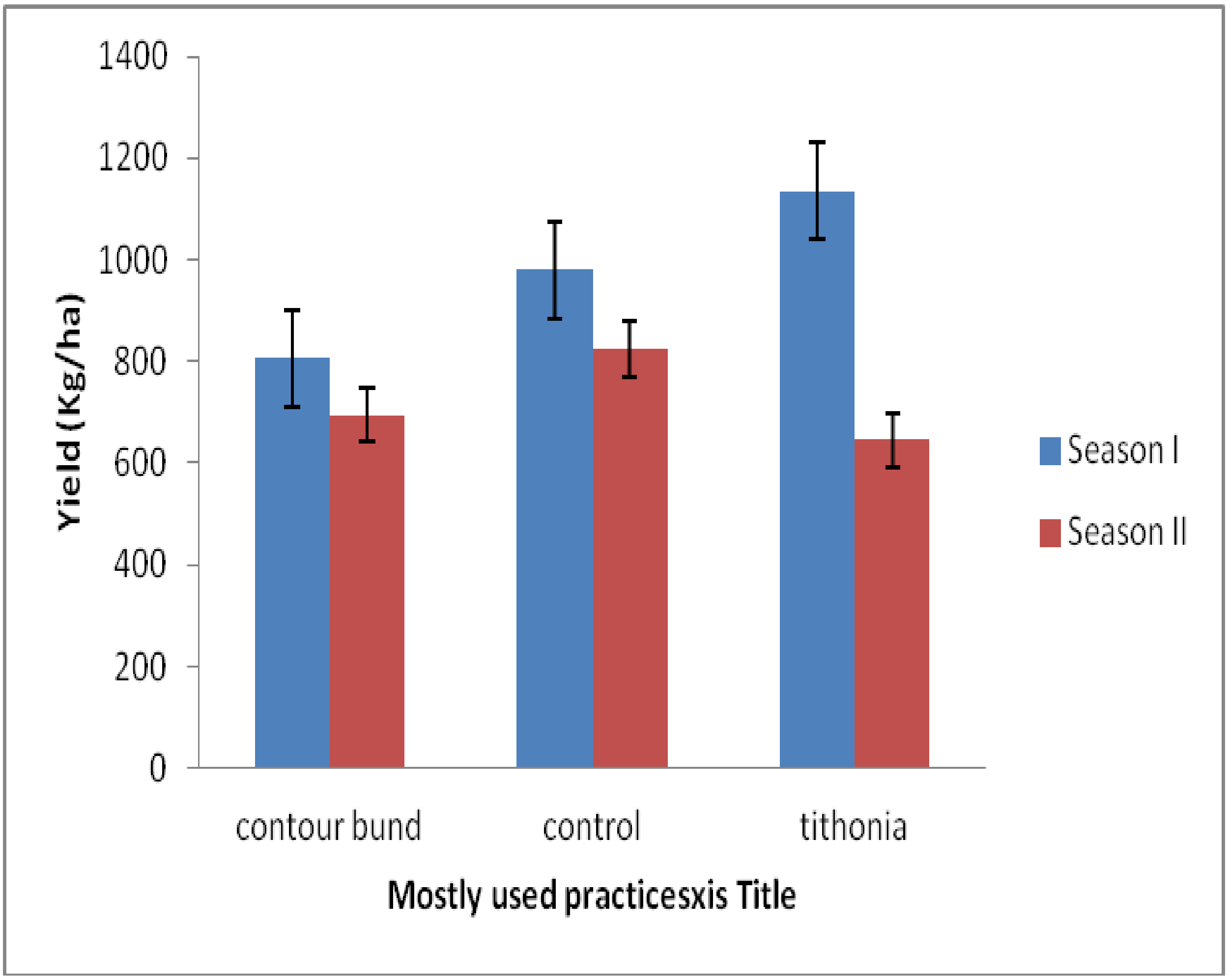

Figure 17: Beans yield in the maize cropping system

4.3.3. Banana yield and bunch number

Banana average yield and the number of bunches did not significantly depend on soil erosion control practices for the first year of the experiment ($P>0.05$). However, the number of bunches and the average yield were relatively higher under banana mulched.

Table 10: Banana yield and the number of bunch

Practices	Number of Bunch per ha	Average yield (Kg/ha)
Banana unmulched	575.86	4367.8
Banana mulched	775.86	4971.3
LSD		NS

CHAPTER FIVE: DISCUSSION OF RESULTS

5.1 Major cropping systems in Lake Kivu

There are three major cropping systems in the Lwiro micro-catchment, Lake Kivu basin in DRC, namely banana, cassava and maize based cropping systems. These crops are generally intercropped with other crops, and farming is mainly subsistence on a small piece of land (0.01 to 0.24 ha), with no inorganic fertiliser input and very limited use of manure in banana based cropping system. These findings corroborate Maass *et al.* (2012) observations that subsistence production in Lake Kivu, is based on maize (*Zea mays*), *Phaseolus* beans, bananas/plantains (*Musa* spp.) and cassava (*Manihot esculenta*). In an earlier studies they also observed that about 50–80% of the found produced is for household consumption, and only few crops are exclusively aimed for sale, like certain fruits and vegetables (Maass et al., 2010).

The low production of the system reinforces the lack of cash and the consequent inability of farmers to finance inputs and adopt technologies to alleviate constraints and therefore increases their vulnerability. Agricultural production in general has decreased in the past decade of turmoils (Vlassenroot *et al.,* 2003) setting of a vicious cycle of food and nutritional insecurity (Kandala *et al.,* 2011), low food production and subsequent extreme poverty (Rossi *et al.,* 2006). In CIALCA's (2008) participatory rural appraisal reaching almost 900 farmers, 30% of households in South Kivu stated that they can only afford one meal a day. This situation has been aggravated by limited access to land and markets (Vlassenroot *et al.*, 2003; Ulimwengu *et al.*, 2009), limited access to agricultural inputs, limited access to public extension services. Demographic pressure on the land is highly due to unequal distribution. Infrastructure is neither much developed nor maintained, especially due to the wars and post-war government neglect of these parts of the country (Van Acker 2005; Ulimwengu *et al.*, 2009).

5.2 Commonly used soil erosion practices in the Lwiro micro-catchment in the Lake Kivu basin

Soil erosion practices in the Lwiro micro-catchment of Lake Kivu basin included contour bunds, mulch and *Tithonia, tripsacum* and Agroforestry though it is used by small number of farmers. This limited adoption of soil and water conservation practices in the Lake Kivu basin corroborate previous findings by other researchers (Biragi, 2011) in the region.

The major causes of this limited utilisation /adoption of soil and water conservation practices were lack of awareness/Limited information, poverty, political instability/ civil war, livelihood change and land tenure system. Several studies have shown that farmers with high awareness invest in soil and water conservation (eg. Gunathilaka, 1990; Amarasekara et al., 2008). In India, Gunathilaka (1990) showed that soil erosion problem is severe in farms which are operated by people who have less awareness of soil conservation. The level of awareness of soil and water conservation practices in Lwiro micro-catchment is due to inadequate extension services and farmers education level. The public extension service collapsed in DRC long time ago, the task is currently being done by local and international organisations with low efficiency due to high level of political instability in which DRC was plunged into for long time. Amarasekara *et al.* (2008) found that households with higher education level adopt conservation measures better than others since they are in a better position to understand soil erosion issues and have more access to information in India.

Strong association between farm income and adoption of soil and water conservation practices was established by Blaike (1986). According to Lovejoy *et al.*, (1986) and Dano and Midmore (2004) farmers investment in soil and water conservation is viewed from a business perspective as they need to survive in competitive markets while struggling to meet basic needs. Investment in these practices is hence decided by the short-run economic gains associated with those practices. Therefore, soil and water conservation investments cannot be seen in isolation from development dimensions that frame the livelihood strategies of households in a specific area.

Many resource poor farming households have been sustained by land use practices that have tended to perpetuate poverty, soil erosion and other land degradation phenomena (GTZ, 1995). It is well documented that poverty, agricultural stagnation and resource degradation are interlinked (WCED, 1987; Pleskovic and Stiglitz, 1997). Pender *et al.*, (2004) further said that poverty has many dimensions, which have different impacts on land management, productivity, and incomes. Households that are poorer in terms of the ownership of physical assets are less likely to adopt soil and water management practices and non-labour inputs and are likely to obtain lower production and incomes. This will subsequently lead to the maintenance of the vicious cycle of low productivity, poverty and land degradation (Shiferaw and Holden, 2001, Barbier, 1999; Reardon and Vosti, 1995; World Bank, 1997).

Political instability hinders investment even at farmer level. D.R.C and particularly eastern part has just emerged from two decades of war. This armed conflicts and weak provision of security by the central government have compounded the challenges faced by smallholder farmers since the mid-1990s (Vlassenroot *et al.*, 2003; Van Acker 2005; Cox 2011); and hence aggravating the situation of extreme poverty and an alarming nutritional status with high incidence of food insecurity (Rossi *et al.*, 2006; Kandala *et al.*, 2011). Agricultural production in general has decreased in the past decade of turmoils (Vlassenroot *et al.*, 2003) setting of a vicious cycle of food and nutritional insecurity (Kandala *et al.*, 2011), low food production and subsequent extreme poverty (Rossi *et al.* 2006). This situation has also been aggravated by limited access to land and markets (Vlassenroot *et al.*, 2003; Ulimwengu *et al.*, 2009). Many researchers point out that the land degradation is also associated with insecure land tenure systems (Gunathilaka and Abeygunawardane, 1993; Gamage and Aheeyar, 1998). In the Lake Kivu basin, DRC side is under increasing demographic pressure on the land highly linked to unequal distribution of the latter. Infrastructure is neither much developed nor maintained, especially due to the wars and post-war government neglect of the region (Van Acker, 2005; Ulimwengu *et al.*, 2009). In addition, the formal law does not recognize private land-ownership, (only perpetual or standard concessions), and the legal status of the rights obtained through these land transfers is ambiguous (Vlassenroot and Huggins, 2005; Reynolds and Flores 2008; Leiz, 1998).

Insecure land rights create little incentive for farmers to invest in land improvement. In Uganda, there are mixed reports on the impact of land tenure on land management. Mugerwa (1995) and Roth *et al.* (1994) reported low farmers' incentives to invest due to land tenure insecurity; while Bashaara (2001) found the actual law was protective enough and no investment on the land could be more associated with lack of funds. Bashaara findings corroborate earlier observations by other researchers that tenure insecure farmers invest more than their counterparts. However the results from the four countries suggest that tenure insecurity does not inevitably lead to decreasing investments in land and that the relationship between land tenure and soil conservation measures is not necessary mono-directional as often stated (Neef, 2001).

It is worthwhile to note that other factors can significantly contribute to increased adoption of soil and water conservation technologies including total land operated and parcel size, household size, training and extension services, a larger proportion of total household income coming from farming, total land operated to parcel ratio, gender of the household head, farmers' perception of parcel erosion status, neighbours' parcels having soil and water conservation technologies on them, distance of the parcel from the homestead, perceived risk in terms of possibility of a slide on a parcel, age, credit access, geographical location, slope and soil type. (Asiimwe *et al.*, 2013; Turinawe *et al.*, 2013).

5.2 Soil, runoff and nutrient losses from Maize and Banana cropping system in Lwiro micro-catchment

Soil and runoff losses from both maize and banana cropping systems are moderate and very low; respectively. Nutrient losses are generally very high and relatively lower under Banana compared to Maize. Soil and water management practices effects were not felt during the year of experimentation for soil and runoff but was significant for nutrient losses under Maize and only for K under banana ($P<0.05$).

Soil loss is classified as moderate (FAO, 1979; 1990) in the study area and is relatively low compared to results obtained in the region (Majaliwa, 1998; Majaliwa, 2004; Azanga, 2013). Majaliwa (1998) obtained soil losses of 45 t/ha on maize intercrop with beans under sub-humid conditions and on slopes of 22% in the Lake Victoria crescent. Measured average annual soil loss ranged from 86.8 t/ha/yr in Rakai; and 27.9 t/ha/yr under banana (Majaliwa, 2004). Similar results were observed by Mulebeke (2003) where annuals lost 71 t/ha/season and 25.1 t/ ha/ season for banana. Runoff observed under this study was relatively very low compared to values obtained by Majaliwa (2004) for the same land use. Runoff under maize and banana was a seventh and half of what was obtained by Majaliwa (2004) for the same land use respectively. Nutrient losses were very high but less than values obtained by Majaliwa (2004) in Rakai. Other scientists reported values of 0-2 and 0.1-13 kg ha-1 season-

1for P and K, respectively, in arable lands of sub-Saharan Africa (Wortman and Kaizzi, 1998; Zobisch *et al.*, 1995)

Differences between the results of this study and aforementioned ones are attributed to slope, soil type and climatic conditions. In fact, the slope used in this study was of 11 % compared to 22 %, 49 % and 20% for Majaliwa (1998), Majaliwa (2004), and Mulebeke (2003). However, very small values (1.4 t/ha/yr) of soil loss were measured by Tukahirwa (1996) in Kabale for similar slope of 10 % and quasi similar values of 30-t ha-1 yr-1 were recorded on slopes of 20%. Type of soil affects soil loss through infiltration and erodibility. The infiltration rate of the experimental soil was generally very rapid (Landon, 1995) compared to moderate and rapid rate under Majaliwa and Mulebeke's soils. High infiltration rate contribute to reduced runoff, runoff sediment detachment (Le Bissonnais *et al.*, 2005) and nutrient loss (Lal, 1998; Simard *et al.*, 2000; Ng Kee Kwong *et al.*, 2002). Several studies demonstrate that runoff generation is driven by antecedent soil moisture (Fitzjohn *et al.*, 1998; Meyles *et al.*, 2003; Castillo *et al.*, 2003; Wei *et al.*, 2007), and soil management systems (Martınez *et al.*, 2006; Gomez *et al.*, 2009). The latter generally affects soil surface structure (Farres, 1987; Lecomte *et al.*, 2001; Le Bissonnais *et al.*, 2005). A strong relationship exists between soil structure, soil water retention and organic matter (Vaezi *et al.*, 2010). The experimental soils are deep and have high organic matter contents ranging from 3.68 to 5.7 %. This explains the higher values of infiltration for these soils.

Variation in runoff, soil loss and nutrient losses between the different studies is also due aggressive climatic factors. The erosivity factor is relatively higher in the study area than in Uganda where Mulebeke and Majaliwa conducted their studies (Majaliwa, 2004; Mulebeke, 2003; Ischebeck *et al.*, 1984). It was ranging from 170 and 196 J m^{-2} in Uganda while in DR Congo it ranged between 220 and 300 J m^{-2}.

It is worthwhile to note that maize and beans yields were generally high despite declining in the second season. The soil chemical and physical properties were not significantly influenced by practices. High maize and beans yields are due to the good fertility status of the soil. Most of the soil parameters were above the critical values, therefore adequate for plant growth. For banana, mulched plots had better yield reflecting the relative better nutrient conditions of the soils under mulch in terms of organic carbon, available phosphorus, extractable potassium and nitrogen.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In light of the above results and discussion, it was concluded that:

The major cropping systems in the Lwiro micro-ctahcment include banana-based, cassava and maize based cropping systems. The dominant features of farming in the study areas were small land holdings, sloping marginal land, and rainfall-dependent farming. A variety of crops like include banana, cassava, maize, beans, sorghum, and sweet potatoes were grown.

There are few soil and water conservation practices currently used in the Lwiro micro-catchment. These include *Tithonia, Tripsacum laxum*, contour bunds, mulch and agroforestry. Their adoption rate was very low because of the lack of extension services, lack of awareness/limited information, livelihood change, insecurity/looting, land tenure and poverty/food insecurity. Soil loss was generally moderate (20-35 t/ha/season) and runoff very low (<1%) on both maize and banana based cropping systems. The reduction in soil and runoff losses due to soil and water conservation practices was not significant during the period of the study. Nutrient losses were generally high on both systems and varied from one practice to another under maize but only K under banana. Nitrogen, phosphorus and potassium losses under banana varied from 46-107 Kg/ha/season; 23.6-48.1 Kg/ha/season; and 17 -53.9 Kg/ha/season; respectively. They ranged from 71-409 Kg/ha/season; 24-94 Kg/ha/season; 35-112 Kg/ha/season for N, P, and under maize; respectively.

6.2 Recommendations

Based on the results and observations made in the study area there is need:

- To improve the extension services in the micro-catchment, and the country at large, in order to promote and increase the adoption of the tested soil erosion control practices.
- To conduct long term experiments to assess the efficiency of existing soil erosion control practices in the Lwiro micro-catchment and the region.

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Appendix 1: HOUSEHOLD QUESTINNAIRE

Assessment of land use/ cover changes and livelihood feedbacks in River Sio system

SECTION A

1. Date……………………………………Time started………………………….

2. Name of interviewer…………………………………………………………….

3. Village…………………………………Parish…………………………………

4. GPS location of home…………………………………………………………...

SECTION B

5. Respondents Name:---

6. Marital Status:---

7. Sex:---

8. Age (year of birth)---

9. How many people live in that household?

   Children (below 18)------------------ Adults------------------disabled--------------

10. What is the highest level of education you have attained (Tick)
    a) None
    b) primary
    c) Secondary
    d) Post secondary

SECTION C: SOURCES OF LIVELIHOOD

11. What livelihood activities are you involved in? (Tick)
    a) Cropping
    b) Livestock
    c) Fishing
    d) Petty trade
    e) Employment
    f) Others (name them)---

12. What livelihood activities where you involved in 10 years ago?
    a) Cropping
    b) Livestock
    c) Fishing
    d) Petty trade
    e) Employment

f) Others (name them)--

13. If you have changed the livelihood activities, why?

i) ---

ii) ---

iii) ---

14. What are the types of crops grown and size of the farm (list three major crops and indicate farm size for each crop)

Crop	Size (Acres)
a)-------------------------	------------------------------
b)-----------------------	--------------------------------
c)-------------------------	---------------------------------

15. What type and number of livestock is kept in the household?

	Type	Number
a)	Cattle---------------------------	------------------------
b)	Goats----------------------------	--------------------------
c)	Sheep----------------------------	---------------------------
d)	Pigs-------------------------------	----------------------------
e)	Chicken--------------------------	-----------------------------

16. List in order of importance the contribution of the above mentioned activities to household incomes.

i) Very important ---

ii) Important --

iii) Fairly important---

iv) Least important ---

17. Is your livelihood improved in the last 10years? Yes or No

18. If Yes , how? (mention at most three things that show that you have improved)

i) ---

ii) ---

iii) ---

19. If no, why do you think so?

i) --

ii) --

iii) --

20. What measures have you put in place to improve your livelihood?

i) --

ii) --

iii) --

SECTION D: LAND USE

Cropping

21. Do you own any land? Yes or No (Tick appropriately)

22. If no, where do you cultivate your food?

23. If yes, how much land do you own (in acres)? ----------------

24. Do you own a land title for your land? Yes or No (Tick appropriately)

25. If no, how do you own your land? (Customarily or otherwise)

26. Do you rent out land to other people to use for cultivation or grazing? Yes or No

27. Do you use someone else's land for cultivation? Yes or No

28. Has the size of your cultivated land changed in the last 10 years? Yes or No (Tick appropriately)

29. If yes, has it increased or decreased?
a) Increased--------------------
b) Decreased---------------------

30. If it has decreased, what are the reasons? (Mention three)

i) --

ii) --

iii) --

31. How have you addressed the problem of decrease in your cultivated land area? (Give at most three solutions)

i) --

ii) ---

iii) ---

32. If your cultivated land has increased, is the newly cultivated land as productive as the previous one? (Tick appropriately)

a) No difference---------------------------------

b) More productive------------------------------

c) Less productive---------------------------------

33. Do you grow trees on your farm/ Yes or No

34. If yes what trees?

i) ---

ii) ---

iii) ---

35. What do you use the trees mentioned above for?

Purpose	Tree species
i) Fuel wood	--
ii) Building materials	--
iii) Fodder	--
iv) Soil fertility maintenance	--
v) fruits	--
vi) Wind breaks	--
vii) Shade	--

36. If no, where do you get your tree requirements?

a) Wetland b) forest c) others (Specifiy)

37. Do you get your tree requirements easier than 5-10 years ago?

38 What are the major crops grown on your farm in order of importance?

i) ---

ii) ---

iii) ---

39. Do you grow each of these crops alone or do mix with other crops?

a) Alone ---

----

b) Mix (mention the combinations)

----

40. Do you plant the same crops every year? Yes or No

41. If no, which crops do you change and how do you interchange them

i) --

ii) --

iii) --

42. Do you practice fallowing? Yes or No

43. What do you do with the crop residues from your garden?

a) Burn them b) use them as feed c) use them for cooking d) others (specify)

44. What land management practices do you use in your garden?

a) bush burning b) mulching c) Crop rotation d0 others (specify)

Livestock keeping

45. What method of rearing your cattle do you use?
a) open grazing on land b) open grazing in swamps c) tethering around home

46. Do you have shortage of pasture or feed for your livestock? Yes or No

47. If yes, what are the critical months?---

48 How do you deal with the problem?

i) --

ii) --

iii) --

49. Problems have you encountered as a result of shortage of pasture or feed for your livestock? List at least two.

i) --

ii) ---

iii) ---

50. If you have shortage of pastures, do you think that reducing the numbers of your livestock will help solve the problem? Yes or NO

51. Do you water your animals in the river, lake or wetland? Yes or No

52. If No, how many permanent watering points does your village have besides rivers, lakes and wetlands?

53. Do you observe emergence of unpalatable pasture species in the grazing areas? Yes or No

54 If yes, what are the names of these species

i) Local name------------------------Scientific name---------------------------

ii) Local name------------------------Scientific name---------------------------

iii) Local name------------------------Scientific name---------------------------

Fishing

55. Do you practice fishing? Yes or No

56. If no, why? Give at least two reasons
i) ---

ii) ---

iii) ………………………………………………………………………….

57. If you practice fishing, what fishing gear do you use?

i) ---

ii) ---

iii) ---

58. Where do you fish?
a) Riverb) Lake c) swamp/ wetland d) others (specify)

59. What season do you fish?

60. Which Species do you harvest?
i) ---

ii) ---

iii) ---

61. How much fish do catch per fishing day?

62. What problems do you encounter in the fishing activity?

i) --

ii) --

iii) --

63. How can these problems be tackled?

i) --

ii) --

iii) --

SECTION E: PERCEPTION ABOUT LAND USE CHANGES AND IMPACT ON LIVELIHOOD ACTIVITIES (for persons above 40 years of age)

64. What was land being used for 20 years ago? (Describe)

----

65. How has use of land today different from 20 years ago? Describe

----

----

66. In terms of fertility, what is the condition of your land? (Tick appropriately)

a) Good b) Fair c) Bad d) Not sure

67. What was the condition when you started using your land? (Tick appropriately)

a) Good b)Fair c) Bad d) Not sure

68. What do you think the condition will be in the next 5 to 10 years?

a) Good b) Fair c) Bad d) Not sure

69. What activities affect land productivity? (Mention at most three)

i) --

ii) ---

iii) ---

70. What features makes believe that there is a problem of loss of soil fertility on your land

i) ---

ii) ---

iii) ---

71. Is the investment on your land profitable? Yes or No

72. If yes, what kind of improvement or investment have you made?

i) ---

ii) ---

iii) ---

73. Have you ever had conflict regarding the land you use? Yes or No

74. If yes, what kind of conflict

i) ---

ii) ---

iii) ---

75. What was the cause of the conflict? Describe

----

76. Is soil erosion a problem on your land? Yes or No

78. If yes, what features lead you to believe that such a problem exists?
a) Rills b) gullies c) stonelines d) others (specify)

79. Do use some measures to control soil erosion? Yes or No

80. If yes, which of the following measures do you practice?

Control measure/practice	Yes/ No
Cultivation along contours	
Terracing	
Strip-cropping	

Wind breaks	
Vegetative and crop cover	
Grassed water ways	
Tree planting	
Check dams	
Others (specify)	

80. If no, why?

i) ---

ii) ---

iii) ---

81. Have ever taken any of the following measures because of soil erosion

- Abandoned your land
- Expanded to marginal land
- Have taken off-farm employment
- Others (specify)

82. Do you have problems accessing or being prohibited from using your land? Yes or No

83. If yes, what problems?

i) ---

ii) ---

iii) ---

84. Do you fill secure that the land you cultivate belongs to you? Yes or NO

85. If no, what are the reasons?

i) ---

ii) ---

iii) ---