EFFECTS OF PERIODIC FLOODING AND LAND USE ON SOIL PROPERTIES IN THE LAKE VICTORIA BASIN

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A Thesis Submitted To the Graduate School in Partial Fulfilment for the Requirements of the Master of Science Degree in Environmental Sciences of Egerton University

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DECLARATION AND RECOMMENDATION

Declaration

I hereby declare that this is my original work and has not been presented for the award of any degree in any other university.

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Recommendation

This work has been submitted with our approval as University supervisors.

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DEDICATION

To ladies who work against all odds to achieve their dreams

ACKNOWLEDGEMENT

Let me acknowledge that this project would not have been possible without the intellectual stimulation from my supervisors, a number of Egerton University lecturers, and emotional support from my family and friends. It is not possible to acknowledge by name all who have helped me. However, I would like to mention a few.

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ABSTRACT

Soil fertility change resulting from changes in land use often leading to soil erosion and periodic flooding downstream is a major challenge to crop production in Lake Victoria basin. A study of soil properties was carried out to determine the effect of land use and periodic flooding on soil fertility in two river catchments draining into the Lake Victoria, namely; Sondu-Miriu in Kenya and Simiyu-Duma in Tanzania (2007). Focused group discussions were held and structured questionnaires administered to farmers whose farms were sampled to assess local peoples' knowledge on soil fertility indicators. Soil samples were collected from cropped and grazed fields following flooding and non-flooding conditions at 0-20 cm depth along the river transect from upstream to downstream and analysed for organic carbon, total nitrogen, extractable phosphorus and exchangeable potassium, β- glucosidase activity, texture and pH. Analysis of variance was performed using Proc GLM to determine variation between treatments and Pearson linear correlation in SAS program to determine associations among soil properties. Crop yields, soil colour (dark), and presence of local weeds such as pig weed (*Amaranthus hybridus*), and tropical spiderwort (*Commelina benghalensis*) were the most commonly used local indicators of high soil fertility. Soil properties were not statistically different between various land use categories with exception of β glucosidase activity that was significantly higher on the grazed than cropped fields of Sondu midstream (203 vs. 107 μg /g dry soil $h^{-1)}$ and Simiyu downstream (163 vs. 82 μg g^{-1} dry soil hr^{-1}) at $P > 0.05$. Conversion of natural land to either cropped or grazed fields resulted in decline of total nitrogen (total N) by 100% in Sondu catchment and 57 % in Simiyu catchment, and exchangeable potassium (K) by 90 % in Sondu. There was no difference between soil properties from flooded and non-flooded sites on both catchments. The most significant trend was reduced β glucosidase activity, OC, total N and clay across the Sondu catchment from upstream to downstream while these properties, in addition to K and P increased from upstream to downstream for Simiyu. In Sondu, β glucosidase activity correlated positively to organic C ($r=0.61$, $p<0.0001$), total N ($r=0.60$, $p< 0.001$) and clay ($r=0.46$, $p=0.005$) and negatively correlated to sand ($r=-0.36$, $p=0.01$). Simiyu had a weak correlation of β glucosidase but organic C and total N correlated positively with clay in both catchments. This study results indicate that the change in soil properties was more apparent across the river catchment from upstream to downstream than between the various land use and flooding conditions.

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CHAPTER ONE
INTRODUCTION

1.1 Background Information

Soil quality assessment does not only give an early warning of soil status but also enables land use planning and cropping based on the capability of such soil to ensure the uses are sustainable (Geordama, 1996). Soil degradation processes are set in motion by deterioration of soil structure and disruption in cycles of carbon, depletion of nutrient especially on the eroded catchments, and weakening of nutrient recycling mechanisms (Greenland and Szabolcs, 1994). Soil degradation brought about by inappropriate land use affects the overall functioning and sustainability of ecosystems (Dick, 1997). Soil erosion has increased in Lake Victoria basin due to fragmentation of land in pursuit of inheritance rights, population growth and increased poverty levels (Kibwage, et al. 2006). In these smaller land parcels farmers overgraze and continuously cultivate land with little regard to soil and water conservation measures with the consequence of the loss of fertile soil. Most farmers do not adequately replenish the soil to improve fertility. Weitkamp, et al (1996), observed that cultivation practices affect nutrient balance negatively in that more nutrients are taken away in plant biomass during harvest and little is brought back through fertilizer application or naturally by organic matter decomposition. Other cultivation practices that affect fertility are such as; losses due to aggregate disruption by tillage that increase aeration, crop residue burning, accelerated water erosion and livestock grazing. Land use modifies structure by influencing aggregate formation and protection of organic matter, which is mineralized to release plant nutrients, between the soil aggregates (Gregorich, 1991). Anguilar and Heil (2008*)* also observed that cultivated fields in the central U. S. A. had significantly lower soil organic matter than grazed fields. Organic matter losses were attributed to increased decomposition due to tillage practices, decrease in litter inputs, and soil erosion. It is clear that the management of soil by farmers is a major determinant of its fertility and capacity to sustain high crop yields especially through conservation and fertility replenishment. Farmers use local indicators such as soil colour and texture to assess the fertility status of the soil that will sustain crop production and these forms the basis of land use systems (Mairura, et al. 2007).

Once soil is eroded, it is carried as by run off as overland flow and causes flood downstream. The flooding and sedimentation affect nutrient cycling mechanisms by retarding organic matter decomposition and biochemical properties (Greenland, et al. 1994), nitrogen and phosphorus from leaf litter on floodplain soils. Substrate availability increases microbial activity and occurrence of exogenous enzymes in the soil. The activity of microbes in transforming the organic matter is likely to be affected by death of microbes that do not survive the floods and the organic matter may accumulate. The β glucosidase enzyme activities studied have been associated with soil biological activities and crop productivity because of their role in catalyses of the breakdown of cellulose to supply energy to the microbes. (Haynes, 2000 and Hoffman, et al., 2003) and therefore such enzymes indicate soil quality in advance (Roper and Ophel-Keller, 1997). The increase in microbial activity may ultimately lead to the onset of anoxia in floodplain soils and, consequently, reduction processes especially denitrification and dissociation of iron hydroxide that reduce the pH of the soil (White and Reddy, 1999).

The reduction in pH after flooding is likely to affect P availability in that most inorganic form of P occurs in combination with various forms of aluminium and iron at pH below 4.5, while magnesium, calcium and other elements bind inorganic P in high pH soils–above 7.5 rendering it unavailable for both plant and microbial uptake (Chacon, et al. 2005). Therefore phosphorus solubility is at its maximum between 5-7.5 pH. The pH changes also affect the tendency of soil system to reduce or oxidise chemicals which affect their availability. Changes in electrical conductivity and displacement of cations may lead to leaching or volatilisation of ammonia. However, partial drying of wet soils will result in an increased soil particles affinity for phosphorus usually retained on the surfaces of clay and this may reduce the availability of P to crop (Imbellone, et al. 2001). Conversely, on complete desiccation of sediments, the death of bacteria means mineralization of N and P in the microbial biomass, a decrease in the affinity of P for iron minerals which forms oxidized layer around the phosphate particles, a decrease in microbial activity and a cessation of all anaerobic bacterial processes e.g. denitrification. This leads to availability of N and P which is readily taken up by the colonizing plants.

Potassium occurs in significant quantities in exchangeable form but the wetting of soil, followed by expansion of clays fixes potassium ions in the interior of the crystal structure and trapped in the interior lattice on drying of clay thus not available to crops. Flooding conditions may lead to leaching of potassium thus it is rendered unavailable to crops (Mclatchey and Reddy, 1998).

Fine textured soils deposited by flood water are more chemically active and therefore able to hold more nutrients than coarse textured soils. Conversely, this adsorption capacity to bind or fix nutrients in fine textured soils may render them unavailable to plants or unavailable phosphorus from leaf litter on floodplain soils. Substrate availability increases microbial activity and occurrence of exogenous enzymes in the soil. The activity of microbes in transforming the organic matter is likely to be affected by death of microbes that do not survive the floods and the organic matter may accumulate. The β glucosidase enzyme activities studied have been associated with soil biological activities and crop productivity because of their role in catalyses of the breakdown of cellulose to supply energy to the microbes. (Haynes, 2000 and Hoffman, et al., 2003) and therefore such enzymes indicate soil quality in advance (Roper and Ophel-Keller, 1997). The increase in microbial activity may ultimately lead to the onset of anoxia in floodplain soils and, consequently, reduction processes especially denitrification and dissociation of iron hydroxide that reduce the pH of the soil (White and Reddy, 1999).

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Fine textured soils deposited by flood water are more chemically active and therefore able to hold more nutrients than coarse textured soils. Conversely, this adsorption capacity to bind or fix nutrients in fine textured soils may render them unavailable to plants or unavailable for microbial breakdown (Walworth, 2003). The activity of acid phosphatase was reduced substantially in the fine fraction of the soil (silt + clay) in the maximum flooding zone which was attributed to adsorption onto non-crystalline Al oxide, Al (OH) x of montmorillonite complex, kaolin and Fe oxide (Chacon, et al 2005). Texture also determines the aeration of soil for micro organisms that mineralize nutrients.

1.1 Statement of the Problem

Sustainability of land uses in Lake Victoria basin is a concern due to clearing of forested land and converting it to overgrazed and continuously cultivated arable lands. The soil is left bare and susceptible to erosion, whereas intensive cropping mine nutrients leading to decline in soil fertility and low crop yields. The problem is aggravated by the fact that most farmers do not have measures to conserve soil and water on their farms and do not replenish soil fertility. The eroded soil from upstream catchments leads to overland flow that is deposited on the downstream sites leading to floods. The floods lead to low food production by causing extensive damage to cropped lands and setting conditions that affect nutrient availability. In areas where floods persist long enough to cause biochemical change, nutrient mineralization is reduced substantially. The sediment influx may lead to anoxic conditions that hinder microbial activity and decomposition of organic substrates. The numerous socioeconomic activities exacerbate the problem by reducing the amount of land available to dissipate floods. In the end, more floods are experienced and the subsequent loss of food production and the extensive damage to crops lead to food insecurity and poverty for over one third of the total population in East Africa that live in the Lake Victoria region.

1.3 Objectives

1.3.1 Broad objective

The main objective is to assess land use and periodic flooding effects on soil properties along two river catchments in Kenya and Tanzania.

1.3.2 Specific objectives

i. To map soil quality using local indicators of soil fertility at the two river catchments; Sondu Miriu and Simiyu-Duma
ii. To assess the influence of various land use classes on soil properties in the two floodplains
iii. To assess change in soil properties due to conversion of land from natural to other uses
iv. To assess soil properties as influenced by periodic flooding
v. To assess soil properties change from upstream to downstream of the two river catchments; Sondu Miriu and Simiyu-Duma

1.4 Hypotheses

i. Soil quality can be mapped using local indicators that are used by farmers to define soil fertility status.
ii. Soil properties vary with different land uses.
iii. Soil properties change from conversion of natural land to other uses
iv. Soil properties vary under different flooding conditions.
v. Soil properties change from upstream to downstream

1.5 Justification of the study

Land use practices have significant effects on sustainability of soil fertility for continuous production and ability to recover from disturbance. Soil erosion is brought about by inappropriate land uses such as overgrazing, continuous cropping and tillage on the slopes with little regard to soil and water conservation. Soil fertility declines continuously as natural land is converted to cropped lands with the consequence of declining soil fertility. Flooding of downstream sites is a recurrent problem of the area once the loaded run off is deposited, with adverse consequences to crops and livelihood of the communities. Studies of Lake Victoria basin have indicated that the highest predicted soil loss was from crop land use with 93 t ha^{-1} yr^{-1}

compared to rangeland with 52 t ha^{-1} yr^{-1} and forested sites with16 t ha^{-1} yr^{-1} (Rwetebula, and Desmedt, 2005). So far, no efficient intervention has been taken to reverse the situation neither has scientific field assessment been done to propose informed interventions. For any intervention to be successful there is need to tap on the local knowledge and complement it with empirical soil quality assessments to allow knowledge extrapolation in management of such ecosystems. The soil fertility gradients generated from this study will assist land users in coming up with short and long term measures to replenish soil fertility in order to achieve sustainable food production.

CHAPTER TWO: LITERATURE REVIEW

2.1 Role of indigenous knowledge in soil fertility management

Farmers are aware of the soil types, soil characteristics, soil fertility status and soil distribution in their farms (Kimiti, et al. 2007). The knowledge was tested scientifically in a study by Mairura, et al. (2007) in Central Kenya. They verified that farmers' soil fertility knowledge had a matching relationship with the scientific indicators of soil organic carbon, total nitrogen, extractable phosphorus and soil pH. In their study, most farmers identified, crop yields and performance, and weed type as the most common indicators of high or low fertility. Kimiti, et al. (2007) also observed that farmers use different organic and inorganic fertilizers to replenish reduced soil fertility on their farms. The organic inputs were ranked as poultry > goat manure> cattle manure in that order of decreasing quality. Despite the fact that cattle manure was ranked as having the lowest quality, farmers attested that it is commonly used because it is readily available though not in adequate amounts. Other soil fertility managements were terracing, use of leguminous plant residues, fallowing and crop rotation. Thus local soil knowledge has been utilized in land management so as to increase productivity. Such knowledge of soil may benefit agricultural development by providing more environmentally and culturally acceptable basis for technological change in agriculture. The relationship between local indicators and fertility level is useful in extrapolating nutrient levels of different soils as depicted by local indicators thus presenting farmers with a rapid appraisal of land management given the limited access to soil analysis facilities. Mapping by farmers also provide a mechanism for field assessment and monitoring of soil quality by scientists.

2.2 Land use effects on soil properties

Land use practices exert a major influence on soil nutrient enrichment especially on wetland soils because they impact on soil structure and function of ecosystem. Gathumbi and Graetz (2005) observed that land use on wetland soils affect air and soil temperature that greatly influence the vegetation type and soil surface properties. Houghton, et al. (1991), reported lower soil organic matter in agricultural sites than in natural sites which they attributed to faster decomposition of residues and accelerated mineralisation as a result of increased exposure to the sun and subsequently higher temperatures. Taboada (2003) found that, soil porosity was significantly higher in non grazed than in grazed fields on dry soil but having macro porosity when smaller aggregates are bound into large structural units in wet soils. He attributed this to the weakened soil structure that results in large and massive soil clods which become very hard when dry.

Cultivation of soil means constant mixing of the soil which leads to faster decomposition of organic matter which if not adequately replenished, renders the soil susceptible to erosion and loss of fertility. Weitkamp, et al. (1996) observed that the influence of cultivation practices on soil properties is gradually strengthened and that of natural factors weakened in that cropping systems influences nutrient cycling and nutrient balance of soils due to the output taken away in plant biomass and this nutrient mining differs with crop varieties. Therefore, on floodplain soils, the nutrients brought in by flood waters may in some cases not complement that taken away by crop harvests. Gregorich, (1991) found that nutrient availability depended on textural differences brought about by cultivation in that aggregate formation protects organic matter that is mineralized to release plant nutrients.

Soil conservation measures increased yields substantially since terraces, strip cropping and trash lines provide favourable environment for plant growth by retaining adequate available water, soil air, soil temperature, structure and a continuous supply of essential elements.

2.3 Flooding effects on soil properties

The main electrochemical and chemical changes that affect fertility include decrease in redox potential; changes in soil and floodwater pH; changes in electrical conductivity; reduction of Mn (IV), Fe (III), and SO_4^{2-}; changes in the availability of nutrients such as nitrogen, phosphorus, potassium, sulphur, boron, copper, and production of carbon dioxide, organic acids, and hydrogen sulphide.

When soil is flooded, oxygen supply decreases to zero in less than a day because biological activity including root and microbial respiration rapidly diminishes the available free oxygen through oxidation of decomposing organic substrates. In absence of oxygen, organic matter accumulates as a result of reduced microbial activity. Reduction of different elements takes place at different times and this alters the oxidation- reductions potential (Eh), pH and nutrient availability (Unger, et al., 2009; Imbellone, et al. 2001). The (Eh) controls the stable form of nitrogen in soil through denitrification and its availability to crops although low (Eh) favours nitrogen fixation. A low (Eh) increases availability of phosphorus, iron, manganese and molybdenum but decrease sulphur and zinc.

Soils which have been saturated with water for a prolonged period of time may show an increased soil pH. The main reason for the increase in pH change is the denitrification of soil nitrate to nitrogen gas which occurs under anaerobic conditions. For each atom of nitrate nitrogen which is converted to nitrogen gas, 6 atoms of acidic hydrogen are neutralized by forming water molecules as part of the bio-chemical reaction. It is also attributed to the release of hydroxyl ions when $Fe(OH)_3$ –soluble at low pH - and similar compounds are reduced to $Fe(OH)_2$ or $Fe_3(OH)_8$. In alkaline soils, the pH will tend to decrease due to accumulation of carbon dioxide in calcareous or sodic soils. The variations in soil pH are more pronounced in the first cycles than in the second cycle and stabilizes at 5.9-7.2 in the subsequent cycles (Imbellone, et al. (2001). Many biochemical reactions are dependent on pH levels which influence the chemical equilibria, sorption and desorption, NH_3 volatilization, and microbial processes that release or destroy plant nutrients as well as toxicity of elements such as aluminium, iron and manganese at pH below 4.5. Concentration of the toxic levels of carbon dioxide, organic acids, and hydrogen sulphide is also high at very low pH.

Most microbial activities influenced by enzymes are known to be optimum at a neutral pH (Frankenberger and Dick, 1983). For instance, ammonification, denitrification, SO_4^{2-} reduction and methane formation are favoured in submerged soils at an optimum pH of 5-8 (Peter, et al. 1996). The range also enhances microbial release of nitrogen and phosphorus, by reduction of concentration of substances that interfere with their availability such as aluminium, iron, and manganese. The electrical conductivity is influenced by the mobilization of Fe^{2+} and Mn^{2+}; formation of $NH4^+$, HCO_3^- and carboxyl in acidic environment and the subsequent displacement of cations from soil colloids by Fe^{2+}, Mn^{2+} and NH_4^+. The displaced cations may be lost in percolating waters and soil fertility is reduced. The subsequent decrease in electrical conductivity is as a result of their precipitation into stable compounds. However, the soil may exhibit a buffering quality where flooding may result to an optimum pH range for the availability of most nutrients at pH 6-7.5 when the negatively charged clay attract basic ions of calcium, magnesium, sodium, aluminium and other positive ions.

Hupp, (2000), observed a rapid decrease in decomposition rates even with low sedimentation levels (i.e., 0.20–0.32 cm yr^{-1}). Rates of carbon loss appeared to approach a reduced equilibrium at sediment accumulations above 0.50 cm yr^{-1}. In comparing decomposition among several floodplain forests in the South Eastern United States, Baker, et al. (2001) observed the lowest rates of foliar litter decomposition on the Cache River floodplain in Arkansas, a system characterized by high rates of sediment accumulation. They also observed that, impacts of sedimentation on arthropod numbers and composition were not apparent. These data suggest that reduced decomposition rates could only be associated with declines in microbial populations rather than changes in arthropod populations. It is therefore apparent that fertility of the soil is influenced by microbes that drive nutrient transformations that are important in releasing nutrients to plants (Sparling, 1991). For this to occur, the microbes require the help of exoenzymes that break down the substrate for microbes therefore enzymatic activity depicts ability of soil microbes to mineralize various substrates to release soil nutrients as those of nitrogen, potassium and phosphorus (Roys and Hornsby, 1994). β glucosidase is derived predominantly from soil microbial heterotrophs, in particular members of the mucorales (fungi) to catalyse the cleavage of cellobiose broken down from cellulose to release two moles of glucose per mole of cellobiose and, therefore, regulates the supply of an important energy source for microorganisms unable to directly take up cellobiose. Therefore it has a potential for monitoring biological soil quality and this is ascertained by its high correlation with carbon and microbial carbon (Turner, 2002). Tabatabai, (1994) observed a positive correlation in activity of β glucosidase with soil fertility and crop yields and these measurements were superior to measuring microbial abundance for the same purpose. The enzyme activity directly affects soil quality and vegetation communities by controlling the biological activities that are responsible for releasing nutrients (Chrost, 1991; Sinsabaugh et al. 1991).

Enzyme (β glucosidase) activities are affected by soil physical properties such as the clay contents of the soil, organic matter availability and management practices or conditions such as flooding that affect aeration. On the other hand, nutrient brought to floodplains affect the microbial processes and plant communities (Wright and Reddy, 2001a); for instance, phosphorus enrichment stimulates microbial activity and organic nitrogen mineralization (White and Reddy, 2000). Of these processes, the most important is mineralization of organic carbon which is the chief element of soil organic matter (58 %) as a source of energy for decomposition and mineralization of nutrients. The carbon contents available may therefore indicate potential of microbial activity (Haynes, 2000 and Hoffman, et al., 2003) in decomposition of organic material in to various nutrients and remobilization and cycling of nutrients (McLatchey and Reddy, 1998), and thus play a central role in the metabolism of the entire ecosystem (Chrost and Siuda 2002).

Under flooded conditions, the series of nitrogen cycle processes: fixation, mineralization, nitrification, immobilization, and denitrification are altered. Biological nitrogen fixation accounts for 72 % of nitrogen used by legumes hence the inhibition of *Rhizobia* activity means the crops meet the entire nitrogen requirement from the soil (Giller, 2001). Mineralization of nitrogen in waterlogged conditions is characterized by incomplete decomposition due to reduced activity of *Nitrosomonas* and *Nitrobacter* oxidation activities at pH above 7.7 at which calcium is deficient. Mineralization by soil microbes is at its best from organic matter and symbiotic fixation at pH 6-8. Higher pH induces nitrogen loss through ammonia volatilization (Noah, et al. 2002). Mineralization also varies with soil temperature being as high as 170 mg l^{-1} at 30° C as compared to 90 mg l^{-1} at 20° C; and the organic matter pool which reduces with the length of wet period (Haynes, 2000). The ammonium mineralized in submerged soil may be in solution phase and thus liable to loss by leaching especially in sandy soils (Pinay, et al. 1995). Nitrification of ammonia to nitrate is inhibited by flooding and the death of nitrifying microbes due to desiccation or dormancy if they cannot withstand the osmotic pressure (Rice, et al. 2005). Denitrification process sets in whereby some anaerobic organisms obtain oxygen from reduction of nitrates (NO_3) and nitrites (NO_2). The nitrite may be further reduced to dinitrogen oxide (N_2O) or molecular (N_2) and lost to atmosphere or simply reduced to ammonium (NH_4^+). Losses on the order of 20- 300 kg N ha^{-1} yr^{-1} have been recorded within a month after flooding. The loss is even higher when wet conditions alternate with dry season, due to upward NO_3- movement during dry season that result in nitrite accumulation on the top soil where it is easily denitrified when flooding sets in (Ponnamperuma, 1980) or leaching of nitrates accumulated during the dry season in to lower horizons.

On flooded soils, phosphorus is found in the least soluble form of calcium and aluminium phosphates while the plant absorbs it in form of di- and mono- hydrogen phosphate ($H_2PO_4^-$ and HPO_4^{2-}). Phosphorus availability on flooded soils is mostly limited by soil organic matter, pH, clay content, the distribution of microorganisms, root condition, and soil fauna in the soil as well as environmental perturbations such as organic amendments, waterlogging, fertilizer additions, tillage, heavy metal inputs, and pesticides. The activity of acid phosphatase is reduced substantially by texture where the activity was negatively correlated with the fine fraction of the soil (silt + clay) in the maximum flooding zone which they attributed to adsorption of acid phosphatase onto non-crystalline Al oxide, Al (OH) x of montmorillonite complex, kaolin and Fe oxide. This suggests that dissolved-P retention is dependent on soil mineralogy and pedogenic processes that form sesquioxides (Chacon, et al. 2005). This was only found in soils flooded for more than 8 months per year. Their findings are contrary to the findings of Jonathan, et al. (2005) who indicated that available phosphorus is high where clay content is high due to the weak associations of phosphorus with clay edges. This was attributed to the fact that clays usually have high organic matter that reduces the crystallization of aluminium and iron oxides indicating that there is more phosphate in solution form; whereas, the inorganic phosphate may fit in crystalline of aluminosilicate sand that deprives soil of inorganic phosphorus.

Waterlogging affects solubility of phosphorus binding compounds of aluminium, iron, and calcium depending on soil mineralogy. Iron phosphate is the dominant form found on flooded soils due to the surface area exposed when the ferric hydroxide is reduced to more reactive ferrous compounds while aluminium is released excessively at pH below 5.2. The deficiency of phosphorus is exacerbated by the precipitation of iron phosphate around the roots thus hindering plant uptake of any available phosphorus. Phosphorus application helps to reduce the toxic precipitate taken up by plants and also increases P absorption. In high pH soils, above 7.5, phosphorus is bound by calcium and magnesium rendering it unavailable to plants (Chacon, et al. 2005). Therefore phosphorus solubility is at its maximum between pH 5 to 7.5 (Walworth, 2003). Joner and Johansen (2000) reported that P mineralization on flooded soils would also be affected by mycorrhiza activity that reduces substantially due to flooding or drought which soils are subjected to after floods.

Potassium occurs in significant quantities in exchangeable form but the wetting of soil, followed by expansion of clays fixes potassium ions in the interior of the crystal structure and trapped in the interior lattice on drying of clay thus not available to crops. Thus, the absolute amount of potassium is not of importance as the potassium in the soil solution and on the exchange sites. Potassium availability is dependent on moisture availability to move to the plant roots. At the same time, too much moisture may leach potassium out from the plough layer

(Mclatchey and Reddy, 1998). Potassium is also important in growth of vascular bundles which strengthen structure support for enhanced oxygen transportation and root respiration which is critical in waterlogged soils.

In flooded soils, the weight percentage of sand, silt and clay particles can be diverse as sedimentation takes place at different hydrological fluctuations of high and low water levels thus depositing both the coarse and fine sediments. Most deposited materials exhibit heavy to very heavy texture top soils that gradually grades to more sandy materials with depth (Mineslav and Vladimir, 1999). In general, gravel and coarse sand are deposited on channel floor, finer sand and silt on levees and the clay in low catchments together with peat. Soil texture affects physical properties of the soil as well as the chemical properties. For instance, a fine textured soil has greater surface area per given volume of soil than coarse textured soil and since the surfaces of soils are chemically active, the fine textured are more chemically active and therefore able to hold more nutrients. Conversely, this adsorption capacity to bind or fix nutrients may render them unavailable to plants or unavailable for microbial breakdown (Walworth, 2003). The physical properties such as water holding capacity, compaction and capillary action are determined by texture and affect erodibility and nutrient mineralization.

2.4 Conceptual model of the study

Figure 1 below shows that inappropriate land use, conversion of land from natural to other uses, without soil and water conservation measures on the upstream leads to soil erosion and soil fertility decline. Subsequently, the eroded material is washed downstream where it causes flooding. Flooding leads to sedimentation on downstream sites, which improve soil fertility leading to higher crop production but at the expense of decreased soil fertility on the upstream. On the other hand, deposited material may bury organic matter and retard decomposition leading to low nutrient release for the cultivated crop. Hupp, (2000), observed a rapid decrease in decomposition rates even with low sedimentation levels (i.e., 0.20–0.32 cm yr^{-1}). The sediment particles clog the soil pores downstream thus hindering water infiltration which leads to more floods that reduced arable land. Under these circumstances, crop production is low and farmers try to cope by cultivating land more intensively and the problem of soil erosion and flooding is exacerbated. This unsustainable land use practices have a major impact on socioeconomic status where people are caught in a vicious cycle of poverty.

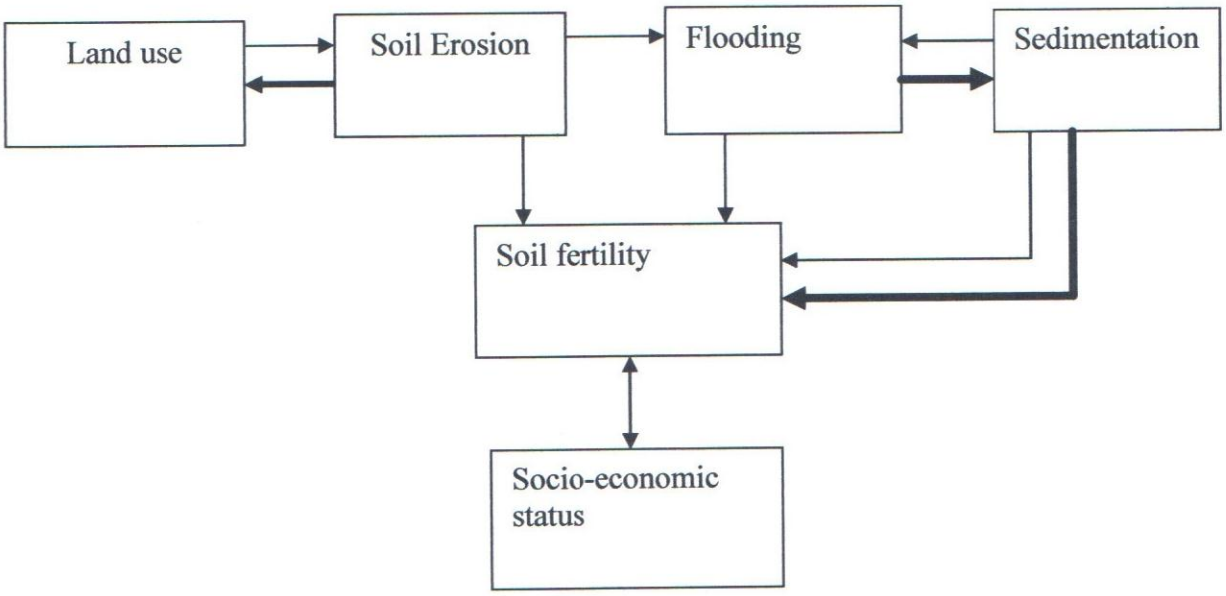

Figure 1: A diagram showing relationship between soil fertility and land use

The bolded **⟶** arrows indicate positive effects to the variable pointed

The normal ⟶ arrows show a negative effect to the variable pointed

CHAPTER THREE

METHODOLOGY

3.1 Study Area

Lake Victoria catchment extends over an area of 193000 km^2 of which 44 % is Tanzanian, 22 % Kenyan, 16 % Ugandan, 11 % Rwandan and 7 % Burundi while the Lake covers an area of 68800 km^2 of which 6% is in Kenya, 43 % in Ugandan, and 51 % is in Tanzania. The study was carried out in Simiyu-Duma (referred to as Simiyu hereafter) and Sondu Miriu river catchments (referred to as Sondu hereafter) of East Africa with a catchment area of approximately 33 and 3,487 km^2 respectively (SIDA International, 2005).

Sondu catchment receives annual rainfall of more than 2,000 mm, with peaks during the long rains in March-May and the short rains in September-October. The headwaters start at 2000 m asl and descend to 1100 m asl to the lake. Flooding occurs twice a year; May to June and November to December to an average depth of 0.3 to 0.6 m. Generally, the catchment has a warm tropical savannah climate with average temperature of about 23° C (Rwetebula, and DeSmedt, 2005). The Simiyu catchment situated in Magu district within Mwanza region in Tanzania has two rainy seasons as well; the long rains from March to May and the short rains occur from November to December amounting to 700 to 1000 mm of rainfall annually. The headwaters start at 1640 m asl and descend to 1140 m asl at Speke Gulf of Lake Victoria (Rwetebula, et al 2004).

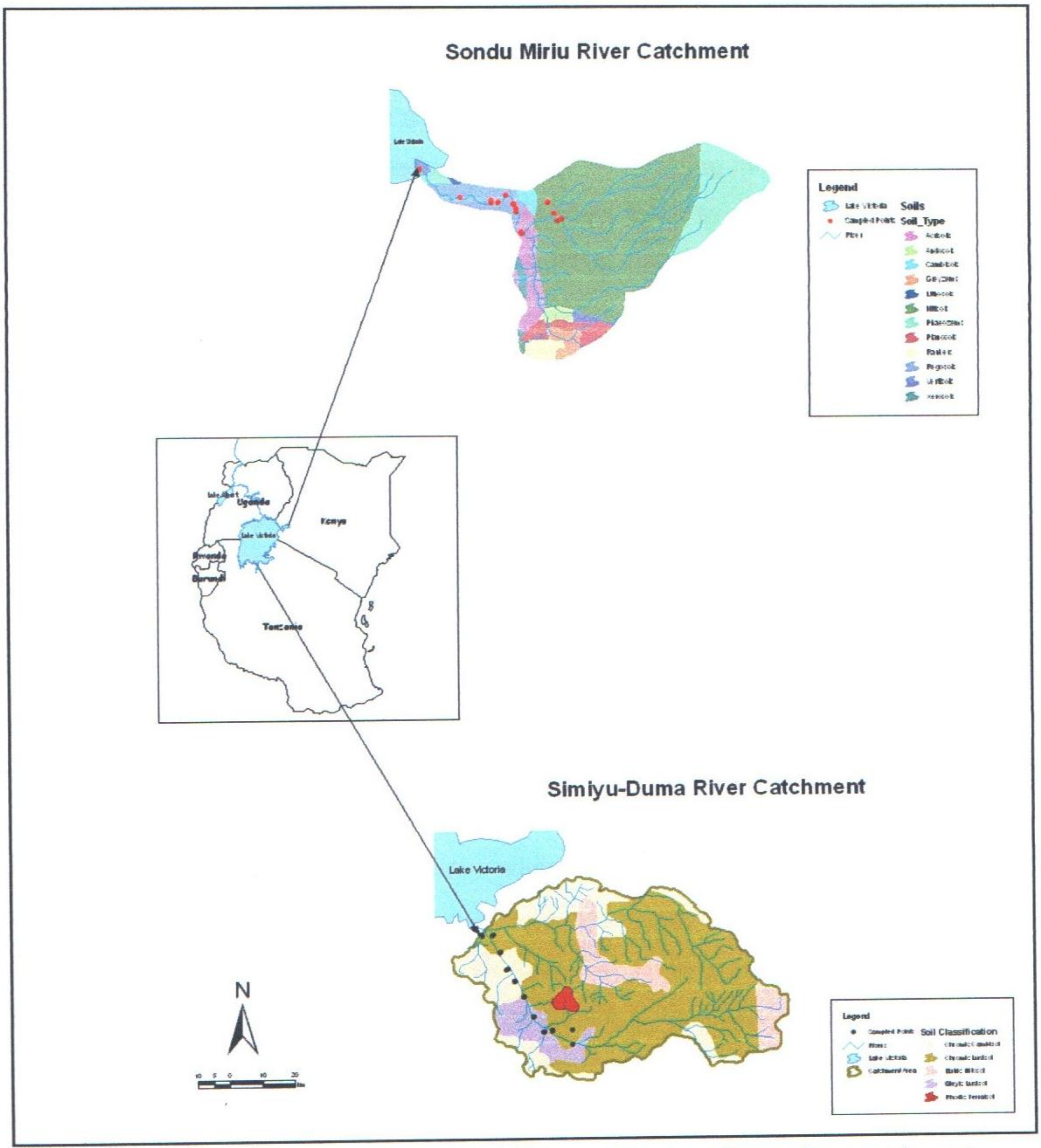

Figure 2: Sampling points used in Sondu-Miriu and Simiyu-Duma river catchments

Source: Ecosystem Management and Restoration Information System (EMRIS) Africa

The upstream of Sondu Miriu river catchments is dominated by nitisols that are strongly weathered and being on hilly land, are susceptible to erosion (Fig. 2). The midstream catchments is dominated by regosols that are not well developed due to constant erosive activities that leave the soil bare and this is exacerbated by inappropriate farming methods. Towards the river mouth, the vertisols dominate and the shrink swell property leads to extensive flooding during the rainy season and cracking during the dry season that leads to drought (Sombrek, et al 1982). The clay content is higher 46% in the subsoil but lower (31 %) in the top soil compared to 40-80% of clay on top soil for most vertisols. The sand is high (16-59 %) due to the surrounding granitoid gneisses at the river mouth. The Simiyu catchment is mostly covered by sandy loam - 60% of the total area (Rwetebula, et al., 2004). The upper catchments is dominated by gleyic luvisols that are mucky due to its clayey nature that occur on high landscape position, the midstream has cambisols that are slightly weathered due to active geological erosion while the downstream catchment is dominated by chromic luvisols that are moderately weathered (Samki, 1977).

More than 80 percent of the population in the Lake basin is engaged in agricultural production, the majority are small scale farmers and livestock owners producing maize, beans, sorghum, millet, wheat and cash crops such as cotton, sugarcane, tea, coffee, with light levels of fertilizer application on crops. The main types of woody vegetation are savannah woodland (*Acacia, Albizzia and Butyrospermum*) while the main species of herbaceous vegetation are *Cymbopogon, Hyparrhenia, Londetia and Cyperus papyrus*. There is an observable trend of change in land use with decrease of forest areas due to very high population (International Lake Environment Committee, 1999). Communal grazing is the most practiced livestock management system in both catchments with some pastures reserved for the dry season. In a later study, Rwetebula and de Smedt, 2005) observed that 46.5 % of Simiyu catchment is open land mainly covered by cultivated and grazing land that is subjected to erosion. The south eastern part is covered by bushland of the Serengeti game reserve.

3.2 Data Collection

3.2.1 Social Data Collection

The local knowledge on soils was obtained using participatory approaches by holding focused group discussions to identify and classify local indicators of soil quality such as texture, soil colour, weed type, crop yields, water holding capacity and landscape position Semi-structured questionnaires were administered to 25 farmers whose farms soils were sampled. (See appendix 1).

3.2.2. Soil Sampling

Sampling was done in upstream, middle stream and lower catchments. The samples were picked from grazed and cropped land uses under flooded conditions and under non-flooded conditions. In Sondu sampling was done in November 2007 during the dry spell, 15, 15 and 17 samples were collected from upper, middle and lower catchment. In the Simiyu catchment, sampling was done in March 2008 before the long rains. 13, 16 and 12 samples were collected from upper, middle and lower catchment (Fig. 2).

A natural site that was relatively undisturbed was also sampled to act as a reference point for Sondu at a field at the South West block of the Mau Forest. The area had indigenous trees dominated by *Croton macrostachyus* and *Newtonia hilderbranditii*. The reference point for Simiyu catchment was at Mwakinyama Game Reserve, Maswa which is dominated by indigenous trees Msubata (*Dispyros fischeri*), Msingisa (*Boscia mossambicensis*), Mbapa (*Markhamia obtusifolia*), and Mkoma *(Grewia bicolor)*.The samples from reference points were used to calculate the deterioration index as:

Deterioration index (%) = {(land use soil fertility level –natural site soil fertility level) / land use soil fertility level} × 100

At each sampling point, several soil cores (depending on size of the field under each land use; 40 cores per hectare) were taken at 0-20 cm depth using a soil auger (5 cm diameter). The core sub samples were mixed thoroughly to make one composite sample. This composite sample was divided into four sections and some soil scoped from each subsection into the polythene bag and labelled as one sample. The samples were stored in a cool box then transported to the laboratory and analysed for organic carbon, total nitrogen, extractable phosphorus and potassium, soil enzyme activities (β glucosidase), texture and pH. The samples were prepared for analysis by air drying indoors for two weeks. Crushing was done using a mortar and pestle to increase surface area for chemical reactions and sieved using 2 mm openings to remove large debris.

3.3 Laboratory analysis

3.3.1 Determinaton of organic carbon

Organic carbon was determined by oxidation. 1 g of soil was sieved to pass (0.3 mm). Ten ml of 5 % potassium dichromate was added to the soil followed by slow addition of 5 ml of sulphuric acid as the mixture was stirred by a vortex mixture. This was then digested at 150° C for 30 minutes. The mixture was allowed to cool before addition of 50 ml of 0.4 % Barium Chloride and then left to stand overnight. The absorbance of the clear supernatant solution was determined spectrophotometrically (ICRAF Manual version 1, 1994).

3.3.2 Determination of Total nitrogen

Nitrogen was extracted by Kjeldahl's method, 7.5 ml of the digestion mixture (hydrogen peroxide, selenium and salicylic acid) was added to 0.4 g of soil and left to stand overnight. This mixture was then heated at 100° C for two hours in the digestion block then allowed to cool before addition of 3 ml of 30 % hydrogen peroxide. The mixture was further heated to 360° C for two hours and by that time, the solution was colourless. This was heated for two hours more to ensure oxidation of all soil nitrogen compounds. After cooling, deionised water was added up to a final volume of 75 ml and then mixed thoroughly. The tubes were stoppered tightly to avoid the absorbance of free ammonia by the digested solution. After settling overnight, 5 ml of Reagent N1 (sodium salicylate, sodium citrate and sodium tatrate) made 24 hours earlier were added. Then 5 ml of Reagent N2 (sodium hydroxide and sodium hypochlorite solutions) made just before use, was added as well. The absorbance was read out spectrophotometrically at 655 nm (ICRAF Manual version 1, 1994). Some samples that gave higher readings than the highest standard were repeated using half the sample weight.

3.3.3 Extractable phosphorus and potassium

Extraction of potassium and phosphorus was done using Modified Olsen's method where 2.5 g of soil was extracted with 25 ml of the extractant (0.5M sodium bicarbonate at pH 8.5 adjusted with sodium hydroxide + ethylene diamine tetra-acetic acid (EDTA). The resultant solution was stirred for 10 minutes and then filtered through Whatman No. 5 filter paper. After filtration, potassium was read out on a flame photometer. Then the phosphorus colour reagent of antimony potassium tartarate and ammonium molybdate and sulphuric acid was added to the remaining aliquot to determine phosphorus colorimetrically at 880 nm (ICRAF Manual, version 1, 1994).

3.3.4 Measurement of soil enzyme activities

The activity of β glucosidase was assayed by using the substrate para-nitrophenol- β glucopyranoside (PNG). Dry soil (1.00 g) was weighed into Erlenmeyer flasks (two replicate samples per soil sample), and incubated for 1 h in an incubator at 37°C with 0.25 ml toluene to inhibit metabolism during the assay, (Tabatabai, 1994) 4 ml of 0.05 M modified universal buffer (pH 6.0) and 1 ml of 0.05 M PNG dissolved in buffer. The reaction was terminated by adding 1 ml of 0.5 M $CaCl_2$ and 4 ml of 0.1 M Tris–hydroxymethyl amino methane (THAM), adjusted to pH 12 with 0.5 M NaOH. The mixture was filtered and the absorbance measured at 410 nm. Values were read out against a standard prepared with ρ-nitrophenol. β glucosidase activity is expressed as μg PNP released per g of dry soil per hour (Rice, et al. 1996).

3.3.5 Soil texture determination

Soil texture was determined quantitatively by the hydrometer method. Fifty grams of soil was saturated with distilled water and 10 ml of 10 % sodium hexametaphosphate was added to disperse the soil particles. After 10 minutes, the particles were finally separated by shearing action using electric shaker for 15 minutes to avoid the rupture of individual particles. This was then transferred to a 1000 ml graduated cylinder and filled to the mark. The suspension was mixed by inverting the cylinder for 10 times. A hydrometer was used to take the reading at the end of 40 seconds and this was recorded as the weight in grams of soil smaller than sand (silt and clay) in a litre of suspension while the reading taken after two hours was the weight in grams of soil smaller than silt in a litre of suspension. The percentage of sand was determined by the difference in total weight of the sample and the sum of the silt and clay. Then description of deposits in classes was defined by the principle particle in weight percentage of any given class (Okalebo, et al. 2005).

Since the hydrometer calibration was taken at a standardized cylinder of a particular dimension and condition, a cylinder of such diameter and volume was used and, a correction was therefore made for temperatures that were different from that for which the hydrometer was calibrated (Gee and Bauder, 1996).

3.3.6 Soil pH measurements

Soil pH was measured in 1:1 water: soil and 1:1 KCl: soil suspension. The pH meter was calibrated over the appropriate pH using buffer 7 then 4 at room temperature- 22 ° C range using standard buffers. Ten grams of soil were weighed into beakers into which 10ml of distilled water and 0.001 M KCl was added. The mixture was stirred for 30 seconds and allowed to stand for 30 minutes. The electrodes were placed in the slurry, avoiding the overlying solution that may have external influences as that of carbon dioxide, and swirled to ensure equilibrium state then the reading of the pH was done.

3.4 Data analysis

Statistical Package for Social Sciences (SPSS V 11.5) was used for descriptive statistics. All statistical procedures were performed using SAS program (SAS Institute 2001). Analysis of variance (proc GLM) were done to estimate the effect of flooding regime and land use on soil properties and mean separation was done using Tukey's test Pearson linear correlation (proc CORR) analysis was performed to determine associations among different soil properties.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Local indicators of soil fertility

Weed type was the most commonly used local indicator of soil fertility with a frequency of 70.6 % (Table I). Kikuyu grass (*Pennisetum clandestinum*), pig weed, (*Amaranthus hiybridus)*, Macdonald's eye, (*Galinsoga parviflora*) and tropical spiderwort (*Commelina benghalensis*) were weeds indicative of fertile soils while fever tea (*Lippia javanica),* and couch grass (*Digitaria scalaram, chemorut, oyongo*) were indicative of poor soils. Crop yield quantity was also used by 64.7 % of farmers, with a range of 607 to728 kg ha^{-1} of maize being indicative of fertile soils. On the other end, 109 to 291 kg ha^{-1} was quoted as the average yield of poor soils. The yields do not match the classification in the study by Tittonell, et al., (2007) where farmers in western Kenya classified poor soil yield as, 500-1100; medium, 1000–1800; high, 1400–2500 kg ha^{-1}. In a research station in western Kenya, maize grain yield was 4160 kg ha $^{-1}$ when 30kg of phosphatic fertilizer and 2.5 tonnes farm yard manure was applied (Odendo, et al. 2007). The discrepancy shows the suboptimal food production that is experienced on farms partly because of non – application of soil fertility amendments, poor quality seed and poor cultural methods such as not planting or weeding on time.

The use of soil colour as an indicator of soil fertility is not new, for 23.5 % of the farmers interviewed attested to having used colour with 76.5% of them attributing the dark colour of the soil to high fertility. They also cited the light red earth *(ng'ung'unyek)* as indicative of poor soils. The dark colour would be an indicator of high organic matter because of presence of organic matter which has the dark colour.

Table 1: Common soil fertility indicators used in Sondu catchment

Fertility indicators	Fertile Soil	Poor Soil	% of respondents using indicator
Weeds	Kikuyu grass Pig weed	Couch grass Fever tea	70.6 %
Crop yields	607-728	109-291kg ha^{-1}	64.7%
Colour	Dark	Light red	23.5%
Texture	clayey	sandy	17.6
Water holding capacity	High	Low	5.9%

Soil texture has been used by a small number of farmers as a sign of soil fertility with the sandy soils being referred to as poor by 66% of the farmers. This would be explained by the low capacity of the sandy soil to hold water and the loose nature of the soil particles that does not allow nutrients storage. The clay soil was termed as fertile due to the fact that it is mostly found down slope where the nutrients collect after run off. The clay particles are tiny so they expose a large surface area and being colloidal -negatively charged- they have sites to hold most essential cations in the exchange sites thus are able to supply plant nutrients. The findings are similar to those of Chacon, et al, (2005) in their study of local fertility indicators along Oronoco River basin of Venezuela, farmers identified finer texture sediments floodplain soils as fertile which they trapped by using natural barriers that keep out the coarse material from the plot. The farmers then optimized this knowledge by planting drought resistant crops such as cow pea (*Vigna unguiculata*), cassava (*Manihot esculanta*) in the sandy soils while annual crops such as beans (*Phaseolus vulgaris*) were planted on clayey soils and maize on mixed textured soils. Most of the farmers (64.7%) were taught the use of soil indicators by the older experienced farmers from when they were young. This is a clear indication of the untapped local knowledge that ought to be disseminated to all farmers once documented. Overall the soil fertility indicators had a strong relation to the scientific information obtained from analysis of the soils sampled.

4.2 Socio-economic factors affecting soil fertility

Poor soil conservation measures and insufficient use of inorganic fertilizers were the major factors contributing to low soil fertility. Most farmers (65%) do not practice soil conservation measures. Those that do practise soil conservation measures have not done as effectively as most farmers have one or two trash lines, terraces or strip cropping (Fig. 3) along the whole landscape from shoulder to the foot slope. Fallowing is practised by only 9% of the farmers interviewed due to scarcity of land as the population grows leading to fragmentation.

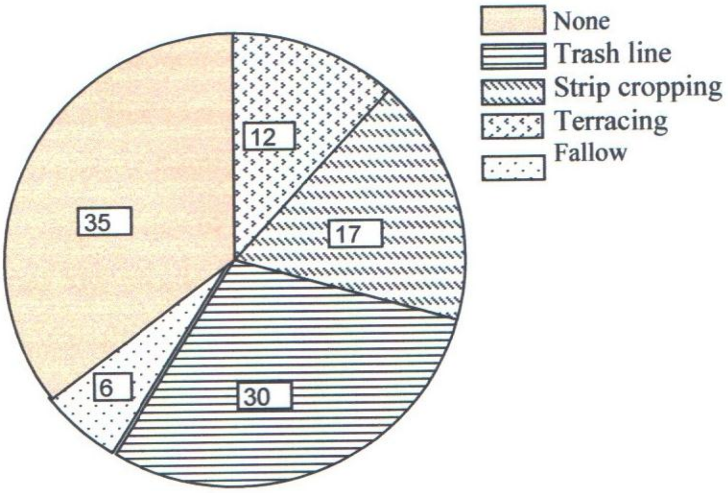

Figure 3: Soil conservation measures used by farmers and their relative frequency

Eighty eight percent of the farmers use both organic (such as animal manure, crop residues) and inorganic fertilizer (mostly di-ammonium phosphate-DAP) on their farms, while the rest use inorganic fertilizer exclusively. The major challenge cited by 65% of those that use inorganic fertilizer is that, they do not use sufficient quantity because of the high prohibitive costs, while 35% were not sure if what they use is enough.

The findings here confirm the findings of Sanchez (2003), who noted that the biophysical cause of stagnant per capita food production in Africa is soil fertility depletion which he attributed to the lack of fertility replenishing inputs such as mineral fertilizer as the costs are 2-6 times as much as in other parts of the world.

The farmers mentioned that they have no alternative fertilizer. DAP was the only fertilizer stocked in the shops for over the last 5 years (for 64%) of the farmers interviewed and over 10 years for 40% of the farmers interviewed. They strongly believe (90%) that a different fertilizer will improve yields hence the loss of interest in the use of DAP as they have uncertainty of achieving higher returns. This finding is similar to that of Hoekstra and Corbett, (1995) in their study of fertilizer use, where they observed that the broad recommendations that assume homogeneity of farming conditions have partly contributed to the reluctance in use of fertilizer technologies by farmers. They suggested that recommendations should be targeted on a group of farmers who share similar circumstances and most important as defined by the agro-economic and socio-economic status. Only 1 % of the farmers had been advised on use of fertilizer, a clear indicator that extension services are limited, with 64% having been advised by other farmers on what type of fertilizer to use.

The use of farm yard manure was mostly confined to the fields near the cattle shelter since few people have established zero grazing systems. Most of the respondents (91.7%) said the manure was not enough with most farmers citing few numbers of animals as the limiting factor. In their study in Western Kenya, Kimiti, et al (2007) found that application of farm yard manure was limited by low availability and low quality which they attributed to poor grazing methods and poor storage.

4.3 Effect of various land uses on soil properties

As seen in Table 2 and 3 below, organic carbon, total nitrogen and extractable phosphorus and potassium were not significantly different across land uses. The lack of observable change in soil properties was probably due the fact that there were different crop varieties on the sampled fields, with different amount of nutrient mining and variation in the time within which the land use has been practised on that field. The same applies to grazed field in that different fields had varying intensity of grazing and density of grass cover hence variation between the two treatments was not apparent. This brought about heterogeneity within the treatment other than between treatments. Wilson and Lemon, (2008) reported similar results, where minimal differences were observed between cultivated fields and unimproved grasslands. However, Wright and Hons (2005) observed that soil organic carbon and soil organic nitrogen was higher in no tillage fields than in cropped fields and there was also significant different for various crops with grain sorghum (*Sorghum bicolor*) having the highest level, wheat (*Triticum aestivum*) and soya bean (*Glycine max*) in that order .

Table 2: Effects of land uses on soil properties (0-20 cm) along the Sondu catchment

Parameter	Land use	Upstream	Midstream	Downstream
Organic Carbon (%)	Cropped	2.5(0.5)[a]	1.6(0.3)	1.3 (0.3)
	Grazed	2.4(0.3)	1.7 (2.5)	1.4 (0.3)
Total Nitrogen (%)	Cropped	0.33(0.16)	0.20 (0.06)	0.13 (0.01)
	Grazed	0.34(0.11)	0.20 (0.06)	0.13(0.04)
Extractable P (mg kg^{-1})	Cropped	2.6(1) *	7.4 (4)	6.2 (7)
	Grazed	5.4(3) *	6.9 (8)	4.5 (3)
Extractable K (mg kg^{-1})	Cropped	234(0.4)	195(0.1)	234 (0.2)
	Grazed	273(0.1)	195(0.3)	195 (0.2)
pH KCl	Cropped	4.4(0.3)	4.2 (0.4)	4.8 (0.1)
	Grazed	4.2(0.5)	4.5 (0.3)	4.5 (0.7)
pH H_2O	Cropped	5.4(0.3)	5.5 (0.3)	5.9 (0.1)
	Grazed	5.2(0.6)	5.7 (0.3)	5.7 (0.6)
β glucosidase(μg /g dry soil h^{-1})	Cropped	211(116)	107(109) *	85 (41)
	Grazed	211(116)	203 (145) *	67(77)
Sand (%)	Cropped	30(9)	41 (6.9) **	50 (9)
	Grazed	26(4)	33 (4) **	46 (16)
Clay (%)	Cropped	50(0.5)	20 (5)	31 (7)
	Grazed	48(0.3)	27 (5)	31 (9)
Silt (%)	Cropped	19(2) *	16 (5) **	18 (7)
	Grazed	26(6) *	39 (6) **	22 8)

[a] numbers in parentheses represent one standard deviation. ** shows significantly different values at P=0.05, * shows significantly different values at P = 0.1

The observable change among different land use was attributable to textural differences in both catchments. In Sondu midstream, β glucosidase activity was significantly higher on the grazed than cropped field (203 vs.107 μg /g dry soil h^{-1}) at $P < 0.1$ where sand was also significantly different (33 vs. 41 %). Simiyu downstream (Table 3) also has higher β glucosidase activity on the grazed than cropped fields (163 versus 82 μg g^{-1} dry soil hr^{-1}) at $P < 0.05$. The same site has relatively more clay (25 vs. 22 %) though not statistically significant. The grazed fields with significantly less sand (Table 2 and 3) and obviously more clay that is known to have more organic carbon that is a substrate for β glucosidase (Chacon et al., 2005) had more activity. In addition high organic C and β-glucosidase activities may be associated with increased organic inputs through sloughed grass roots, exudates and litter in well managed pastures (Martinez et al., 2007). Contrary to this finding, Monkiedje, et al. (2006), observed that land use significantly stimulated organic C, available N, β glucosidase activities, available P, pH, electrical conductivity, and total dissolved substances, whereby these parameters were significantly higher in all cropped lands than in the relatively undisturbed forested land. This they attributed to the agricultural management practices that increased microbial activity/ diversity and carbon turn over. But this was true for fields without pesticide or herbicide application that would interfere with the microbial activities.

Table 3: Effects of various land uses on soil properties (0-20 cm) along Simiyu catchment

Parameters	Land use	Upstream	Midstream	Downstream
Organic Carbon (%)	Cropped	0.7(0.4)[a]	0.6(0.2)	1.2(0.4)
	Grazed	0.6(0.5)	0.5(0.2)	1.1(0.5)
Total Nitrogen (%)	Cropped	0.07(0.03)	0.07(0.03)	0.09(0.4)
	Grazed	0.07(0.04)	0.05(0.2)	0.09(0.03)
Extractable P(mg kg^{-1})	Cropped	8(4)	10(7)	33(33)
	Grazed	7(5)	11(10)	19(5)
Extractable K (mg kg^{-1})	Cropped	78(0.3)	156(0.2)	195(0.1)
	Grazed	117(0.3)	234(0.3)	234(0.2)
pH (H_2O)	Cropped	7.7(0.2)	8.0(0.3)	7.7(0.4)
	Grazed	7.9(0.1)	7.8(0.2)	7.9(0.4)
β glucosidase(μg g^{-1} h^{-1})	Cropped	122(112)	188(147)	82(40) **
	Grazed	139(100)	129(98)	163(42) **
Sand (%)	Cropped	34(23)	63(16)	64(16)
	Grazed	40(25)	70(9)	58(14)
Silt (%)	Cropped	19(11)	13(5)	14(7)
	Grazed	19(9)	12(43)	17(8)
Clay (%)	Cropped	47(22)	24(13)	22(10)
	Grazed	41(20)	18(6)	25(8)

[a] numbers in parentheses represent one standard deviation. ** shows significantly different values at P = 0.05, * shows significantly different values at P = 0.1

4.4 Change in soil properties due to conversion of land from natural to other uses

Soils collected at natural undisturbed sites of Sondu catchment, around Mau Forest in Kericho (Table 4) show that nutrient levels have declined as seen from the deterioration index. Phosphorus was the least lost nutrient as compared to other nutrients probably due to phosphatic fertilizer use that was predominantly used by most farmers. There was a deterioration of potassium and total nitrogen by 90% and 100% on average respectively. In Simiyu, total nitrogen declined by 57% as land uses changed from natural to other uses (Table 5). The nutrients have been mined by crops season after season as cropping intensifies with insufficient use of fertilizer and the loss was exacerbated by erosion from the farms where soil conservation is poor.

Table 4: Soil properties (0-20 cm) of natural site (Mau Forest-Kericho) and deterioration index for Sondu upper catchment

Parameter	Natural site	Land use (Grazing)	Deterioration Index (%)
Total Nitrogen (%)	0.6	0.3	-100
Extractable P (mg kg^{-1})	4	5.4	20
Extractable K (mg kg^{-1})	480	273	-75
pH (H_2O)	6.0	5.2	-15
		(cropped)	
Total Nitrogen (%)	0.6	0.3	-100
Extractable P (mg kg^{-1})	4	2.6	-53
Extractable K (mg kg^{-1})	480	234	-105
pH (H_2O)	6.0	5.4	-11

The findings are similar to those of a study done by Lumbanraja, et al. (1998), whereby data was collected from primary forests, coffee plantations and cultivated lands to determine fertility decline. Total amounts of organic C, total N, available P, total P, exchangeable cations and CEC decreased significantly by 2-9 % in 6 years and by 2-15 % in 12 years in the surface layers of soils. Similar results were observed by studies of Lake Victoria basin which indicated that the highest soil loss was from cropped fields and rangeland at 93 and 52 t ha^{-1} yr^{-1} compared with forested sites with 16 t ha^{-1} yr^{-1} (Rwetebula, and Desmedt, 2005). However, phosphorus is 87% higher on the grazed and cropped land use than on the Simiyu natural site. This can be attributed to replenishment of through fertilization since most farmers attested to have been using diammonium phosphate.

Table 5: Soil properties (0-20 cm) of reference site (Mwakinyama Game Reserve Maswa) and deterioration index for Simiyu upper catchment)

Parameter	**Natural site**	**Land use (Grazing)**	**Deterioration Index** (%)
Total Nitrogen (%)	0.11	0.07	-57
Extractable P (mg kg^{-1})	1	8	88
Extractable K(mg kg^{-1})	56	78	28
pH (H_2O)	5.9	7.9	25
		(cropped)	
Total Nitrogen (%)	0.11	0.07	-57
Extractable P (mg kg^{-1})	1	7	86
Extractable K(mg kg^{-1})	56	117	52
pH (H_2O)	5.9	7.1	17

4.5 Effect of flooding on soil properties

Extractable phosphorus was significantly higher on the flooded sites upstream of Sondu (5.9 versus 2.5 mg kg^{-1}) (Table 6) and Simiyu (11.5 versus 4 mg kg^{-1}) (Table 7). The observed trend is attributable to the fertilizer washed by run off that floods such sites. Smaling, et al. (2006) reported that the silt and clay deposits that accompany floodwaters give a renewal of top soil and at the same time add plant nutrients.

Table 6: Flooding effects on soil properties (0-20 cm) along Sondu catchment

Parameters	Flooding	Upstream	Midstream	Downstream
Organic Carbon (%)	Flooded(F)	2.3 (0.1)[a]	1.6(0.1)	1.4(0.3)
	Non F (NF)	2.5 (0.4) ***	1.7(0.3)	1.2(0.3) ***
Total Nitrogen (%)	F	0.3(0.01) **	0.24(0.03	0.14(0.03) **
	NF	0.3(0.01)	0.21(0.06)	0.12(0.03)
Extractable P (mg kg^{-1})	F	5.9 (4)*	6.9(6)	5.7(4)
	NF	2.5 (2) *	7.3(6)	5.4(7)
Extractable K (mg kg^{-1})	F	117 (0.1) **	234(0.3)	195(0.2) **
	NF	39(0.6)	156(0.1)	234(0.2)
pH KCl	F	4.0 (0.4)	4.4(0.1)	4.6(0.7)
	NF	4.5 (0.4)	4.4(0.4)	4.6(0.2)
pH H_2O	F	5.0 (0.6)	5.6(0.1)	5.8(0.6)
	NF	5.4 (0.3)	5.5(0.3)	5.8(0.3)
β- glucosidase(μgg^{-1} h^{-1})	F	165 (100) **	71(29)	52(37) **
	NF	245(106) *	195(136)	107(79) *
Sand (%)	F	32 (14) **	39(9)	43(11) **
	NF	28 (8)	36(5)	53(15)
Clay (%)	F	46 (9) **	24(4)	34(6) **
	NF	48 (8)	23(5)	28(9)
Silt (%)	F	21 (9)	36(7)	21(6)
	NF	23 (6)	40(7)	18(9)

[a] numbers in parentheses represent one standard deviation, *** shows highly significant difference at *P*<0.001, ** shows significantly different values at *P*<0.05, * shows significantly different values at *P*< 0.1

Since the soils here are flooded for less than 4 weeks, the chemical changes were not apparent in other soil properties. Imbellone et al. (2001) observed that reducing conditions that do not persist long enough do not substantially influence soil properties in a vertic Argiudolls (luvic Phaeozem) under periodic flooding of three months (during rice production) followed by three years of dry farming. Changes in soil properties are more distinct under prolonged and recurrent water logging conditions of more than 2 months (Chacon et al., 2005).

Table 7: Flooding effects on soil properties (0-20 cm) along Simiyu catchment

Parameter	Flooding conditions	Upstream	Midstream	Downstream
Organic Carbon (%)	Flooded(F)	0.4(0.2)	0.5(0.2)	1.3(0.2)
	Non F (NF)	0.8(0.4)	0.5(0.2)	0.7(0.3)
Total Nitrogen (%)	F	0.06(0.03)	0.05(0.03)	0.1(0.04)
	NF	0.08(0.04)	0.06(0.02)	0.07(0.03)
Extractable P (mg kg^{-1})	F	11(5)	13(7)	19(11)
	NF	4(1)	8(10)	39(36)
Extractable K (mg kg^{-1})	F	117(0.2) *	195(0.3)	156(0.2) **
	NF	39(0.2) *	156(0.2)	312(0.1) **
pH water	F	8.7(0.1)	8.2(0.1)	7.8(0.3)
	NF	8.5(0.2)	7.5(0.1)	7.7(0.1)
β glucosidase(μg g^{-1} h^{-1})	F	92(59)	156(150)	122(78)
	NF	169(125)	145(113)	121(25)
Sand (%)	F	64(19)	64(16)	22(3) **
	NF	58(8)	69(16)	61(21) **
Silt (%)	F	16(10)	14(5)	21(11)
	NF	14(2)	87(4)	15(6)
Clay (%)	F	20(9)	22(13)	57(11) **
	NF	27(7)	20(7)	24(16) **

[a] numbers in parentheses represent one standard deviation, ** shows significantly different values at $P < 0.05$, * shows significant different values at $P < 0.1$

4.5.1 Organic carbon along the Sondu river catchment

The organic carbon reduced significantly across the catchment from upstream to downstream (Fig 4). This can be explained by the variation in sand content which is significantly higher in downstream than upstream sites. High sand means low level of organic matter associated and accelerated decomposition and mineralization of the available organic substrates due to adequate aeration. Houghton, et al. (1991), reported lower soil organic matter in agricultural sites than in natural sites which they attributed to faster decomposition of residues and accelerated mineralisation as a result of increased aeration, exposure to the sun and subsequently higher temperatures.

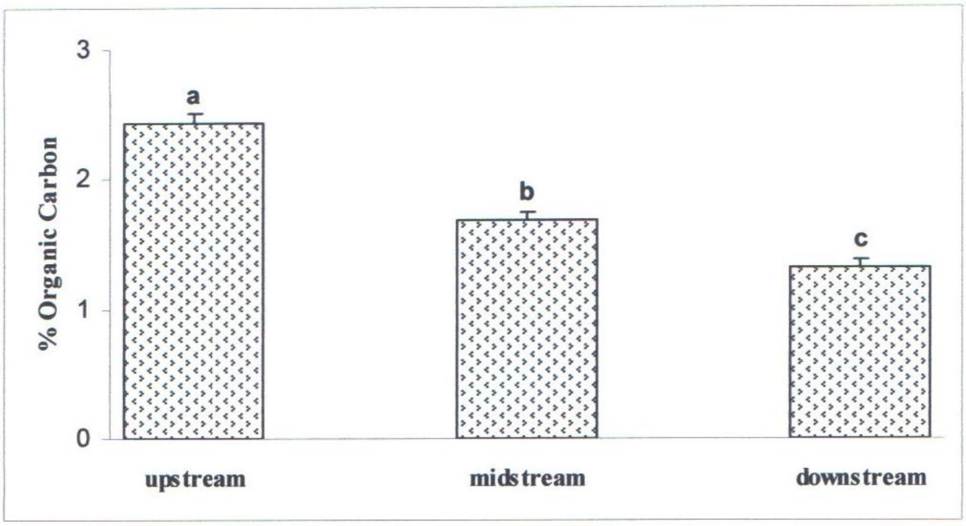

Figure 4: Comparison of organic carbon along Sondu river catchment

Error bars represent standard error, different letters above bars represent statistically significant differences at $P<0.05$

4.5.2 Organic carbon along Simiyu river catchment

Simiyu had significantly high organic carbon on the downstream sites compared to upstream or midstream (Fig 5). This was attributable to the dominance of luvisols that have large amounts of clay particles with high adsorption capacity of organic matter and other unconsolidated material that was deposited on these downstream sites. The clay was significantly higher on flooded section (57 vs. 24%) which created anoxic conditions that retard decomposition of organic matter. In comparing decomposition among several floodplain forests in the South Eastern United States, Baker, et al. (2001) observed the lowest rates of foliar litter decomposition on the Cache River floodplain in Arkansas, a system characterized by high rates of sediment load. It could also be due to pockets of soil which were under anoxic conditions for longer time as that in swamps resulting in reduced microbial activity and hence an accumulation of C. Chacon et al. (2005) reported higher organic C for zones inundated for more than 5 months per year compared to those that were inundated for 2 months along Mapire river basin in Venezuela.

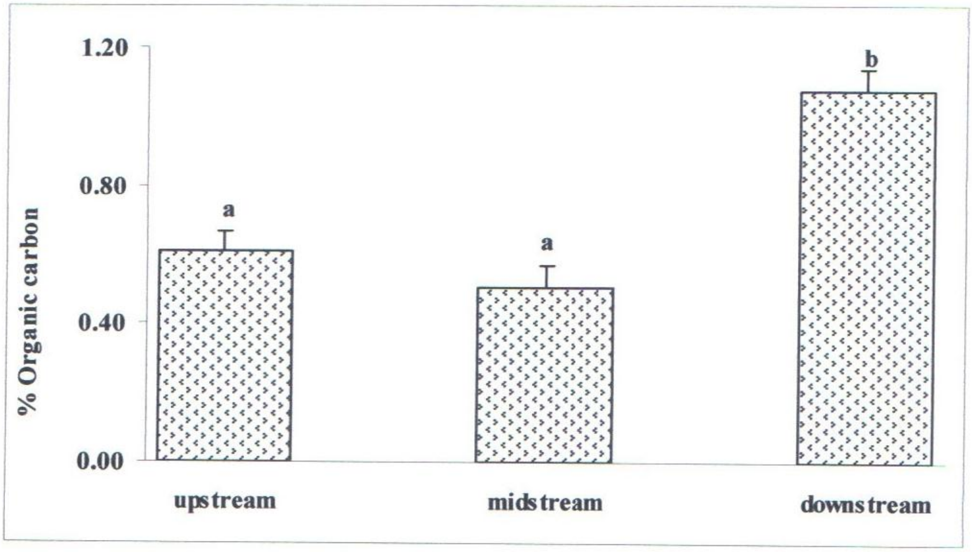

Figure 5: Comparison of organic carbon- Simiyu river catchment
Error bars represent standard error. Different letters above bars represent statistically significant differences at $P<0.05$

4.5.3 Total nitrogen along Sondu river catchment

In Sondu catchment, (Fig 6) total nitrogen was quite low in the downstream site due to losses through leaching on the sandy alluvial soils and the low cation exchange capacity of sand. On saturated soils, nitrates moves by mass flow depending on the efficiency of the plant roots to take it up before it is leached while ammonium nitrogen may be so little due to low quantity of reducible organic matter in the soil. The ammonium mineralized in submerged soil may be in solution phase and thus liable to loss by leaching especially in sandy soils (Pinay, et al. 1995).

The low levels of organic matter and nutrients would be attributed to more intensive cultivation during the dry season observed on the Sondu catchment that mine out the nutrients faster. With repeated drying and flooding cycles, and with no organic matter addition, the readily reducible organic matter decreases with each inundation and this is emphasized by the relative stabilization of soil pH observed when flooding does not significantly result in changes in pH. If organic matter was low, then the available nitrogen was all used up by the microbial community leaving very little in the soil. Unger et al. (2009) observed that flooding affected soil inorganic-N in that NO_3–N decreased under 5-week flood treatments while it increased under 3-week-flowing and on the non flooded treatment. They attributed the decreased nitrogen to anaerobic conditions that hinder decomposition of residues. They also noted that the soluble polyphenolic compounds that bind with proteins or amino acids in the soil form recalcitrant humic-N polymers that are resistant to microbial conversion or plant uptake.

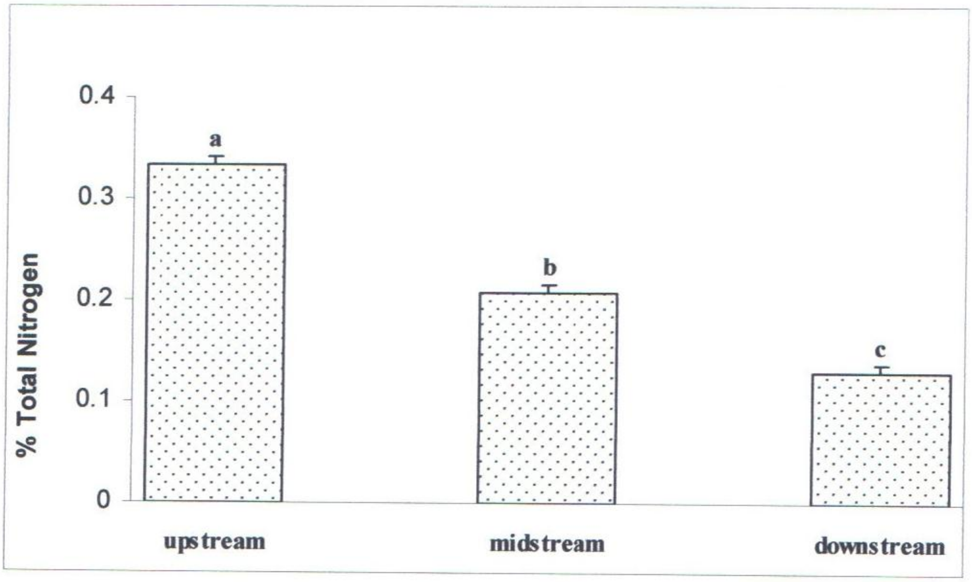

Figure 6: comparison of total nitrogen along Sondu river catchment

Error bars represent standard error. Different letters above bars represent statistically significant differences at $p<0.05$

4.5.4 Total nitrogen along Simiyu river catchment

As seen in Fig 7, higher values of total nitrogen was noted on Simiyu downstream position because values of nitrates may also be observed on drying of previously inundated soils due to the upward movement of nitrates that results in nitrite accumulation on the top soil and when nitrate fertilizer sources accumulates on previously flooded soils (Ponnamperuma, 1980). This may be observed since the soils here were sampled in early March during the dry season. Generally, the level of nitrogen ranged from 0.01 to 0.53 which is similar to the total nitrogen content expected on the surface layer of most cultivated soils (between 0.06 and 0.5 % N) (Atsunobu et al. 2008).

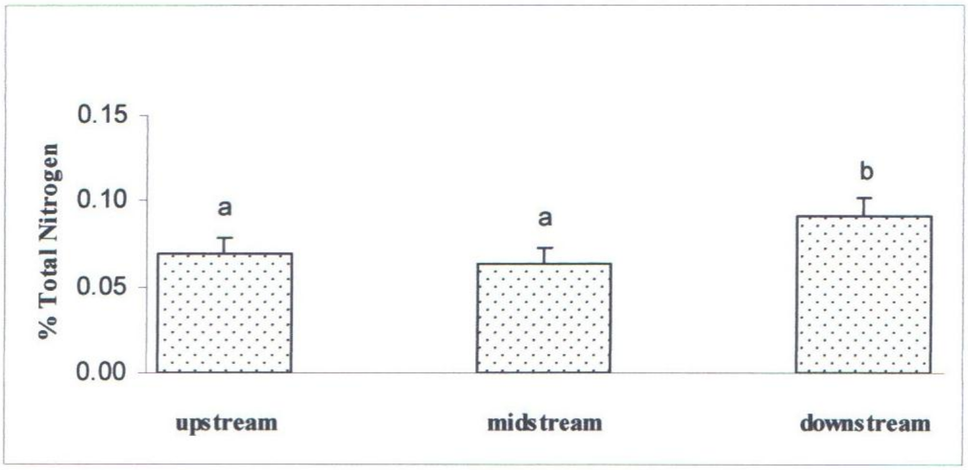

Figure 7: Comparison of total nitrogen along Simiyu river catchment

Error bars represent standard error. Different letters above bars represent statistically significant differences at $p<0.05$

4.5.5 β glucosidase activity along Sondu river catchment

There was decrease of enzyme activity from upstream to downstream (Fig 8). The downstream sites had significantly lower activity (78 $\mu g\ g^{-1}$dry soil hr^{-1}) on average compared to the mid and upstream with 162 and 213 $\mu g\ g^{-1}$ dry soil hr^{-1} respectively. This trend can be attributed to correlation of β glucosidase with the low soil organic carbon in this site. The high amount of sand with less chemically active sites does not hold nutrients for microbes that synthesise β glucosidase. Turner, et al. (2002) attributed correlation, of organic C to β glucosidase activity to the fact that β glucosidase is synthesized by soil micro organisms in response to the presence of suitable substrate.

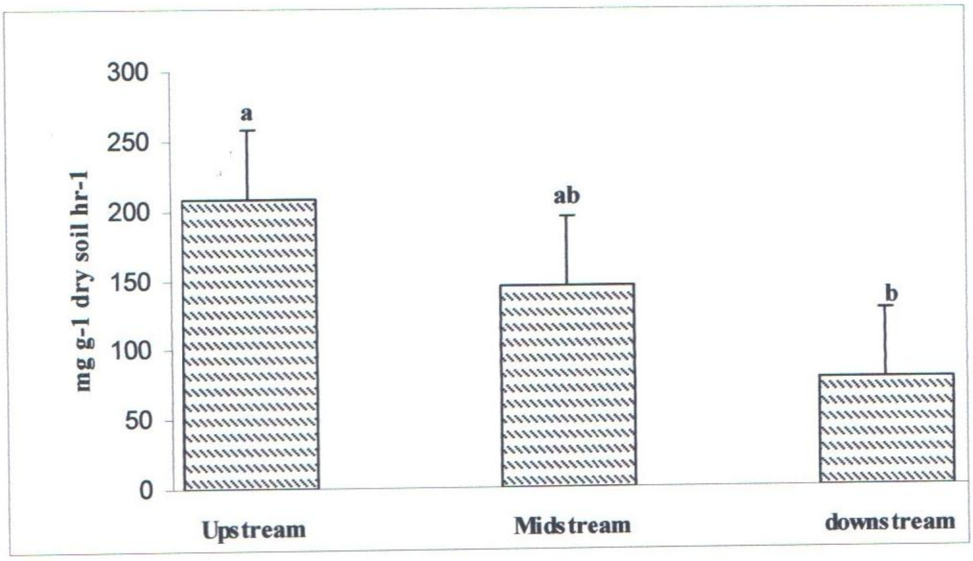

Figure 8: β glucosidase activity along Sondu river catchment

Error bars represent standard error. Different letters above bars represent statistically significant differences at $p<0.05$

4.5.6 β glucosidase activity along Simiyu river catchment

There was observable variation in enzyme activity across the catchment from upstream to downstream although this was not statistically significant at P=0.05. Most notable was the low β glucosidase activity on the downstream where organic carbon had accumulated due to the swampy nature of the soils that lower microbial activity. Chacon, et al. (2005) attributed reduced microbial activity on flooded fields to pockets of soil which remain under anoxic conditions for long time.

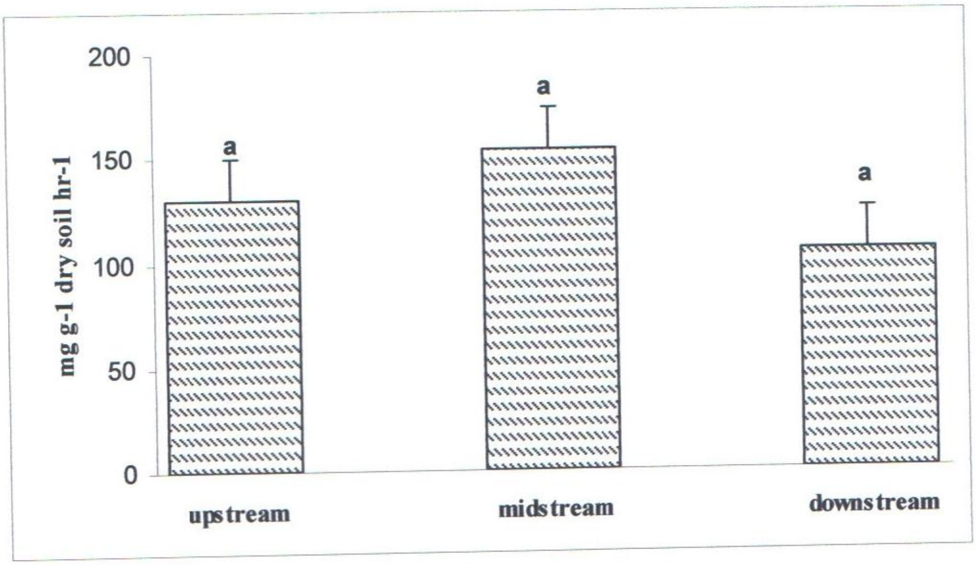

Figure 9:β glucosidase activity along Simiyu river catchment

Error bars represent standard error. Different letters above bars represent statistically significant differences at $p<0.05$

4.6 Soil properties change from upstream to downstream of the two river catchments

On average, organic carbon (2.5 vs. 1.2%) at $P<0.001$, total N (0.3 vs. 0.13%), and β glucosidase activity (205 vs. 79 $\mu g\ g^{-1}\ h^{-1}$) and clay (47 vs.31%) were significantly higher at $P<0.05$ in the upstream than in downstream sites of Sondu (Table 6). However, the reverse was true for Simiyu catchment where total N (0.06 vs. 0.1%), organic C (0.6 vs. 1%), extractable phosphorus (7.5 vs. 29mg kg^{-1}) and potassium (78 vs. 234 mg kg^{-1}) were relatively lower on the upstream than in downstream sites (Table 7). The most probable explanation of this trend would be the difference in major soil type from upstream to downstream. Sondu upstream has significantly higher clay that adsorb organic matter while downstream has more sand (48%) that is well aerated allowing fast organic matter decomposition. The sandy vertisols found here may also be more porous leading to leaching inorganic N. Taboada (2003) found that, soil porosity was significantly higher on dry vertisols that crack thus create macro porosity. One would expect deposition to have taken place but most of the downstream samples were taken on the field across the river where deposition would not take place and also the upper and downstream catchments were not linearly connected for the eroded material to be deposited downstream. Weitkamp, et al. (1996) observed that the influence of cultivation practices on soil properties can be strengthened and that of natural factors such as flooding in this study weakened; in that cropping systems influences nutrient cycling and nutrient balance of soils due to the output taken away in plant biomass and this nutrient mining differs with crop varieties. Therefore, on floodplain soils, the nutrients brought in by flood waters may in some cases not complement that taken away by crop harvests. Simiyu downstream had an extensive flood plain of swampy field characterised by sticky soils and was a dry season grazing land. Zones inundated for longer periods usually have higher clay and Organic C than sandy soils Chacon et al. (2005) which allow better flow of water minimizing durations under water logged conditions. More nutrients can be attributable to retardation in decomposition due to lack of oxygen for microbes when floods set in, animal droppings and fertilizer washed downstream. Baldwin and Mitchell, (2007) observed that periodic floods lead to accumulation of organic matter, and nutrient availability from decay of microbial biomass that can't survive the floods. The highly significant clayey soil on the downstream may be an evidence of sedimentation that takes place on the downstream. Smaling, et al. (2006) reported that the silt and clay deposits that accompany floodwaters give a renewal of top soil downstream and at the same time add plant nutrients. Amanda and William (2007), also observed that river pulsing may have an effect on sedimentation and nutrients accumulation with high values on the steady flow regions expected on the downstream.

4.7 Correlation

There was a high positive and significant correlation between organic carbon and total nitrogen (Table 8 and 9) and the two correlated with clay content in the soil. Clay has high adsorptive capacity of organic matter where nitrogen and organic carbon is a major constituent. In Sondu, β-glucosidase was positively correlated to C ($r=0.61$, $p<0.0001$), N ($r=0.57$, $p<0.0001$) and clay ($r=0.42$, $p=0.0045$) and negatively correlated to sand ($r=-0.36$, $p=0.015$). Turner, et al. (2002) and Mungai et al (2005) also reported positive correlation between β-glucosidase and organic C. β-glucosidase is synthesised by microbes and catalyses the decomposition of carbon compound cellulose in the organic matter. In the same argument, in abundance of organic carbon which is used as a source of microbial energy then one would expect an increase in enzyme activity. Some scholars argue that the fine aggregate of clay protects organic carbon availability for microbial breakdown (Gregorich, 1991) since they are highly adsorbed on clay surfaces. Other scholars argue that clay soils support a large number and variety of micro organisms and enzymes due to physical protection from predation and parasitism as well as safety from desiccation (Turner et al., 2002). Clay may also have a range of oxygen tensions in which micro organisms survive as much as in sandy soils depending on the management practices that affect aeration and organic matter availability. Thus the clay soils may have more enzymatic activity.

Table 8: Pearson's Correlation coefficients (r) between soil properties in Sondu catchment

	Carbon	Nitrogen	Sand	Clay
Carbon	1			
Nitrogen	0.80(<0.0001)[a]	1		
Sand	-0.55 (<0.0001)	-0.46(0.001)	1	
Clay	0.64(<0.0001)	0.53(0.0002)	-0.82(0.0001)	1
β- glucosidase	0.61(<0.0001)	0.60(<0.001)	-0.36(0.01)	0.46(0.005)

Numbers in parentheses represent the significance level

Table 9: Pearson's Correlation coefficient (r) between soil properties in Simiyu catchment

	Carbon	Nitrogen	Sand	Clay
Carbon	1			
Nitrogen	0.87(<0.0001)	1		
Sand	-0.8(<0.001)	-0.80(<0.0001)	1	
Clay	0.85(<0.0001)	0.68(<0.0001)	-0.95(0.0001)	1
β- glucosidase	0.12(0.3)	0.23(0.14)	-0.09(0.5)	0.11(0.5)

Numbers in parentheses represent the significance level

4.8 Testing of research hypotheses

- The local communities are indeed aware of fertility indicators on their farms which they use for a rapid appraisal of soil fertility status on their farms.
- The measured variables were expected to differ across different land uses due to expected differences in nutrient mining by the various crops, land management and tillage practices. But, land use effect was minimal probably because there was high variation on the duration under which the various fields sampled were under particular land use class. Usually, observable changes are expected after at least five years under any one land use.
- Land deterioration was seen due to change from natural to more intensive use.
- Flooding was expected to cause variation of variables measured and although a few sites had significant difference on the activity of β glucosidase, most sites had no clear trend on the soil properties. There was a high degree of variability in both the frequency and period of inundation of various parts of the catchments.
- Soil properties changed from upstream to downstream as hypothesized.

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

- Farmers have local indicators that they use to asses fertility status of the soil.
- There was no observable trend in change of soil properties between the cropped and grazed land use classes. Probably there were variations within the defined class due to land use history, intensity of use and amendments from organic or inorganic fertilizer application.
- There is deterioration of soil fertility due to conversion of land use from natural to either cropped or grazed. This may be caused by soil erosion, poor soil conservation measures and continuous cultivation with sub optimal fertilizer application.
- Soil properties change between soils that flood periodically and those that do not flood was not observed due to the variation of duration under which soil was flooded. For areas that do not remain inundated for prolonged periods of time, soil properties may not be affected.
- There is a general decrease in total N, organic C, and β glucosidase activity in Sondu catchment from upstream to downstream sites and the reverse was observed for Simiyu catchment. This was mainly due to variations in soil types.

5.2 Recommendations

- Since inappropriate land use in the upstream is the main cause of flooding on the downstream, soil and water conservation measures will not only reduce soil erosion but flooding of downstream sites will be controlled as well.
- The replenishment of soil fertility on the eroded catchment need to be emphasized by laying incentives for application of appropriate organic and inorganic fertilizers

5.2.1 Areas of further research

- The impediments to adoption of soil and water conservation measures and fertility replenishment need to be investigated.
- To capture effect of land use trends on soil fertility, a more detailed assessment of land use classes, land use history and other management treatments is necessary to remove heterogeneity of the sample.

CHAPTER SIX
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CHAPTER SEVEN

APPENDIX

Appendix 1: Questionnaire on soil fertility indicators and management

Questionnaire Number……….

Profile of respondent

Name (optional) ………………….

Sex…………

Age (*Tick appropriately*)

a) 15-25yrs
b) 26-35yrs
c) 36-50yrs
d) 51-95yrs

Primary occupation

a) Farmer
b) Business
c) Fisherman
d) Others

The highest level of education

a) Primary School
b) Secondary Education
c) Post secondary
d) None

Farm research

Landscape position

1. Summit 2. Shoulder 3. Footslope

Land use

1. Cultivated 2. Grazing 3. Natural 4. Other (specify)

Average plot size

1. less than one acre
2. One to two acres
3. More than three acres

Type of land ownership

1. Exclusive ownership
2. Communal
3. Rented
4. other

Do you practise any soil conservation measures?

1. Yes
2. No

If yes, which ones (observe)

1. Strip cropping
2. Cover crop
3. Mulching
4. Terracing or cut off drains
5. Others(specify)

Generally classify the soil on your farm as below

Field #	Fertile	Moderately fertile	poor
Field 1			
Field 2			
Field 3			

Knowledge, Classification and Use of Local Soil Fertility Indicators

Indicators used 1. Colour 2. Texture 3. Weeds present 4. Water holding capacity 5.Slope 6.Others (specify)	Does this property signify 1.Fertile soil 2.Poor soil	Crops associated with this soil property (Name)	How did you know about them a. From experience b. From extension c. Other sources	What are the local names for this soil?	How useful are the indicators to you and the community a. Very useful b. useful c. useless d. not sure