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TOPIC:

IMPACT OF LAND MANAGEMENT ON SOIL QUALITY IN MIGINA CATCHMENT AT KANSI SECTOR, GISAGARA DISTRICT

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BUSOGO, Octomber, 2019

DECLARATION

I, Everygiste TUWAMINE, hereby declare that the work presented in this dissertation entitled "the impact of land management on soil quality in Migina catchment at Kansi Sector, Gisagara District" is my owner research. It hasn't been submitted for any degree in any other university or in any institution.

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Prof. Dr. Ir. François Xavier NARAMABUYE, Main supervisor

ABSTRACT

Rwandan economy and livelihood are depending on the agriculture. Environment/ natural resources which are currently under stress could negatively affect the agriculture production. In order to contribute to their protection and to have a sustainable agricultural production for food security and soil conservation, this research was carried out in order to determine the Impact of land management on soil quality. This study has been conducted at Akaboti cell, Kansi Sector, Gisagara District of the Southern Province, exactly as one part of Migina Catchment watershed, where there is different agricultural activities. Soil samples have been collected under six different selected land management practices including: Radical terrace, Forestry, Agroforestry, Trenches, Soil Amendment and control where there is no management of land. Three composite soil samples were taken on each land management practice by considering Upper, Middle and the Bottom part of the hill where each land management practice is located. The following physic-chemical soil tests were done in Laboratory: soil reaction (pH), Organic Carbon, Nitrogen, Phosphorus, Exchangeable Basis (Calcium, Sodium, Magnesium, Potassium,), exchangeable acidity, Soil texture, Moisture Content, Bulk Density, and Electrical Conductivity. The laboratory results show that the soil texture was dominated by a Sand Loam class, the soil bulk density varies 0.96 to 1.44 g/cm^{3}in general, the soil porosity ranges from 50.2 to 52.08 % in terraced land; 47.2 to 58.16% in trenches; 53.8 to 63.87% in agroforestry; 53.08 to 53.8 % in forestry; 56.39 to 58.9 % in amended soil and 45.9 to 51.84% in the control (undisturbed land). The soil pH measured in water ranges from 4.73 to 5.14 for radical terraces land, from 5.79 to 5.29 for trenches; 6.29 to 5.79 for agroforestry land, 4.93 to 4.49 for forested land, 5.11to 6.34 for amended soil, 4.69 to 527 for control. The electrical conductivity is low in treatments ranging from 0.076 to 0.390%, The values of mineral Nitrogen measured in treatments were higher compared to control. Ammonium values range from 2.55 to 7.24 mg/Kg while Nitrate values range from 4.36 to 28 mg/kg. Available P values were high in treatments compared to control. The values of available P range from 8.55 to 17.10 ppm. The values of exchangeable bases were slightly high in treatments compared to control. Those values were generally low. Generally the agroforestry land showed high nutrients values compared to the control and other treatments. From the results of this study, it is clear that the land management practices have generally a positive impact on soil properties. Farmers are advised to adopt those practices especially agroforestry.

DEDICATION

This thesis is dedicated to:

The Almighty God,

My beloved parents,

My dears, brothers and sisters,

My friends, colleagues and all of my relatives who contributed in successful and achievement of this work.

May God bless you!!!!!

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List of acronyms and abbreviations

ANOVA: Analysis of Variance

NGO: Non-Government Organization

AAS: Atomic Absorption Spectrophotometer

CEC: Cation Exchangeable Capacity

BD: Bulk Density

MC: Moisture Content

EC: Electrical Conductivity

OM: Organic Matter

SOM: Soil Organic Matter

ANC: Acid Neutralizing Capacity

AWC: Available Water Capacity

CAVM: College of Agriculture, animal science and Veterinary Medicine

DDP: District Development Plan

GDP: Gross Domestic Product

UR: University of Rwanda

UK: United Kingdom

TAE: Total Exchangeable Acidity

List of Chemical symbols and measuring units

N: Nitrogen

P: Phosphorus

K**:** Potassium

NH^{4+}: Ammonium

NH^{3+}: Ammonia

NO_2^-: Nitrite

NO_3^- : Nitrate

Ca: Calcium

pH: Hydrogen Potential

C: Carbon

%: Percentage

Km^2: Kilometer Square

Cmol/ kg: Centimol per kilogram

Ppm : Part per Million

Mm: Millimeter

Cm: Centimeter

^{o}: Degree

Ppm: Parts per million

Ha: Hectare

Cmol: Centimols

dS: Decisiemens

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CHAP I. GENERAL INTRODUCTION

1.1. Background of study

The land management has great importance on land productivity, ecosystem function, soil health, environmental protection and social-economic activities (Ruslanjari & Taufan, 2017). Particularly lands is one of natural resources which is providing profits and food through agricultural activities and the most of people who are living in Sub- Sahara African depend upon natural resources especially lands, Agriculture production is supply a big contribution to the most gross domestic product of Africa (Majule, 2010). In Rwanda, the majority of people are depending on agricultural activities while agriculture employs about 80% of the population and provides over 40% of the GDP of the country as Population density of Rwanda is about 305 persons/ Km with about 3.5% growth rate (Wali, 2014). The land management sustainability depend on a combination of different approaches from different perspective including technologies, policies that integrate socio-economic values for enhancing production and decrease land , environment and natural resources degradation (Hurni, 2018).

Even if land management practice are very important but are challenged by several factors including climate change, erosion, overexploitation, overgrazing, population pressure, deforestation, improper land management and other different human activities (Majule, 2010). The greatest problem to the food production in dry lands is land degradation which influenced by composite interaction among human activities and the environment, wherever it is the permanent or temporary decreasing of the possible productive capability of land resources. for that case the utilization and management of natural resources could be a central issue (Tesfahunegn, 2018). As results of land degradations are manifested by soil erosion, compaction of soil, animal and plant species, soil biota losses, and nutrient depletion , with associated risks to the production sustainability of ecological and food commodities and services (GEF, 2005).

Several researches have been conducted and mainly focused on farmers perception on land management practices (Tesfahunegn, 2018). Loss of productivity under land use change (Olson & Berry, 2003). And watershed management was implemented by public and private institution to improve land use sustainability, unfortunately many rural farmers are not participating in local community activities since they do not involved in same practices' decision making as well as insufficient research, lack of skill and financial constraints (Kuria et al., 2018).

Furthermore, recently few studies has made attention of the interrelation among land management practices and soil quality then the lack of information has impaired the sustainability of agricultural productivity, ecosystem functioning and well fare of livelihood of farmers (Paul & Rattan, 2014). Therefore this study aims to assess the impact of land management practices such as the radical terrace, forest, agroforestry, trenches and soil amendment on soil quality in Migina catchment and we were based on physico-chemical elements that are improving soil fertility for increasing crop productivity.

1.2. Problem statement

The population cultivates even the marginal areas in trying to satisfy their needs in food security and they are growing but the arable land decrease (Olson & Berry, 2003). To feed the rapidly growing population, it is necessary to improve agricultural productivity in the country; this can be achieved by a change in agricultural practices (Wali, 2014).

The poor land management and overexploitation of soil in Migina catchment leads to the soil degradation then agricultural productivity decline, removal of vegetation cover, soil erosion acceleration, nutrient depletion and decrease arable land. There are few land management practices that are established in this area but some on them are degraded due to the population poor management and other are not well established. Then to achieve a sustainable agricultural development, the soil restitution or land management activities are here needed for soil quality and land productivity improvement.

For achieving the increasing of agricultural productivity, it is necessary to take care on land degradation issues for preventing loss of soil nutrients and sustainability of agricultural productivity and then it is very important to reinforce the level and awareness of citizen's participation for land use management process. This study released in order to find the equivalent solution to the cited above problem and to enhance land management practice improvement for managing soil quality in Migina Catchment. Specifically it was based on the result of different land management practices on physic-chemical properties variation by basing to the elements that are influencing soil fertility status. Particularly the study took place in Gisagara District, Kansi Sector at Akaboti Cell where we found our proposed different land management practices in farmers land.

1.3. Objective of study

1.3.1. Overall objectives

The main purpose of this study was to evaluate the impact of land management on soil quality in Migina catchment, Kansi sector, Gisagara District in Southern Province of Rwanda

1.3.2. Specific objectives

The detailed objectives of this work are:

- To determine the effect of different land management practices on soil physico-chemical properties
- To compare the ability of different land management practice for improving soil fertility status.

2.4. Research Question

i. How does radical terraces, trenches, Agroforestry, forest and soil amendment influence soil pH, Soil Carbon, CEC, Al and soil macronutrients (NPK)?

ii. How does radical terraces, trenches, Agroforestry, forest and soil amendment contribute to the soil texture, Electrical conductivity, bulk density and moisture content improvement?

1.5. Hypothesis

To achieve these objectives the following hypothesis were established:

- ❖ Land management practices increase same chemical nutrient in soil like soil pH, soil organic carbon, CEC, soil macronutrients and micronutrients.
- ❖ Land management practice may improve soil physical properties.

1.6. The significance of the study

This study will help people, government, owner of land to know how the land management activities affecting soil quality and also the positive effect of this activity to the environment. Then this will help with the further collaboration of all stakeholders including non-governmental organization and institutions, government authorities, Big and small farmers and population to take care on land management practice for soil quality improvement.

1.7. Scope of the works

This research study comprises five chapters that are arranged as this follow:

- First chapter is General Introduction
- Second chapter Literature Review
- Third chapter is Material and Methods
- Fourth chapter is Results and Discussions
- Fifth chapter is Conclusion and Recommendations

CHAP II. LITERATURE REVIEW

2.1. General description of land management

Sub-Saharan Africa is especially at risk on threats of natural resources degradation and financial condition. this is often because of different factors as well as a high growth's rate of population and population pressure's increasing, reliance on agriculture that's at risk of environmental variation, Ecosystem and nature resources fragile, elevated level of land degradation and erosion, and both high post-harvest yield losses and low yields, hence properly land management are here in required to extend production through both tradition and modern systems, and to enhance resilience to the different environmental pressure (Hanspeter Liniger, Rima Mekdaschi Studer, Christine Hauert, 2011).

2.2. The main causes of land degradation

Land degradation is harmfully affecting the state and also the natural resources management like water, soil, animals and plants and then decrease agricultural production (Hanspeter Liniger, Rima Mekdaschi Studer, Christine Hauert, 2011) . The pressure on land and the overexploitation of land resources have resulted numerous types of degradation like desertification, land degradation, water degradation, loss of biodiversity, deforestation(WGEA, 2013). Land degradation suggests that loss or decrease the economical or biological production of irrigated cropland, pasture, rainfed cropland, woodlands and forest ensuing from land uses or form a process processes combination, as well as processes comes from the activities of human and habitation patterns, for example erosion of soil which is caused by water and wind, destruction of physical, biological and chemical or economic soil properties; and natural vegetation that are lost long period of time (GEF, 2005).

There are environmental problems in land use that are associated with a mixture of the many composite of natural and human-induced phenomena. The deforestation, urbanization, cultivation, intensification and mechanization of agricultural practices, global warming, overexploitation of animal populations, desertification and general pollution resulted by the alteration of natural and semi-natural ecosystems are all direct and indirect causes of speed up environmental degradation (WGEA, 2013).

2.3. Effect of land degradation on soil quality

Land management like the method by which the resources of land are place into sensible result and it encompasses all works associated with the land management are needed to attain proper development, it is taken as measures to overcome land degradation (Enemark, 2005). Therefore the major challenge of development sustainability is land degradation, as development means to satisfy the current needs without deteriorating the ability of future generation to satisfy their own needs (Hurni, 2018).

Rotations of crop, incorporations of crop residues, improving inorganic fertilizer uses, and irrigation and engineering of drainage, side by side with rapid industrialization and urbanization are the intensive agricultural production strategies that are used at closely inhabited areas and significantly enhanced variations of soil quality. These variations have been making challenges to the lengthy property of those agricultural systems of intensive cultivation and have raised up the problems about applicable management practices (Huang, 2011)**.**

2.4. Different practice of land management

The land management as best practices is depending on these different groups of technologies as integrated soil fertility management, agricultural conservation like harvesting of water from rain , soil amendment, the management of smallholder irrigation, cross-slope barriers like trenches and radical terrace, agroforestry, management of integrated crop-livestock, rangeland management and pastoralism, management of sustainable planted forest, sustainable forest management in drylands, sustainable rainforest management, trenches, new opportunities and sustainable land management approaches. These differences groups of technologies can be successful by achieving those following principles of sustainable land management that are passing through the efficiency water use, the increasing of land productivity, soil fertility, plants and their management, livelihoods improvement, micro-climate, costs and benefits, input challenges for land users, improved ecosystems through taking care environment, improve biodiversity then mitigating and rehabilitating land degradation (Hanspeter Liniger, Rima Mekdaschi Studer, Christine Hauert, 2011). Liming, Nitrogen fertilization, organic amendment, tillage, and vegetation cover changes that are including usually land management practices. The organic matter concentrations are dissolved by these practices measuring in the group of experimental and group of control was consistent (Li, Wang, Guo, Yang, & Fu, 2019).

2.4.1. Impact of Agroforestry on soil quality improvement and agricultural productivity.

Agroforestry is an integrated system of land resource management in rural where shrus and trees are cultivated together with the crops and/ or livestock, where this interactions are providing economical, environmental and social profits (De Baets, Gariépy, & Vézina, 2007).

Agroforestry will develop the resiliency systems of agriculture and alleviate the impact of climate change. The improved trees on farms can stop degradation of environment, improve productivity of agriculture, provide cleaner water, increase carbon sequestration, and sustain healthy ecosystems and healthy soil whereas generating constant different profits and incomes to human wellbeing. Carbon sequestration potential, runoff and soil erosion control, improved nutrient and water cycling are promoting agroforestry, and then they are providing high agricultural productivity and socio-economic benefits (Brown, Miller, Ordonez, & Baylis, 2018). Briefly, Agroforestry generate environmental goods and services array that hold up integrated management of rural spaces and farmland (De Baets et al., 2007).

2.4.2. Impact of radical terrace on soil property management

The most of constraints in land management is erosion. radical terraces are mainly designed in order to decrease soil losses through improved retention and infiltration of runoff, to encourage stability of agriculture on steep slopes , to develop land consolidation and intensive land use, then it has been established exceeding 50% means on steeper slopes field (FAO, 2014).

The erosion was the main cause for soil degradation. The several strategies and techniques were taken in order to protect the environment against effects of different natural disasters. Among them for example are the digs and hedge anti-erosion and radical terraces. It was revealed that the Radical terraces have a positive impact to increase farm productivity. The lack of materials, lack of financial supports, hard soil and straight slope were among main problems identified in region that were barriers for significant positive achievements (Mupenzi et al., 2012).

2.4.3. Impact of forest on soil quality

A forest is a large area dominated by trees and it provides ecosystem services to humans and serves as tourist attractions. Soil quality of is very importance for: the production and forest systems sustainability, the soil and water resources conservation, the persistent toxic substance accumulation and the global carbon cycle comes from to the forested systems contribution.

Soil properties within time are influenced by Forest development, which is also extremely dependent on the practice of forest management throughout life cycle of the forest and on the primary choice of tree species. The trees improve soil by different process which may be sorted into four completely dissimilar classes that are rising inputs (Organic matter, nitrogen fixation, nutrient uptake), decreasing organic matter and nutrient losses with enhancing recycling and checking erosion, increasing physical properties of soil, together with holding capacity of water and valuable effects on processes of soil biological (Vanguelova, Moffat, & J, 2005).

Additionally the forest management practices, makes environmental conditions changes through activities of human which intimidate the capacity of soil to supply the required forests' function. Kind of soil damage related to the deposition of atmosphere particularly concerns in forest, contain acidification of soil, imbalance of nutrients, enrichment of nitrogen (Eutrophication) and contamination of heavy metal. Soil weakness is frequently based on soil behaviors like chemical status of soil, as soil pH, Base saturation, Acid Neutralizing Capacity (ANC), Cation Exchange Capacity (CEC), and the parent material. Some soil chemical indicators like for example soil pH, content of organic matter, C/N ration have been planned in the UK by the forest Commission and in Europe order to be used for monitoring the practices of forest and environmental changes' potential effects on soil quality (Vanguelova et al., 2005).

2.4.4. Importance of trenches practice on soil management

The two basic and essential elements for agriculture are soil and water. Sometime due to the area water is consider more valuable than soil. Continuous loss of forest, unscientific agricultural practices, unplanned development results in loss of soil. Its leads the runoff and reduces water percolation rate. The final hazard is decreasing ground water level and ecosystem disturbance. Then as water and soil conservation practices are continuously neglected by people, society and government, with every passing year the drought intensity is becoming more and more serious. Many efforts were made for water, soil and forest conservation but they are done individually and separately, there is lack of awareness about integrated conservation methods. Continuous contour trenching is an experiment in the forest areas since 1993and is the best appropriate technique for low rainfall, hilly and undulating terrain areas (Bajirao, 2016).

Trenching was established from top to bottom. Distance from one trench to another is depending upon the slope and accessibility of resources and time. The main purposes of establishing Continuous contour trenching technique are to stop the soil loss, to decrease the rate of runoff, enlarge in percolation, to increase the green cover over the area and soil quality, to make the increasing of the ground water level, to increase the availability of drinking water, development and employment of agriculture, and then to develop the land degraded and increasing the soil moisture to vegetation (Bajirao, 2016).

2.4.5. Impact of soil amendment on soil quality improvement

All inorganic and organic substances are element of soil amendment where they are assorted into the soil for succeeding a better soil constitution concerning productivity of plant, essentially, any organic or inorganic materials which are putted into the soil in order to enhance their quality can be taken as amendments of soil. Briefly to improve drainage and aeration, soil texture, water retention, here elements of soil amendments like organic and inorganic matter must added into the soil. Amendment of sandy or rocky needed for improving its texture and add water retention properties. And to improve soil texture, aeration and drainage of clay soils require the addition of material.

Soil amendments are available in a range of sources. Organic substances accommodates material resulted by living material as plants, while substances of inorganic are extracted or man-made. Vermiculite, tire chunks, perlite, pea gravel, lime or sulfur and sand are common inorganic amendments. And referring to the cost inorganic is more expensive than organic amendments. In order to raise aeration, reduce excessive water holding capacity, improve drainage, reduce or increase weight and the Inorganic amendment are here used, whereas organic occur naturally growing medium amendments sometimes are comes from product of plants or plant like moss of peat from peat bogs, or derived from processing plant products or mills like cedar chips, sawdust, Begasse, rice hulls, bark or waste disposed by plants as processed sewage sludge, compost, Biosolids and then from wastage of animal that are manufacturing organic manure.

The organic amendment practices are generally important in soil quality improvement like manure used for adding nutrients into soil , compost used for improving the soil texture, aeration increasing, promotes together water retention and drainage in order to increase the nutrients capacity needed for plant growth. The soil retains its moisture through mulch, Humus provide stability to soil imbalances and rectifies deficiencies while keeping its own balance, Peat the capability of the soil to keep water and is ideal for sandy or rocky soil is increased by Moss. It is ideal for stabilizing clay soils as well, and then products of wood like wood ships and shavings are used to make soil improvement, but may read to the deficiency of nitrogen. To release the soil and make huge pores to increase aeration, water holding capacity usage , drainage, nutrient holding capacity, growing of medium weight decreases (compare to the soil) are the main objective of using organic amendments all of them enhancing plant sustainability and soil quality improvement (Rana, 2018).

2.5. Importance of sustainable agricultural Management

Sustainable agricultural management is the use of land to gather the changing human desires, whereas making certain long-run socio-economic and ecological functions of the lands, for the advantage of current and future generations, and given for: Exploitation natural resource on a long-run basis, meeting current wants with no compromising future potential, increasing per capita output, protecting the natural resources potential and stop water degradation and soil quality and productivity restoration and degraded and insolvent ecosystems.

For maximizing the net profits that society gets from agricultural production of fiber, food and ecosystems service is the objective of sustainable agriculture. This will require improved crop production, judicious use of pesticides and antibiotics, increased efficiency of nitrogen, ecologically based on practices of management, phosphorus and water use, sweeping changes in some practices of livestock production. Advances in the basic Agro ecological understandings, biogeochemistry and biotechnology that are connected directly to the programmes of breeding can supply immensely to be sustainable. For this reason, sustainability of agriculture is our current perfect way for an environmentally resonance, economically feasible, productive, and socially desirable agriculture (Sultana, 2011).

2.6. The challenges of land management

By scientific ways believable data backed by practical and targeted strategy of management are needed to handle main international threats which embrace the growth of population and required water, food and Energy; management and conversation of land use indiscrimination; environmental hazards like flooding and pollution, and also the dangerous impacts of rapid climate change as extended drought and flash floods. Models synthesizing soil property data will play a crucial function within the abstract soil system understanding and also the key property identification of key property agro-ecosystem practices (Tesfahunegn, 2013).

Degradation of land has been responsible on different factors as well as agricultural practice which are not sustainable that highlight employ the external inputs while is not considering the processes which are natural and that sustain the formation of soil and construct agro-ecosystem flexibility. These contain control of soil erosion, cycling of nutrient, carbon sequestration and regulation of water. Other drivers comprise deforestation and loss of land-cover, government policies that are not favorable, tenure insecurity, open grazing and overstocking, slash and burn, insufficient water and soil conservation interventions and those are challenging land management sustainability. Degradation of soil quality also happen because of nutrients loss ensuing from nonstop cultivation with less or without inputs, and due to the decreasing of household size of land asset read to the short or no fallow periods. Other drivers embrace cultivation of non appropriate areas such as wetlands and steep slopes. The other challenges are limited capital to invest in land management practice, knowledge and scientific studies (Kuria et al., 2018).

2.7. Description of soil quality to land management

The soil quality is the ability of selected types of soil to function; the maintenance of soil quality is key environmental issues as a result of humans rely powerfully on the services delivered by soil ecosystems. The management of land is known as one of the main drivers touching improvement of soil quality or degradation (Thoumazeau, Bessou, Renevier, & Panklang, 2019). Soil quality reduction is resulted by unsuitable use of land and their management system of soil are now continued like an economic and an environmental concern worldwide. Poor use of soils, read to a distressed endeavor by farmers to extend yields for the growth of population intensify more degradation of soil quality in developing countries, since their agriculture is mostly foundation of their economy. Natural resources' exploitation like soil that direct to degradation, socioeconomic and political problem are also stimulating that event, for instance like lack of financial investment and land tenure. In most developing countries are seriously challenged with the resultant soil quality degradation connected with depletion of soil nutrient and degradation of soil physical by soil erosion. Management ways that effectively decrease degradation are therefore basic to the food security insurance (Tesfahunegn, 2013)

According to one researcher, "through the population growth and the fast development worldwide economies, the impacts of activities from human on natural ecosystem are more and more crucial to ecosystem sustainability. Soil quality in modern agricultural activities is associated directly to the productivity of soil and to the human's ability in order feed ourselves, has been significantly affected with human activities. The improvement of crop varieties of high-yield and the rising the use of fertilizers which are chemically manufactured, mechanization, irrigation and pesticides lead to the increasing of crop production the previous three decades. In latest years, there has been growing regarding to the impact of activities of human onagricultural soil quality and their changes in given periods of time. Research mention that acceptable agricultural practice like irrigation, soil tillage, lime application and fertilizer, crop residues integration in the soil and conversion from agricultural dry land to the paddy rice production are used to improve soil quality "(Huang, 2011).

These conditions are speed up soil properties' changes, both indirectly and directly, to the level that new trends expose that induced by human soil properties changes which has surpassed natural variation. Soil quality in agricultural based to the land capacity and condition, as well as its soil biological properties and climate, Conservation and environmental management, for production's purpose. Negative and positive impact of human activities on soil quality take place simultaneously, they are extended referring to the ecosystem resilience and disturbance feedback. On the contrary, unsuitable human activities decrease soil quality like too much chemical and inorganic fertilizers application and sewage sludge irrigation. A much better understanding on variation of soil quality while is encouraged by activities of human is significant for improving land use management practices sustainability to offer early notice of unfavorable trends, problem areas identification and offer a important base against which successive and evaluation outlook measurement can be done (Huang, 2011).

2.7.1. Indicators of soil quality

Soil quality indicators are categorized as physical, chemical and biological but some research also add ecological as indicator of soil quality. So physical indicator is gaseous exchange and water support provision, structure and erodibility, contain texture of soil and surface area, bulk density (qb), available water capacity (AWC), porosity, depth, aggregate strength and stability. The chemical indicator focus on control of availability of nutrient like soil pH, Soil organic matter (SOM), Cation exchange capacity (CEC) and Electrical Conductivity (EC); as some literature add ecological indicator is which based on biodiversity, landscape process and hydrological budget and then Biological indicator based to microbial biomass, species, Enzymes and soil respiration (OBADE, 2017). But many of literatures have been based on three main soil quality indicators as chemical, physical and biological (Kuria et al., 2018).

2.7.2. The interest of soil quality evaluation

Soil is very significant component of the Earth's biosphere that is the reason why the interest in soil quality degradation evaluation has been increased, the soil performance not only in yield of food and fibers however additionally within the environmental quality regulation. In normal conditions, the equilibrium by pedogenetic processes can be maintained by soil quality indicators. However, human activity is easily disturbing this equilibrium like for example agricultural activities, and such result is especially detected in developing country without modern technology and financial support to control natural ressource. It is then very interesting to evaluate indicator that confirm change in soil quality correlated to the different management strategy and land use system so as to devices management strategy that further maintain, improve and prioritize sustainability of soil system in catchment (Tesfahunegn, 2013).

Soil quality indicators analyses identify degradation of soil quality regard to totally different land use system and management strategy is trustable. Planners and decision maker's evaluation can be easily while soil quality indicators of site are specific, by responding question of which is the most sustainable land use and management system. Such data may also advise for the need of suitable measures of remedial like application of fertilizers and other suitable options of land management considering to the potential and constraints of different field at scale of catchment. in spite of the previous importance on soil quality indicators in fighting against soil quality degradation, some research assessed soil quality indicator of different land use system and management strategies in catchment condition (Tesfahunegn, 2013).

2.7.3. Importance of soil quality evaluation

Different functions of soil quality are reported by Studies elsewhere, like for example physical support to plants, make regeneration of soil fertility, retention and delivery of nutrients to plants, and regulate the main element cycles and the way successfully such soil functions react to the system of management and process of degradation. Significant soil quality indicators that explain functions of soil are those which can be evaluated by quantitative or qualitative approaches, simple to evaluate and measure change in functions of soil, achieve goals of management, responsive to changes in climate, existing components of databases, land use, and management systems. Soil quality indicators can be used to describe those soil functions; these are physically, chemically and biologically measurable on soil attribute or morphological and visual features of soils and plants. Soil quality is projected as an environmental quality indicator and viability of economic as a result of agricultural production sustainability can be observed by using soil quality indicators (Tesfahunegn, 2013)

2.7.4. Major Soil physic-chemical indicators for soil quality analysis

According to (Nsengimana, Kaplin, & Francis, 2018) the main physic-chemical indicators for soil quality analysis and soil nutrients availability on crop productivity. This table contains all information related to the physic-chemical indicators.

Soil conditions indicator	**Measured soil quality**
Physical indicators	
Soil texture	The capacity of retention and transport of water, minerals and level of soil erosion.
Depth of soils or top soils	Potential productivity and level of soil erosion.
Bulk density	The potential for leaching, productivity and level of soil erosion.
Water holding capacity	The level of water retention, transport and soil erosion.
Aggregation	Soil structure, erosion resistance, andsoil management.
Chemical indicators	
Soil organic matter	Soil fertility, structure, stability and extent of erosion
Soil pH	Biological and chemical thresholds.
Electrical Conductivity (EC) and Cation Exchangeable Capacity (CEC).	The threshold of plants and microbial activity, soil structure and level of water infiltration.
Extractable nitrogen (N), Phosphorus and Potassium (K)	Available plant nutrients and potential for nitrogen loss, productivity and environmental quality indicators

In system of agriculture, soil organic carbon utilized as the main significant indicator of soil quality, as well as electrical conductivity, soil pH and nutrient variability then Physical indicators are mainly commonly used in the measurement of bulk density and aggregate stability (Nsengimana et al., 2018) .

2.8. The relationship between different soil physic-chemical parameters

2.8.1. Soil organic matter

The soil quality is not measured or analyzed directly but the analysis of soil quality it depends on evaluation and analysis of their indicators (Tesfahunegn, 2013). Soil organic matter is delivered from the breakdown of plant and animal residues like plant residues for example lawn, clippings, leaves, cown stalks and straws, manure, sludges, wood and processing wastes of food, green manure and dead matter, it contains large amount of carbon based compound. In the environment plant biomass which made the decomposition in the way of protecting the services of ecosystem for the purpose of increase of soil moisture (Caricasole, Hatcher, & Ohno, 2018)

Different mechanism like protection of chemical through relationship with mineral surface, physical protection by occlusion within aggregate, and protection of biochemical by recalcitrance can protect soil organic matter from decomposition and stabilized in soils. Organic molecules from chemical stabilization through organic matter binding are well established. Even labile organic material will otherwise decomposed rapidly are often shielded from shut decomposition association with clay and sand particles. Analyses shows several research which recommend that stabilization capability is settled by soil clay and silt content and also the area and the reactivity of mineral particles of soil (Plante, Conant, Stewart, Paustian, & Six, 2006).

Numerous researches have proclaimed that soil texture influence aggregation, where enlarged clay contents were related with increasing aggregate stability or aggregation. In rising aggregation of soil, clay content in soil impact the soil carbon storage indirectly through occluding organic material by making them unapproachable to destroy their enzymes and organisms. then, the indirect and direct function in physic-chemical protection mechanisms are played by soil texture particularly soil clay content (Plante et al., 2006).

Soil organic matter (SOM) is that the organic matter organic matter soil's element, containing plant and animal residual at different categories of decomposition, cells and tissues of soil organisms and substance synthesized by soil organisms.

2.8.2. The factors affecting decomposition of soil organic matter

The organic matter is the end product of the decaying of plant and animal residues, this decomposition depend upon the various factors like Temperature (where periods of Cold retard plant growth and OM decomposition and in Warm period means in summer might allow plant growth and accumulation of humus), Soil moisture (where boundaries of each anaerobic and arid conditions decrease microbial decomposition and plant growth then close to or slightly wetter than field capacity moisture conditions are most appropriate at every process), Nutrients (where deficiency of nutrients especially Nitrogen decrease decomposition rate), Soil pH (at pH 6-8 is where most of the microbes grow best, but at below pH4.5 and above pH8.5 are severely inhibited), Soil Texture (Larger amounts of humus retained by the soil which is higher in clays content) there are also other factors which is influencing Organic matter Decomposition like Al, Mn, B, Se, Cl elements Toxic levels ,shade, excessive soluble salts and organic phytotoxin in plant materials (Oldfield, Wood, & Bradford, 2017) .

2.8.3. Importance of soil organic matter quality

Soil organic matter (SOM) is taken into account the key moderator and soil fertility indicator based on its contact with soil properties that are physical, chemical and biological (Oldfield et al., 2017), Water holding capacity and Aeration are increased by soil organic matter, provides living place organism of soil that increase cycling of nutrients , retain and offer essential nutrients to the productivity therefore the function of SOM in sustaining and supporting soil as an important resource is gaining improved notice through initiatives promoting the model of soil health (Plante et al., 2006)

Resilient and fertile soils are created by the adding up organic matter into the soil through increasing value of soil properties which is model of guiding of these initiatives. The concentration of organic matter into the soil is the ensuing balance between decomposition and formation, but referring mostly on interactions between intrinsic properties of soil for example soil texture and mineralogy, climate, management and the natural of inputs (Oldfield et al., 2017). Soil organic matter connects or binds soil particles together then form stability of aggregate, increasing porosity and infiltration. While soil with high soil organic matter offer good living place of soil biota like earthworms. The space of pore in soil is increased by Soil biota and it creates continuous pores that joins the upper to subsurface layers (NRCS, 2014).

2.8.4. The role of organic matter on agricultural management

Management of agriculture is essential to construct and improve soil fertility sustainability. Exogenous through inputs principally enhancing nutrient deriver and tith of soil are represented by the additions of organic matter like compost. While system is aiming on the perennial and cover crops to keep up root inputs reach to the shift more to the endogenous cycling of organic matter with the purpose of constructing up inhabitant bags of Soil Organic Matter that present water holding capacity and nutrient. The different pathways given through which amended OM and native may affect fertility of soil, it remains mainly non responded as to whether or not ways which get exogenous or construct endogenous OM have related effects on productivity of crop when organic matter concentration are similar. in spite of advanced above total nitrogen and ground biomass in soil amendment, suggestion of our data is that consequences of accelerating organic matter concentration have effecting the plant (Oldfield et al., 2017).

2.8.5. Importance of Organic amendment to the crop productivity

Organic amendment to tillable soil make a soil organic matter (SOM), it might enhance crop productivity. But, crop production independently of SOM can be influenced by organic amendments by offering nutrient straight to the plants. The comparative significance of resident organic matter against organic amendment isn’t well measured. Both organic amendment and native soil organic matter concentrations experimentally manipulated to measure their relative importance to yields of crop.

The organic matter which is highly concentrated, whether amended or native, were connected with greater soil water holding capacity, nutrients and structure of soil improvement. As a result, increases in equally amended and native organic matter were connected by powerful positive however saturating impact on yield, where it is great through amendment effects. Productivity levels can be supported by native soil organic matter compared to those generated by organic amendment. Even if our quantitative results can probably differ from various soil and amendments, our result provide support thought that soil organic matter stocks directly crop up productivity (Minna, 2017)

2.8.6. Relationship between organic matter and soil properties.

The mechanism had tried to be lost by that organic matter influences productivity measurement variety of soil properties. Every properties of soil enhanced by increasing organic matter, then we have a tendency to couldn't untangle that of properties of soil had the leading directly impact on resultant of productivity's buckwheat. By measurement soil properties there are important relations between organic matter and treatment of soil for nearly all treatments were indicated that the impact of organic matter which is amended became larger than those native Organic Matter as OM concentrations enhanced. The importance of soil treatment impact like for example amended OM against native, various markedly surrounded by these variables of soil. As an example amended OM concentration extremely powerfully impacted extractable Potassium and phosphorus however native OM concentration failed to. Variations in productivity at advanced OM concentration connecting native and amended OM treatment might then after a product of an additional grant plant on the accessible Phosphorus and potassium within the soils amended. We would suppose native organic matter soils to hold lower, the properties of soil measured and their relation with soil organic matter: Water holding capacity, microbial soil biomass, available Phosphorus, available potassium, total Nitrogen of soil, Cation Exchangeable Capacity, bulk density and soil pH commonly, every those analyzed and calculated parameters through the increasing of their organic matter concentration, they are also themselves increased, instead of bulk density and pH (Oldfield et al., 2017).

2.8.7. Relationship between soil properties, erodibility and hillslope

The more and more increasing utilization areas of agriculture and the climate change's ongoing are mostly influencing loss of soil associated with particular to the activity water running. While the vulnerability of soil to erosion based on the multiple relations between soil features and geologic-environmental parameters, (that are also impacted by simply because of the acting processes of erosive), it seems explicit necessary to determine variability of their spatial in respect to the slope options and native relief. Prophetical strategies to consistently approximation of soil erodibility are commonly depend on the investigation on changeability of spatial on only some soil properties, for instance soil texture, structure of soil and organic matter content (Colombo, Palumbo, Aucelli, Angelis, & Rosskopf, 2010).

2.8.8. Soil texture

Soil texture could be a categorization of soil supported its physical texture and characteristics, notably the dimensions of the particle that build up the soil and those particles are categorized into silt, sand and clay. Every separate material located within the soil classifies the soil texture. The categorizations of the soil are usually named for major material found within the sample. This kind of categorization is mainly frequently used to confirm if agricultural soil is appropriate to the crops. Some properties of soil touching plant growth include: soil texture (Coarse of fine), size of aggregate, aeration (permeability), porosity and water holding capacity. A very significant operate of soil is to store and provide nutrients to plants. Generally soil has created up with three major elements that are sand, silt and clay. there's another ideal magnitude relation of these three element wherever each component occupy thirty third this can be known as Loam (Plante et al., 2006).

2.8.9. The importance of soil texture

Texture is a crucial soil characteristic as a result of it determines water intake rates (infiltration); soil water holding capacity; movement of water through soil as hydraulic conductivity; the convenience of cultivating the soil; therefore the quantity of aeration (which is more significant to the growth of root). Fertility of soil will be influenced by Texture. As an example, is simple to till coarse sand, has aeration lots to motivate growth of root, and is irrigated simply. Yet, this same sand soil can quickly dry out before irrigation because of its water holding capacity is low. Plant nutrient which is soluble in water like potassium and Nitrate are going to be quickly leached below the vine plant root zone by water percolation (Hartati & Sudarmadji, 2016)

2.8.10. Influence Soil texture on other soil properties and behavior

Property and Behavior	Sand	Silt	Clay
Water holding capacity	Low	Medium to high	High
Aeration when moist	Good	Medium	Medium to poor
Hydraulic (water) conductivity	High	Slow to Medium	Slow to very slow
Soil organic matter level	Low	Medium to high	High to medium
Decomposition to organic matter	rapid	medium	Slow
Warm-up to spring	Rapid	Moderate	Slow

Compactability	Low	Medium	High
Susceptibility to water erosion	Moderate (high if fine sand)	High	Low
Susceptibility to water erosion	Low under fine sand	High	Low if aggregated high if not
shrink- well potential	Very low	Low	Moderate to very high
Sealing of pond and dams	Poor	Poor	Good
Suitability for tillage when well	Good	Medium	Poor
Pollutant leaching potential	High	Medium	Low (unless cracked)
Cation Exchange Capacity (CEC)	Low	Medium	High
Resistance of pH change	Low	Medium	High

2.8.11. Relationship between soil infiltration and soil texture

Texture of soil, the amount of silt, sand and clay in a very soil, is that main inherent issue impacting infiltration. Water moves a lot of rapidly through the big pores in sandy soil than in clayey soil with small pores, particularly if there is a compaction of clay then has very little or no arrangement or aggregation. Counting on the quantity and kind of clay minerals, some clayey soils expand cracks from reduction as they will be dry. The cracks are directly transports for water to go into the soils. therefore, clayey soils will have a high infiltration rate once dry and slow rate when wet means cracks are closed (Minna, 2017).

Clayey soil can't cracks make unspeedy rate of infiltration except that they keep a more iron oxide content (clayey soils which is red) or they created in ash of volcanic. Practice management that develops soil content of organic matter, soil aggregation, and infiltration may be improved by porosity. Aggregation of soil is crucial for the land surface resistance to the erodibility, and it favours the soils capability to stay productive. The infiltration relies on many factors, together with structure of soil, texture, soil water content initially, size of pores, potential metric of soil and vegetation. Many researchers have publicized that soil which is sandy contain a higher infiltration rate than clay soils from conditions of identical. The accessible volume for added water within the soil based on soil porosity and therefore the rate at that infiltration rate occurs from the soil surface. Since the soil surface water quantity is a smaller amount than the infiltration capacity, every water can inflitrate (Hartati & Sudarmadji, 2016).

According to (NRCS, 2014), this a table of soil type to steady state infiltration rate

Type of soil	**infiltration rate (in/hr) on steady state**
Sand soil	Greater than 0.8
Sandy and silt	From 0.4 to 0.8
Loam soil	From 0.2 to 0.4
Clay soils	From 0.04 to 0.2
Sodic clayey soil	Less than 0.04

2.8.12. Relationship between infiltration, soil moisture content and soil porosity

The soil dryness degree among area of study compare with the outcome of Andreassian et al., (2004), it confirmed that in dry soil the infiltration rate is high. It has been established by many researchers who said that the low soil moisture decreases the cohesiveness with the particles therefore creating water to be freely dispersed and alternative of erosion couse, thus creating it susceptible to erodibility.

Many researchers have known that the water distribution and nutrient solubility within the soil are affected by the speed of soil moisture movement. The soil capability for package water is due to the porosity of soil, as water goes quickly passing through macro-pores on sandy soils than clay soil. The results of the analyses of soil demonstrate that, the capacity of soil storage based on the accessible pores areas (Minna, 2017).

Evaporation, plant water use, surface and residue of plant cover, irrigation and drainage affect soil moisture. Dry soil tend to possess cracks and pores that permit the quickly entrance of water. As soil become wet, the infiltration rate slow to gradual rate reffered on how rapidly water might move by passing into saturated soil; foremost layer restrictive, like a layer which is compacted; or a layer which is dense with clay therefore According to (NRCS, 2014) the infiltration rate decrease as soil moisture content increase.

2.8.13. Relationship between infiltration, organic matter, soil texture and erodibility

Management practices like application of various high crop residues, maintaining residues on the surface, crops cover application, and managing apparatus traffic to prevent compaction have an effect on infiltration by reducing the crusting of surface compaction and enhancing content of soil organic matter and porosity. Except of the soil which is conserved by plant or residue cover,the impact which is direct of raindrop that are filling up the particles, leading to runoff and erosion. Dislodged particles of soil fill within the pores surface, encouraging the surface crust development that restricts water movement into the soil. Use of instrumentation, particularly soils which is wet and tillage may end up in compaction. Compacted or impermeable soil layers have less space's pores , that restricts the motion of water into the soil profile (Minna, 2017).

The soil moisture content increases as the infiltration rate decrease. Organic matter of soil connects together the soil particle into stable aggregate, increasing soil porosity and soil infiltration. Depending on the high organic matter content give smart habitant of soil biota which increase space of pore and make continuous pores that join together the upper to subsurface layer layers. Long period responses for improving or maintaining infiltration of soil take in practices that enhance content of organic matter and aggregation and even minimizing runoff, compaction and disturbance. A great organic matter content end up in better aggregation of soil and improved soil structure, the infiltration rate of soil increase (NRCS, 2014).

2.8.14. Soil infiltration

Soil infiltration based on the power of the soil to permit water to pass through or into the soil profile. Infiltration permits the soil to momentarily store water, creating it obtainable to be used by soil organisms and plants. The infiltration shows how water enter into the soil, generally it's unite is inches per hour. If there is too low rate of infiltration, it may end up in ponding in level areas, erosion in slopping areas and may result in flooding or insufficient moisture for yields of crop. Adequate water should infiltrate the soil for most favorable yields of crop. Except appropriately management, an infiltration rate which is high will result in nitrate nitrogen leaching or pesticides and phosphorus loss from soil that have an elevated level of phosphorus. Practices of management like making zero tillage cropping systems and high residue crops use and cover of crop can advance infiltration by raising the content of soil organic matter. (Duiker, Flanagan, & Lal, 2001).

2.8.15. Factors Affecting Soil Infiltration

According to (NRCS, 2014) there are different factors that are impact soil infiltration and the soil infiltration rate are affected by soil texture, organic matter, aggregation and structure, crust, water content, pores, and compaction and frozen surface.

The soil infiltration rate improvement are looking on hindering the disturbance of soil and instrumentation use once the soil which is wet, Use instrumentation simply on selected roads or between rows, Limit the amount of times instrumentation is employed on a field, from up soil to split up compacted layers, use a continuous, zero tillage cropping systems, Use manure which is solid or alternative organic material, use rotations that contain more crop residues, like corn and little grain, and perennial crops, Plant cowl crops and green manure crops, like grass and alfalfa, farm on contour (NRCS, 2014).

2.8.16. Relationship between soil properties and soil erodibility

There are two groups of soil properties that affect soil erodibility, the first are those properties that influence water infiltration rate, water storage capacity and water movement throughout soil profile, while the second are those properties that influence soil detachment and soil transportation by the effect of rainfall and runoff. Generally, soil texture, organic matter of the soil, aggregate stability and permeability are the most important properties in this respect (Aburas, 2016)

Soil properties are the most important determinates for soil susceptibility to erosion, although there are other effective factors such as topography. Thus, soil susceptibility to erosion is varied in relation to soil texture, shear strength, infiltration rate, aggregate stability, organic matter and chemical composition. The question therefore arises whether soil erodibility can be predicted by using formulae based on soil properties that affect soil structure, particularly, organic matter, clay content, carbonate content and Fe and Al oxides (Wlschmeier & Mannering, 1969).

There are different factors that contribute to soil erosion and their relation to soil properties, he stated that Soil loss by water erosion through Slope Gradient and Length, Soil Erodibility, Vegetation and Land Use and Rainfall Erosivity (GEF, 2005).

2.9. The knowledge of farmers on soil quality indicators and its influences on crop diversity

Soil scientists classify soil quality indicators as chemical, physical and biological, where chemical indicator talk over with cycling of nutrients, water associations and buffering and include: salinity measurement, pH, total nitrogen and soil organic carbon (Nael et al., 2004). Biological is soil quality indicator which comprise animals and plants species that plays an important role for supporting a critical function of soil and hence services of ecosystem and includes: soil quality of biological indicator embrace animal and plant species that plays a significant role for sustaining vital soil functions and then system services ; physical indicators are associated with the solid arrangement particle and pores concerned in hydraulic flows of soil including aggregate stability, soil structure, bulk density, available water capacity, porosity, infiltration, texture, compaction and slaking.

Preceding farmers' information studies on indicators of soil quality have discovered that they need skills on mainly biological or physical indicators. Farmers reporting physical indicator of soil as soil color, soil tilth, texture and retention of moisture; whereas biological indicators contain performance of crop yield, plants indication, soil macro-faunal and also the most important chemical indicators known by farmers is soil organic matter. About productivity, farmers indicate that the soil quality indicators are based on the crops which is appropriate to an a given part of land, the main interest of farmers to the soil is agricultural productivity and this understanding is making key barrier for soil restoration and reduction of soil fertility status of land (Tesfahunegn, 2018).

CHAP III. MATERIAL AND METHODS

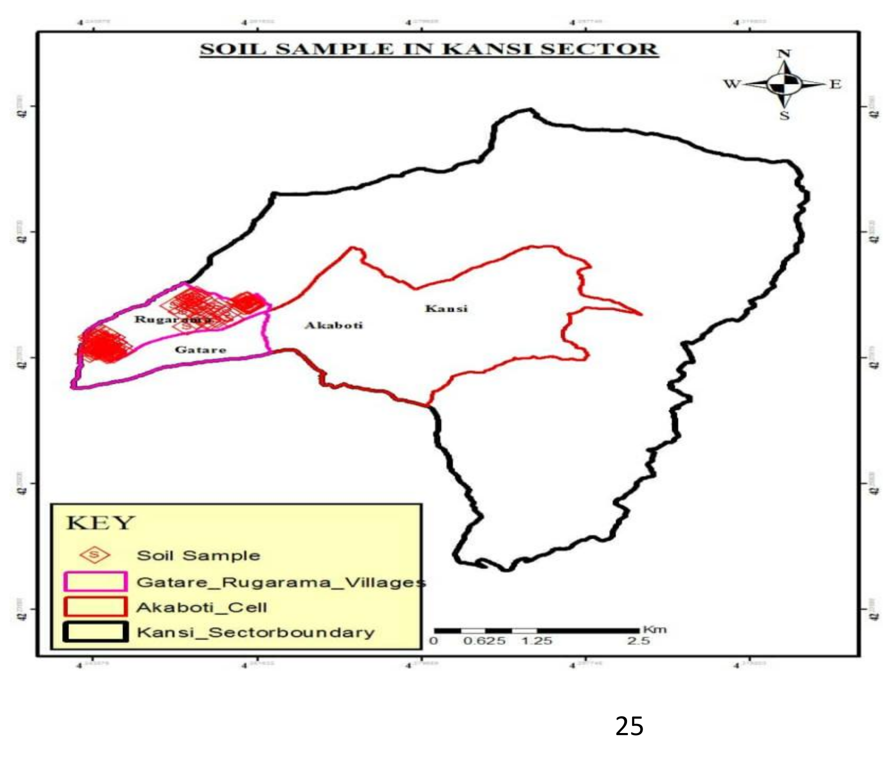
This study was conducted in Migina catchment with the purpose of determining the effect of soil physico-chemical properties on soil quality by basing to the elements that are influencing soil fertility. In order to achieve our main objective of assessing the impact of land management on oil quality, we focused our analysis in five selected land management practices in this area, that are agroforestry, forestry, radical terrace, trenches and soil amendment.

3.1. Description of the study sites

3.1.1. Geographical area localization

The present research was conducted in Migina catchment which is located in Southern Province of Rwanda and pass through Huye, Gisagara and Nyaruguru districts, our analysis were done within five selected land management practices that are agroforestry, forestry, radical terrace, trenches and soil amendment at Akaboti cell, Kansi Sector in Gisagara District.

Geographically, Migina catchment is situated between latitudes 2°32' to 2°48' South and with longitudes of 29°40' to 29°48' East, in southern part of Rwanda, Its mean annual temperature is about 20°C and its mean annual rainfall is 1200 mm/a and then 917 mm/a is estimated to be its mean annual actual evaporation (Munyaneza, Wali, & Uhlenbrook, 2014). The average altitude of Migina Catchment is 1681 m.



3.1.2. Surface, population and density

Rwanda have more different catchment one of them is Migina catchment which is located in Kagera River basin with around 260 km^2 of an area and their population are about 103,000 people with about 3% growth rate. The catchment is containing five sub-catchments referring to the main draining rivers area, in upstream there two sub-catchment which are Munyazi to Rwa-buye and Mukura, in the center there are Cyihene to Kansi and Akagera as other two sub-catchment and the last one is located in downstream area (Munyaneza et al., 2014).

3.2. Materials

3.2 .1.Field equipments

There are different materials that were used in order to gather soil sample for laboratory analysis like Auger, Basket, Cooler box, Coiling, Coiling box, Knife, Hoe, Decameter, Timber and GPS

Auger was used for taking a soil sample from different location of the field (on the Top slope, middle slope, and bottom.

Cooler box used to keep cold and flesh soil for available Nitrogen Analysis.

Coiling and Coiling box was used to take flesh soil and to keep them fresh for soil moisture and bulk density analysis.

Basket used to make mixture of composite soil sample for better laboratory analysis

GPS is an electronic field material that was used to take Geographical Coordinates.

3.2.2. Laboratory equipments

In this study for being achieved, we used those following material and equipment like pH-meter, stirrer, spectrophotometer, digester, distiller flasks, funnels, pipettes, precision balance, cylinders, filter papers, Erlenmeyer, sieves, watch glass, crucibles, sand bath, spoons, auger, mortar, pestle, Electronic Balance, Volumetric flask, Conical flask, Steam distillation, Microburette, Mechanical shaker, plastic bottles with stoppers, Magnetic stirrer, Beakers, Hydrometer, Thermometer, etc. and many laboratory chemical product were used to analyze soil constituent elements.

We used also Atomic Absorption Spectrophotometer (AAS) as the apparatus which help to analyze soil for determining the level of some chemical elements existing in soil. It helps to obtain results quickly than other methods and materials. It is used through the methods named Atomic Absorption Spectrometry, which is new technique, have been suggested as analytical method, this method will be used to analyze Ca, Na, Al and K elements.

3.3. Research methodology

3.3.1. Soil sampling

Stratified soil sampling method using auger were used to collect samples in different land management practices (terraced land, trenches, agro forestry, forestry and control).The sampling was done along a toposequence (Upland, middle and low land) and simple sites were located by international coordinates using Global Positioning system (GPS)(model GARMIN *etrex* 20). From each sampling unit, disturbed (bulk) and undisturbed (core samples) the physico-chemical analysis in laboratory were used those taken samples. Gathered samples were 18 composite soil samples collected to a depth of 30cm, labeled and prepared for analysis.

3.3.3. Laboratory analyses

The laboratory work was done in the soil and plant analysis Laboratory at University of Rwanda. The collected soil samples means disturbed one were air-dried and ground to pass through a 2mm and 0.5mm sieve for laboratory analyses. Undisturbed core samples were used for calculating the soil bulk density, moisture content, particle density, porosity and texture. The core methods were used to determine the Bulk Density (Black and Hartge, 1986). Particle density of the soil was calculated by determining the mass and volume those particle solid occupy. The soli particles mass was also determined by measuring the solid particle and the same at the volume was obtained from the weight and water density displace by soil sample (Blake and Hartge, 1989). Total soil porosity was determined using a formula outlined by NSS (1990) as follows:

Soil porosity = (Particle density - Bulk density)/Particle density)*100 for every sample.

Those sample of soil that are disturbed were used for analyzing the remaining physical and all chemical properties of soil except available nitrogen (N-NO_3^- and N-NH_4^+) which used flesh soil. Hydrometer method after dispersion with sodium hexametaphosphate 5% (NSS, 1990). The USDA textural class triangle was used to determine the textural classes (USDA, 1975). The electrical conductivity was measured on 1:2.5 ratio extract with an EC meter (Okalebo,2002). The soil reaction(pH) was measured potentiometricaly in water and 1N KCl at a ratio of 1:2.5 Soil:

water and KCl (Okalebo,2002). Total exchangeable acidity was determined by 1M KCl extraction solution and the soil extract titrated with sodium hydroxide. A second titration with 1M HCl after addition of sodium fluoride was used to obtain the exchangeable aluminium ((NSS, 1990). Aluminium saturation as measure of toxicity was calculated by dividing exchangeable aluminium by the summation of exchangeable bases and exchangeable aluminium. The Walkley and Black wet oxidation method was used to determine the organic carbon (Nelson and Sommers, 1982) and organic matter were observed by multiplying organic carbon with factor of 1.724 (Duursma and Dawson, 1981). Bray II solution as extractant was used to extract available phosphorus from the soil. The extracted phosphorus is measured colourimetrically based on the reaction of ammonium molybdate and for the development of molybdate blue calour. The absorbance of the compound is measured at 882nm in a spectrophotometer and is directly proportional to the amount of phosphorus extracted from the soil (Okalebo, 2002). The extraction of soil bases were measured by soil saturated by neutral 1M NH_4OAc (ammonium acetate) (Thomas, 1982) and the absorbed NH^{4+} displaced by K^+ using 1M KCl , The bases Ca^{2+}, Mg^{2+}, K^+ and Na^+ displaced by NH_4^+ were measured by Atomic Absorption Spectrophotometer (Thomas, 1982). And the ECEC were calculated arithmetically as total of four exchangeable bases ($Ca^{2+,}$ Mg^{2+}, Na^+ and K^+) plus exchangeable acidity (Al^{3+} and H^+)for a given soil sample.

3.3.4. Data analysis

Genstat software was used to test differences between treatments in Migina catchment area. Least significances were measured to determine significant difference between treatments for each measured parameter and difference were declared significant at α: 0.05 level. Excel software for data entry, calculations and management.

CHAP IV. RESULTS PRESENTATION

4.1. Introduction

This chapter present the results obtained in physico-chemical properties and statistical soil sample analysis of Migina Catchment at Akaboti cell, Kansi Sector, Gisagara District in Southern Province of Rwanda. Those results are presented in form of figures and tables for facilitating their interpretation. The soil nutrients and chemical parameters that assed, are soil pH (H_2O), pH (KCl), Available Nitrogen (N-NH_{4+} and N-NO_3^-), Available Phosphorus, Exchangeable basis (K, Ca, Na, Mg and Base Saturation), Exchangeable Acidity (Al^{2+}, H^+) and Organic Carbon, we was analyzing also soil physical properties like Moisture Content, Bulk Density, Electrical conductivity , particle density and soil texture all of those physico- chemical properties analyzed for observing the parameters improving soil fertility under different land management practices which are Radical terrace, Forest, Agroforestry, Trenches and Soil Amendment in Migina Catchment.

4.2 .Tables of results presentation and interpretation

4.2.1. pH Water, pH KCl in different land management practice

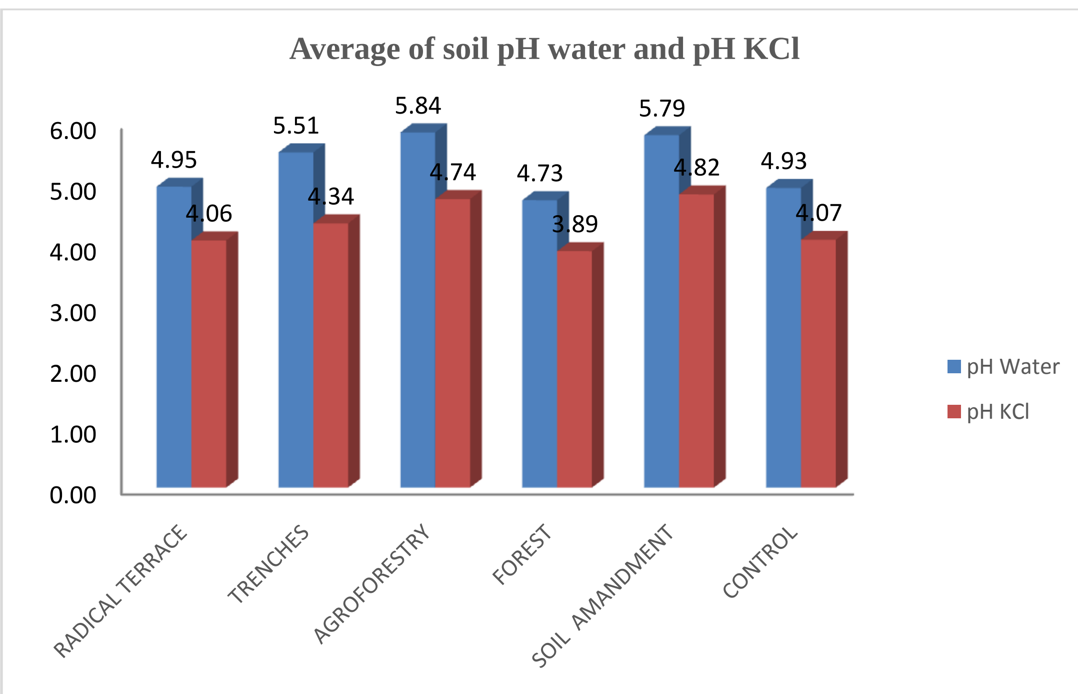


Figure 1: pH Water, pH KCl in different land management practice in Migina catchment

The ANOVA tables (appendix) shows that there is highly significant between land management ($P<0.001$).

The value presented in the figure above are pH water and pH KCl of different land management in Migina Catchment, The pH water and pH KCl of the studied area varies slightly along a topo-sequence in general, (table 1). The figure shows that pH water and pH KCl of agroforestry, trenches and soil amendment practices are greater than the pH of radical terrace and forest management practices. And specifically agroforestry pH is higher than the other land management practices (figure1).

Generally the pH of this area is acidic in nature (table 1). The soils irrespective of the physiographic position along the toposequence were varying from strongly to slightly acidic with the pH (H_2O) values of 4.73 – 5.14 for radical terraced land; 5.79 – 5.29 for trenches; 6.29 – 5.79 for agroforestry; 4.93 – 4.49 for forest and 5.27 – 4.69 for control (ILACO, 1993; Landon, 1991; Baize, 1993; Msanya*et al.*, 2001). The pH in amended land increased with altitude with the values of 6.34, 5.94 and 5.11 for the upper, middle and bottom land respectively there is no trends of pH decreasing or increasing except in soil amendment practice where pH is decreasing downward.

4.2.2. Electrical Conductivity in different land management practice

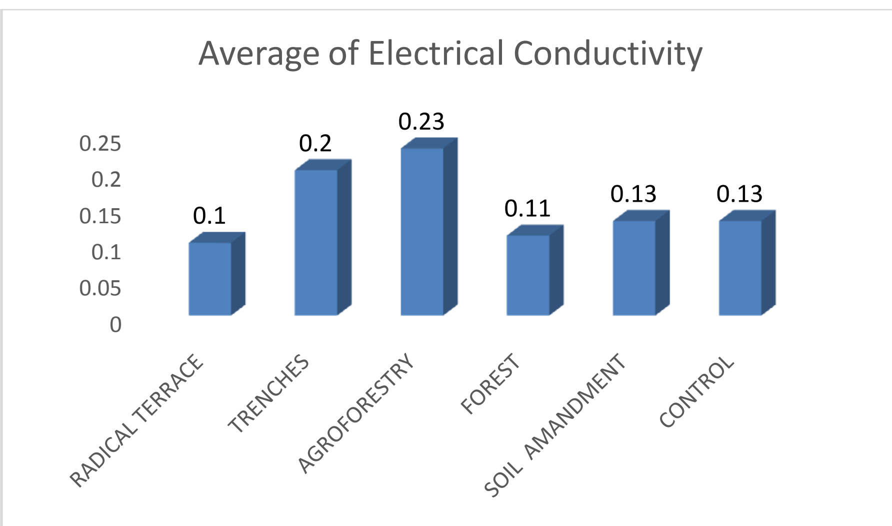


Figure 2: Electrical Conductivity in different land management practice

The ANOVA tables (appendix) shows a highly significant difference between land management ($P<0.01$).

The value presented in the figure above is Electrical conductivity of different land management in Migina Catchment, the Electrical conductivity of our studied area varies slightly along a topo-sequence in general, (table 1). According to (E.S. Marx, J. Hart, 1999), The figure shows that the Electrical conductivity is low for all treatments means there is not any salinity effect in my study area. And specifically electrical conductivity of agroforestry land management practice is higher compared to the other land management practices while in radical terrace its electrical conductivity is smaller than the other land management practice in our study area (figure 2).

Generally the Electrical Conductivity in this study area is low (table 1.). Without based on topo-sequence electrical conductivity variation, normally were varying as this follow, the electrical conductivity values of 0.076 – 0.146ds/m for radical terraced land; 0.087 – 0.366 ds/m for trenches; 0.112 – 0.390ds/m for agroforestry; 0.98 – 0.102 ds/m for forest; 0.15-0.141ds/m for amended land and 0.080 – 0.198ds/m for control. There is no trends of electrical conductivity decreasing or increasing toposequently except in radical terrace practice where electrical conductivity decreasing down ward.

Table 1: The results on pH, Electrical conductivity, Organic Carbon, Available Nitrogen (N-NH4 - N-NO3-), Available Phosphorus

Land Management Practice	Soil Sample Stream	pH_{H2O}	pH_{Kcl}	EC(dS/m)	% OC	% OM	AV. Nitrogen		ppm (Av. P)
							$N\text{-}NH_4$ ppm	$N\text{-}NO_3^-$ ppm	
RADICAL TERRACE	Upper	4.98	4.08	0.080	1.53	2.63	2.554	6.89	9.24
	Middle	5.14	4.18	0.076	3.33	5.73	3.359	18.61	10.21
	Bottom	4.73	3.93	0.145	1.71	2.94	3.019	4.36	8.55
TRENCHES	Upper	5.46	4.27	0.138	2.61	4.49	4.104	18.89	17.10
	Middle	5.29	4.17	0.087	2.88	4.96	4.852	11.04	9.49
	Bottom	5.79	4.59	0.366	3.24	5.58	3.574	16.18	12.11
AGROFORESTRY	Upper	6.29	5.32	0.188	4.04	6.97	6.315	24.00	16.79
	Middle	5.45	4.3	0.112	3.77	6.51	5.658	18.75	14.78
	Bottom	5.79	4.61	0.390	3.24	5.58	4.466	28.00	12.58
FOREST	Upper	4.93	3.9	0.102	2.61	4.49	2.982	9.64	10.02
	Middle	4.49	3.91	0.098	2.88	4.96	3.383	18.57	9.98
	Bottom	4.77	3.85	0.129	3.59	6.20	5.304	12.46	14.75
SOIL AMANDMENT	Upper	6.34	5.37	0.141	3.33	5.73	5.727	17.75	14.65
	Middle	5.94	4.96	0.105	3.41	5.89	4.554	20.82	11.99
	Bottom	5.11	4.13	0.155	2.70	4.65	7.239	19.54	12.40
CONTROL	Upper	4.69	3.95	0.098	2.34	4.03	3.322	13.39	9.12
	Middle	4.83	4.03	0.080	2.88	4.96	3.767	12.82	9.17
	Bottom	5.27	4.24	0.198	3.95	6.82	3.063	14.29	9.42

4.2.3. Carbon and organic matter Percentage in different land management practice

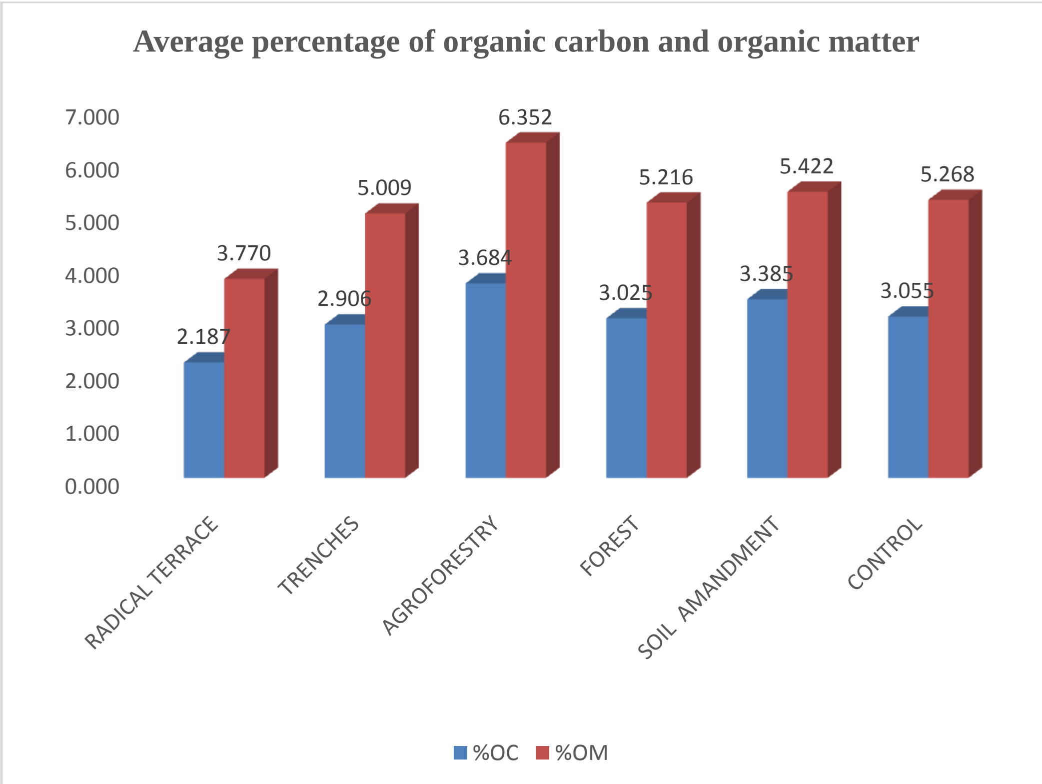


Figure 3: Percentage organic Matter and Carbon Percentage in different land management practice

The ANOVA tables (appendix) shows a significant difference between land management (P<0.02).

The values presented in the figure above are organic carbon and percentage of organic matter of in different land management practice in Migina catchment area. In this different land management practice organic carbon of varies slightly along a toposequence in general, (table 1).The figure shows that the agroforestry practice contains higher organic matter and organic carbon than other land management practices while radical terrace has lower organic matter and carbon percentage compare to the other selected land management in this study area (figure 3).

According to Kileo (2000) and EUROCONSULT (1989), generally the organic carbon and organic matter percentage of the study area varies from medium to very high (table 1.). The percentage of soil carbon irrespective of the physiographic position along the toposequence were varying from Medium to high with the % C values from 1.53 – 3.33 for radical terraced land;

2.61– 3.24 for trenches; 3.24 – 4.04 for agroforestry; 2.61 – 3.59 for forest; 2.70-3.33 for amended soil and 2.34 – 3.95for control (ILACO, 1993; Landon, 1991; Baize, 1993; Msanya *et al.*, 2001). Soil organic carbon varies from the upper, middle and bottom land respectively there is a specific trends of % OC in treatment as it is increasing downward except in soil amendment practice and in radical terrace where there is not specific trend of % OC variation, and in Trenches increase downward.

4.2.4. Ammonium (NH_4^+) of different land management practice in Migina Cacthment

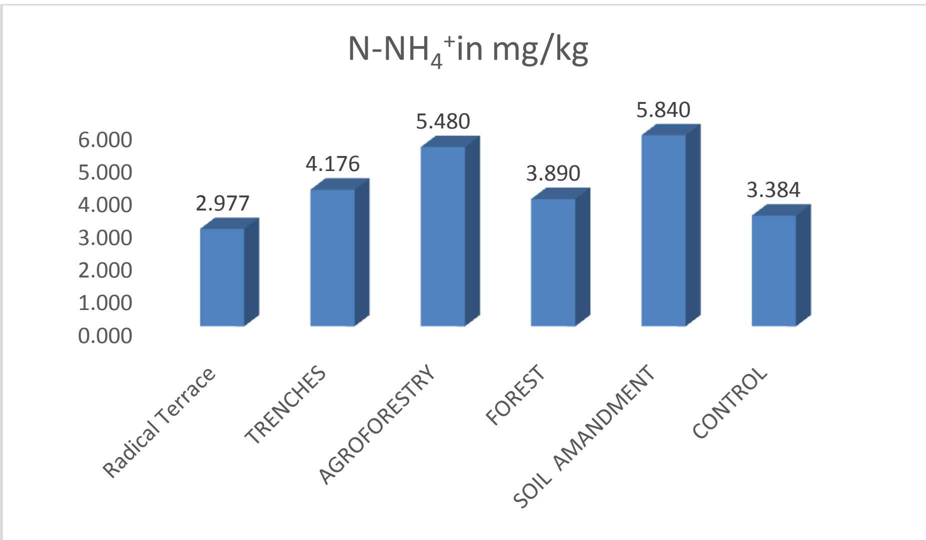


Figure 4: Ammonium ($NH4^+$) percentage in different land management practice

The ANOVA tables (appendix) shows that there is less significant between different land management ($P<0.042$).

The value presented in the figure above are Ammonium (NH_4^+) of different land management in Migina Catchment, Ammonium (NH_4^+) of the studied area varies slightly along a toposequence in general, (table 1). The figure shows that Ammonium (NH_4^+) of amended soil are greater than the Ammonium (NH_4^+) of other practice in this area while radical terrace has smallest Ammonium (NH_4^+) compared to the other land management in Migina catchment (figure4).

Generally the Ammonium (NH_4^+) of the study area is enough (table 1) as the effective values in soil crop production is from 2-10 ppm (E.S. Marx, J. Hart, 1999) . The value of ammonium is presented in (Table 1). According (Murphy and Hazalton, 2007), the upper , middle and lower slopes showed medium to high levels of nitrate ranging from of 2.554 – 3.353ppm for radical terraced land; 3.574 – 4.852 ppm for trenches; 4.466 – 6.315ppm for agroforestry; 2.982 – 5.304ppm for forest,4.554 – 7.239ppm for amended soil and 3.063-3.767ppm for control. Referring to toposequence there is no specific trends of Ammonium (NH_4^+) variation except in forest land management practice where Ammonium (NH_4^+) is increasing downward (table1).

4.2.5. Nitrate (NO_3^-) of different land management practice in Migina Cacthment

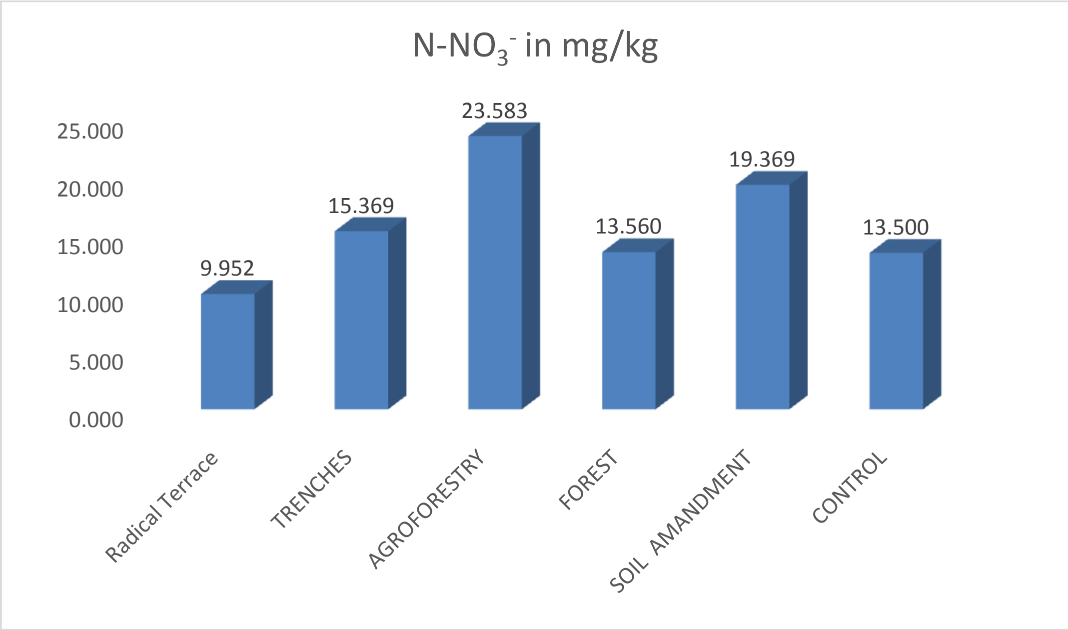


Figure 5: Nitrate (NO_3^-) percentage in different land management practice

The ANOVA tables (appendix) shows that there is a significant different between land management ($P<0.006$).

The value presented in the figure above is Nitrate (NO_3^-) of different land management in Migina Catchment, Nitrate (NO_3^-) of the studied area varies slightly along a toposequence in general, (table 1). The figure shows that Nitrate (NO_3^-) of Agroforestry are greater than the Nitrate (NO_3^-) of other practices in this area while radical terrace has smallest Nitrate (NO_3^-) compared to the other land management in Migina catchment (figure5).

Generally the Nitrate (NO_3^-) of the study area is high (table 1.). The value of Nitrate is presented in (Table 1). According(Murphy and Hazalton, 2007), the upper , middle and lower slopes showed medium to high levels of nitrate ranging from of 4.36 – 18.61ppm for radical terraced land; 11.04 – 18.89 ppm for trenches; 18.75 – 28 ppm for agroforestry; 9.64 – 18.57ppm for forest,17.75 – 20.85ppm for amended soil and 12.82-14.29 ppm for control. Referring to toposequence there is no specific trends of Nitrate variation (NO_3^-) (table1).

4.2.6. Available phosphorus in different land management practice

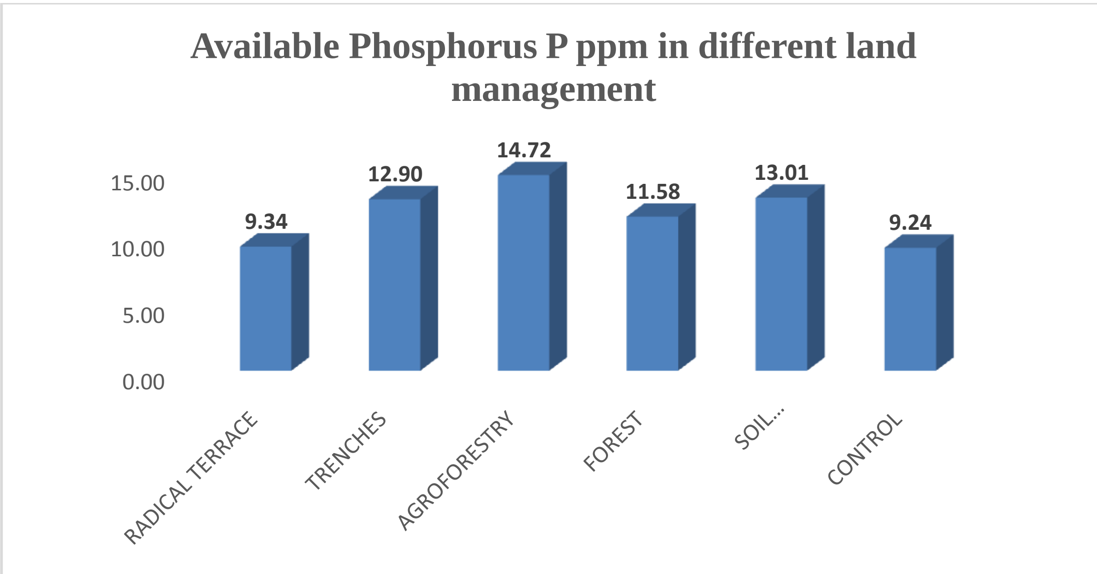


Figure 6: Available phosphorus percentage under different land management practice

The ANOVA tables (appendix) shows a significant difference between land management ($P<0.02$).

The available phosphorus P varies from 9.24ppm to 14.47ppm based to the average available phosphorus of different selected land management in migina catchment. Generally all land management Av. P varied in medium but are different from their toposequence values. According to EUROCONSULT (1989), all practices of our study area classified in medium there are differ in values of phosphorus availability in their treatment, where agroforestry, soil amendment, trenches and forest have great value respectively compared to the radical terrace and control. The most competitive to soil available phosphorus is agroforestry and control is less compare to the other treatments (figure 6).

The soil phosphorus is classified as medium according to (ILACO, 1993; Landon, 1991; Baize, 1993; Msanya *et al.*, 2001). But referring to the toposequence there significant variation of their availability as this follow for radical terrace varies from 8.55-10.21ppm, for trenches is 9.24-17.10ppm, for is Agroforestry 12.58-16.79ppm, for forest is 9.98-10.02ppm, for soil amendment is 11.99-14.75ppm and Control is varies from 9.42-9.12 ppm, and there is no specific trends on treatment toposequence except at control where values varies by increasing downward and in agroforestry varies by decreasing down ward (table 1).

EXCHANGEABLE BASES

4.2.7. Exchangeable Potassium

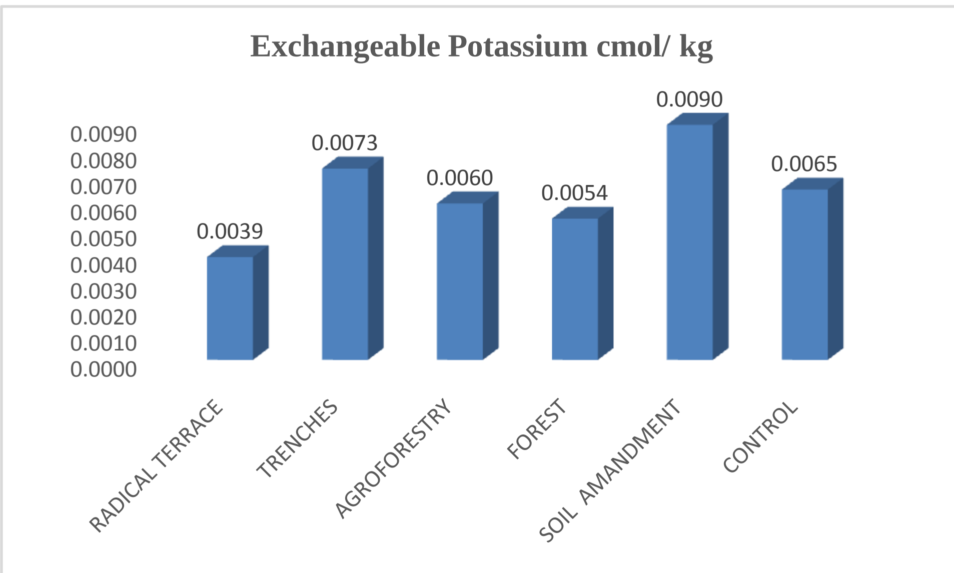


Figure 7: Exchangeable Potassium under different land management practice

The ANOVA tables (appendix) show a significance between different land management (P<0.04).

The value presented in the figure above is Potassium (K) of different land management in Migina Catchment, Potassium (K) of the studied area varies slightly along a toposequence in general, (table 1). The figure shows that Potassium (K) of Agroforestry are greater than the Potassium (K) of other practices in this area while radical terrace has smallest Potassium (K) compared to the other land management in Migina catchment (figure7).

Generally the Potassium (K) of the study area is very low (table 2). The soils irrespective of the physiographic position along the toposequence were varying as this follow values of 0.0028 – 0.0056 cmol/kg for radical terraced land; 0.0035 – 0.0144 cmol/kg for trenches; 0.0036 – 0.0145 cmol/kg for agroforestry; 0.0043 – 0.0066 cmol/kg for forest, 0.0043 – 0.0142 cmol/kg for amended soil and 0.0052-0.0084 cmol/kg for control (ILACO, 1993; Landon, 1991; Baize, 1993; Msanya*et al.*, 2001). Referring to toposequence there is a trends of Potassium (K) in radical terrace, trenches increase downward also in forest and control (undisturbed land) is decreasing downward except in Agroforestry and soil amendment land management practices where there is no trends of Potassium (K) variation (table2).

4.2.8. Exchangeable Magnesium

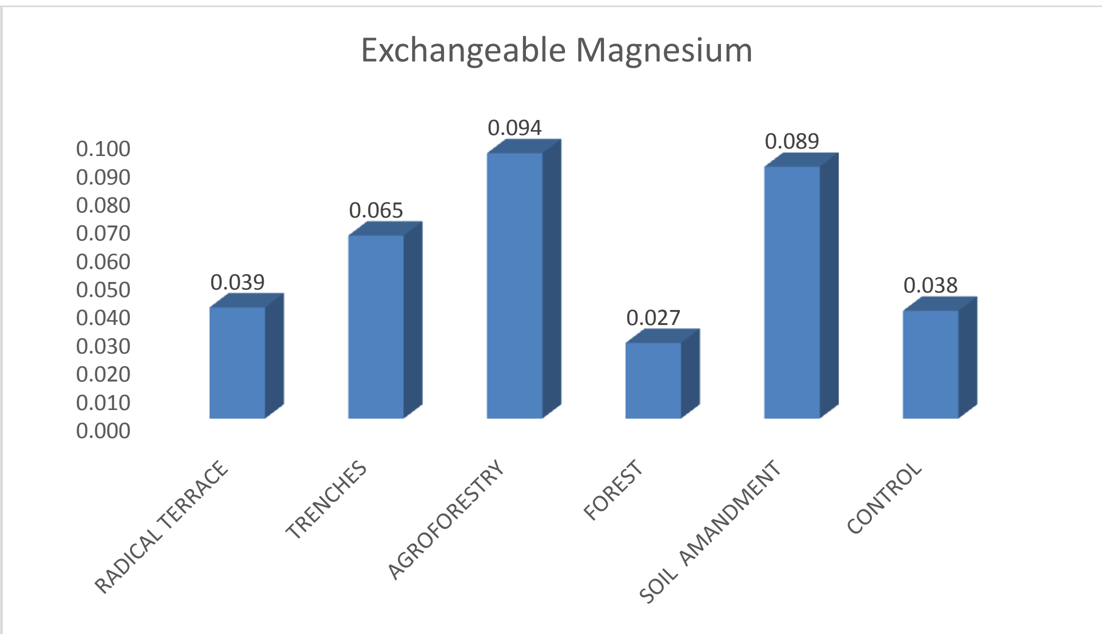


Figure 8: Exchangeable Magnesium under different land management practices

The ANOVA tables (appendix) shows that there is a less significant difference between land management (P<0.042).

The value presented in the figure above is Magnesium (Mg) of different land management in Migina Catchment, Magnesium (Mg) of the studied area varies slightly along a toposequence in general, (table 1). The figure shows that Magnesium (Mg) of Agroforestry are greater than the

Magnesium (Mg) of other practices in this area while forest has smallest Magnesium (Mg) compared to the other land management in Migina catchment (figure8).

Generally the Magnesium (Mg) of the study area is very low to low (table 2.). The value of Magnesium (Mg) is presented in (Table 1). According (Murphy and Hazalton, 2007), the upper , middle and lower slopes showed the levels of Magnesium (Mg) ranging from 0.03 – 0.44cmol/kg for radical terraced land; 0.05 – 0.9 cmol/kg for trenches; 0.08 – 0.11 cmol/kg for agroforestry; 0.02 – 0.09 cmol/kg for forest, 0.03 – 0.11 cmol/kg for amended soil and 0.03-0.06 cmol/kg for control (ILACO, 1993; Landon, 1991; Baize, 1993; Msanya*et al.*, 2001). Referring to toposequence there is no trends of Magnesium (Mg) values (table2).

Table 2: The results of exchangeable bases and acidity Calcium (Ca), Magnesium (Mg), Potassium (K), Sodium (Na),ECEC and Base Saturation

		Exch. Bases						
Land Management Practice	**Soil Sample Stream**	**cmol/kg (Ca)**	**cmol/kg (Mg)**	**cmol/kg (K)**	**cmol/kg Na**	**(TEB)CEC (cmol(+)/kg**	**ECEC cmol(+)/kg)**	**% BS**
RADICAL TERRACE	Upper	0.1	0.04	0.00287	0.021	0.16	1.44	11.34
	Middle	0.14	0.04	0.00328	0.027	0.21	2.29	9.3
	Bottom	0.13	0.03	0.00564	0.016	0.18	1.3	14.12
TRENCHES	Upper	0.14	0.06	0.00354	0.012	0.21	1.81	11.81
	Middle	0.18	0.05	0.00395	0.062	0.29	1.01	28.83
	Bottom	0.24	0.09	0.01446	0.106	0.45	0.93	48.27
AGROFORESTRY	Upper	0.13	0.11	0.00036	0.23	0.48	1.6	29.99
	Middle	0.13	0.08	0.00303	0.101	0.31	0.95	32.65
	Bottom	0.2	0.09	0.01456	0.117	0.42	4.02	10.48
FOREST	Upper	0.12	0.03	0.00667	0.019	0.18	3.22	5.46
	Middle	0.13	0.02	0.00518	0.03	0.19	2.91	6.43
	Bottom	0.16	0.03	0.00436	0.017	0.21	1.01	20.96
SOIL AMANDMENT	Upper	0.14	0.11	0.01421	0.058	0.32	0.4	79.82
	Middle	0.14	0.1	0.00692	0.238	0.48	1.84	25.98
	Bottom	0.15	0.06	0.00585	0.091	0.31	0.95	32.52
CONTROL	Upper	0.13	0.03	0.00841	0.051	0.22	3.1	7.06
	Middle	0.16	0.03	0.0059	0.075	0.27	3.31	8.02
	Bottom	0.18	0.05	0.00523	0.021	0.26	1.38	18.7

4.2.9. Exchangeable Calcium

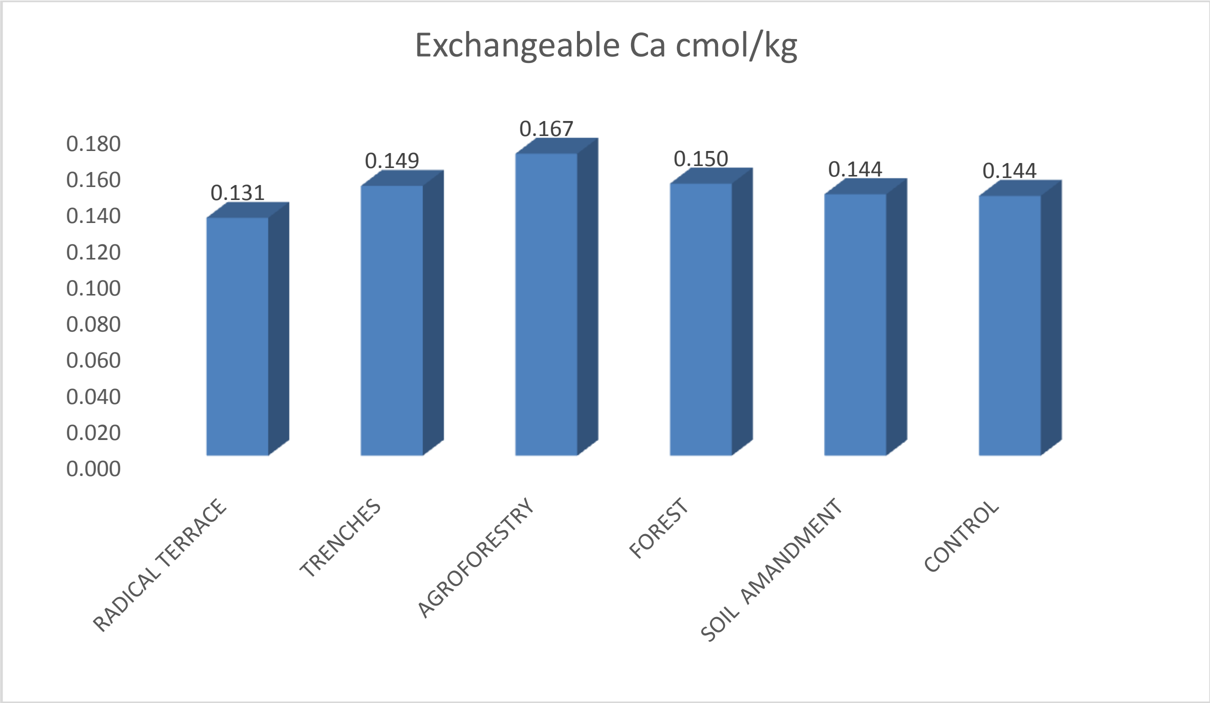


Figure 9: Exchangeable Calcium under different land management practices

The ANOVA tables (appendix) shows a less significance between land management ($P<0.046$).

The values presented in the figure above is Calcium (Ca) of different land management in Migina Catchment, Calcium (Ca) of the studied area varies slightly along a toposequence in general, (table 2). The figure shows that Calcium (Ca) of Agroforestry are greater than the Calcium (Ca) of other practices in this area while radical terrace has smallest Calcium (Ca) compared to the other land management in Migina catchment (figure 9).

Generally the Calcium (Ca) of the study area is low (table 2). The soils irrespective of the physiographic position along the toposequence were varying as this follow values of 0.10 – 0.14 cmol/kg for radical terraced land; 0.14 – 0.24 cmol/kg for trenches; 0.13 – 0.20 cmol/kg for agroforestry; 0.12 – 0.16 cmol/kg for forest, 0.14 – 0.16 cmol/kg for amended soil and 0.11-0.14 cmol/kg for control (ILACO, 1993; Landon, 1991; Baize, 1993; Msanya *et al.*, 2001). Referring to toposequence there is no trends of Calcium (Ca) except in trenches and control (undisturbed land) land management practices where Calcium (Ca) is increase downward (table 2)

4.2.10. Exchangeable Sodium

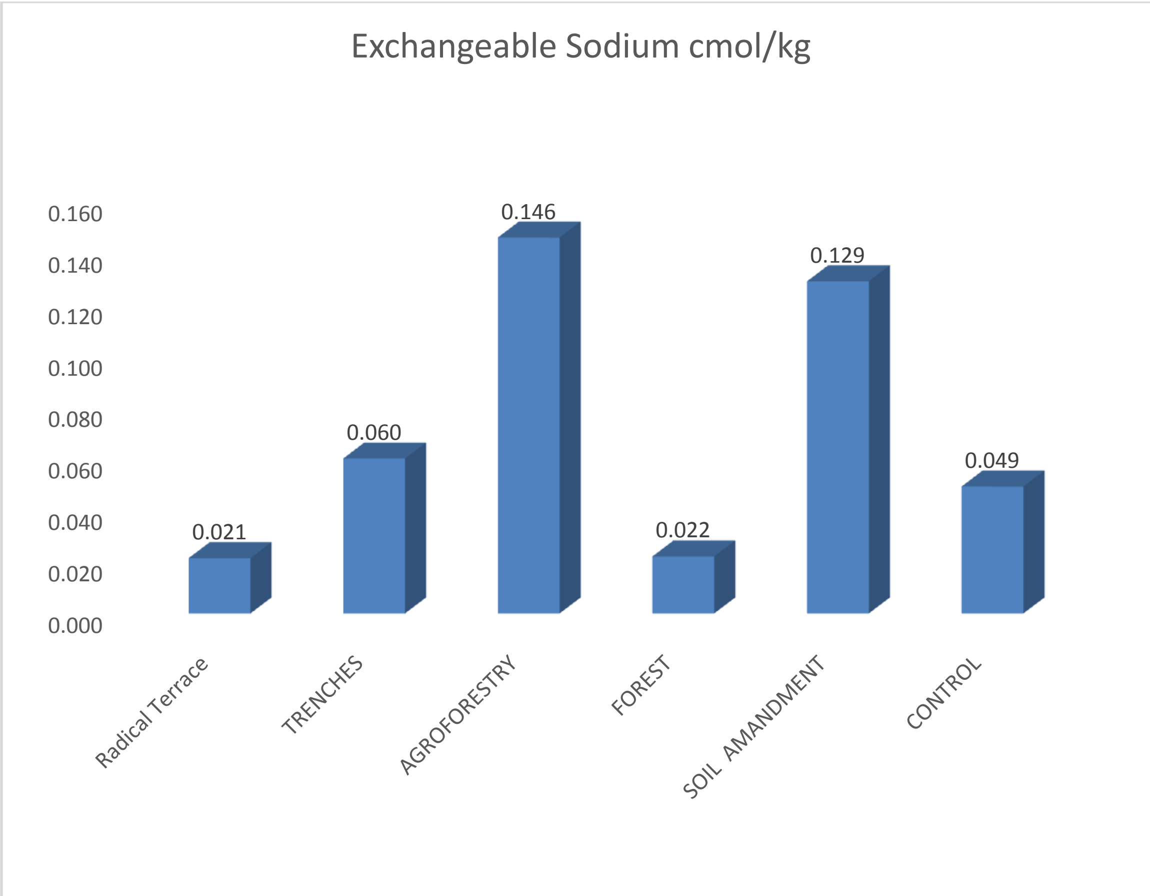


Figure 10: Exchangeable Sodium under different land management practices

The ANOVA tables (appendix) Shows that there is a significant between land management ($P<0.002$).

The value presented in the figure above is Sodium (Na) of different land management in Migina Catchment, Sodium (Na) of the studied area varies slightly along a toposequence in general, (table 2). The figure shows that the Sodium (Na) of Agroforestry is greater than other practices in this area while radical terrace and forested land have smallest Sodium (Na) compared to the other land management in Migina catchment (figure10).

Generally the Sodium (Na) of the study area is very low (table 2). The value of Sodium (Na) is presented in (Table 1). According (Murphy and Hazalton, 2007), the upper , middle and lower slopes showed the levels of Sodium (Na) ranging from 0.016 – 0.021 cmol/kg for radical terraced land; 0.012 – 0.106 cmol/kg for trenches; 0.101 – 0.230 cmol/kg for agroforestry; 0.017 –

0.030 cmol/kgfor forest, 0.058 – 0.238 cmol/kg for amended soil and 0.021-0.075 cmol/kg for control (ILACO, 1993; Landon, 1991; Baize, 1993; Msanya*et al.*, 2001). Referring to toposequence there is no trends of Sodium (Na) except in trenches management practice where Sodium (Na) is increasing downward (table2).

4.2.11. ECEC (Effective Cation Exchange Capacity)

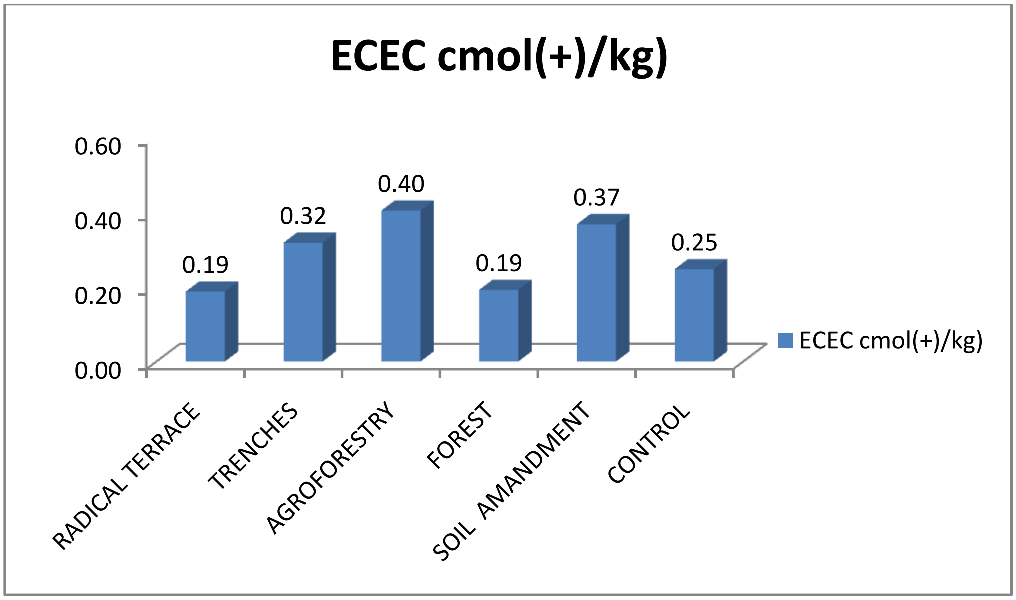


Figure 11: Effective Cation Exchange Capacity (ECEC) under different land management practices in Migina catchment

The ANOVA tables (appendix) shows that there is a less significant in different land management (P<0.046).

The value presented in the figure above is Effective Effect of Cation Exchange capacity (ECEC) of different land management in Migina Catchment, Effective Cation Exchange Capacity of the studied area varies slightly along a toposequence in general, (table 2). The figure shows that the Effective Cation Exchange Capacity of Agroforestry is more than other practices in this area while Forestry and radical Terrace have smallest Effective Cation Exchange Capacity compared to the other land management in Migina catchment (figure11).

Generally the Effective Cation Exchange Capacity of the study area is low (table 2.). The soils irrespective of the physiographic position along the toposequence were varying as this follow values of 0.16 – 0.21 cmol/kg for radical terraced land; 0.21 – 0.45 cmol/kg for trenches; 0.31 –

0.48 cmol/kg for agroforestry; 0.18 – 0.21 cmol/kg for forest, 0.31 – 0.48 cmol/kg for amended soil and 0.22-0.27 cmol/kg for control (ILACO, 1993; Landon, 1991; Baize, 1993; Msanya*et al.*, 2001). Referring to toposequence there is no trends of Effective Cation Exchangeable Capacity (ECEC) except in trenches land management practice where Effective Cation Exchangeable Capacity (ECEC) is increase downward (table2).

4.2.12. Base Saturation

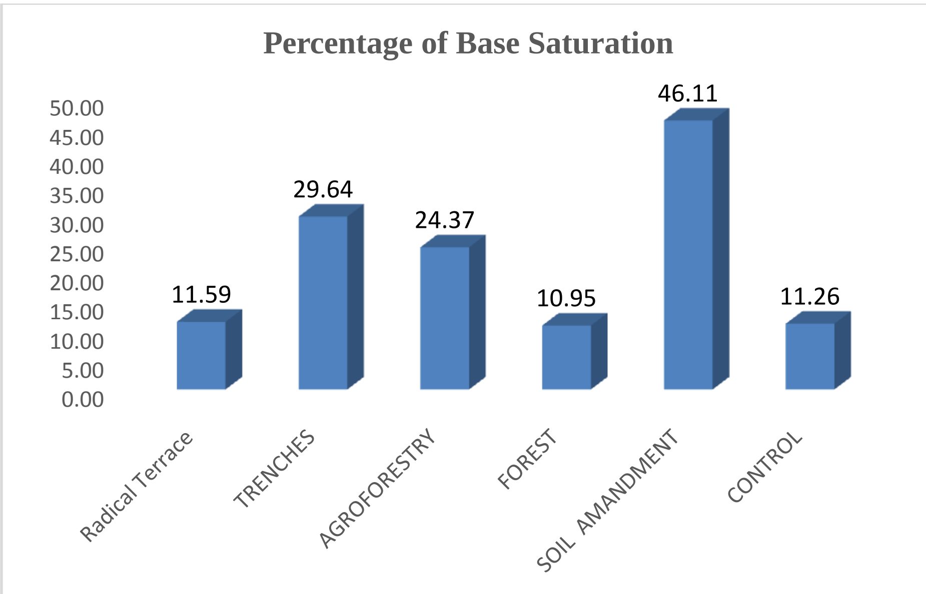


Figure 12: Percentage of base saturation under different land management in Migina catchment
The ANOVA tables (appendix) shows there is a less significant difference land management ($P<0.04$).

The value presented in the figure above is percentage Base Saturation of different land management in Migina Catchment, Base Saturation of the studied area varies slightly along a toposequence in general, (table 2). The figure shows that the Base Saturation of Agroforestry is greater than other practices in this area while radical terrace and forested land have smallest Base Saturation compared to the other land management in Migina catchment (figure12).

Generally the Base Saturation of the study area is low (table 2). The soils irrespective of the physiographic position along the toposequence were varying as this follow values of 9.30 – 14.12 % for radical terraced land; 11.81 – 48.27 % for trenches; 10.48 – 29.99 % for agroforestry; 5.46 – 20.96 % for forest, 25.98 – 79.82 % for amended soil and 7.06-18.70 % for control (ILACO, 1993; Landon, 1991; Baize, 1993; Msanya *et al.,* 2001). Referring to toposequence there is no trends of Base Saturation amended, terraced and agroforested land but in trenches, Forest and control land management practices Base Saturation is increasing downward (table2).

Table 3: The results of exchangeable acidity Aluminium (Al^{3+}), hydrogen (H^{+}) , Aluminium Saturation and Total Exchangeable Acidity

Land Management Practice	Soil Sample Stream	TEA (meq/100g)	Al^{3+} (meq/100g)	H^{+} (meq/100g)	Al. Saturation
RADICAL TERRACE	Upper	1.28	1.12	2.4	0.887
	Middle	2.08	0.96	1.12	0.907
	Bottom	1.12	1.36	2.48	0.859
TRENCHES	Upper	1.6	0.88	0.72	0.882
	Middle	0.72	0.8	1.52	0.712
	Bottom	0.48	0	0.48	0.517
AGROFORESTRY	Upper	1.12	1.12	0	0.700
	Middle	0.64	0.16	0.8	0.673
	Bottom	3.6	3.2	0.4	0.895
FOREST	Upper	3.04	0.16	3.2	0.945
	Middle	2.72	0.48	3.2	0.936
	Bottom	0.8	2.32	3.12	0.790
SOIL AMANDMENT	Upper	0.08	0.08	0	0.202
	Middle	1.36	0.48	1.84	0.740
	Bottom	0.64	0.48	0.16	0.675
CONTROL	Upper	2.88	0.64	3.52	0.929
	Middle	3.04	0.16	2.88	0.920
	Bottom	1.12	1.44	2.56	0.813

4.2.13. Exchangeable Acidity

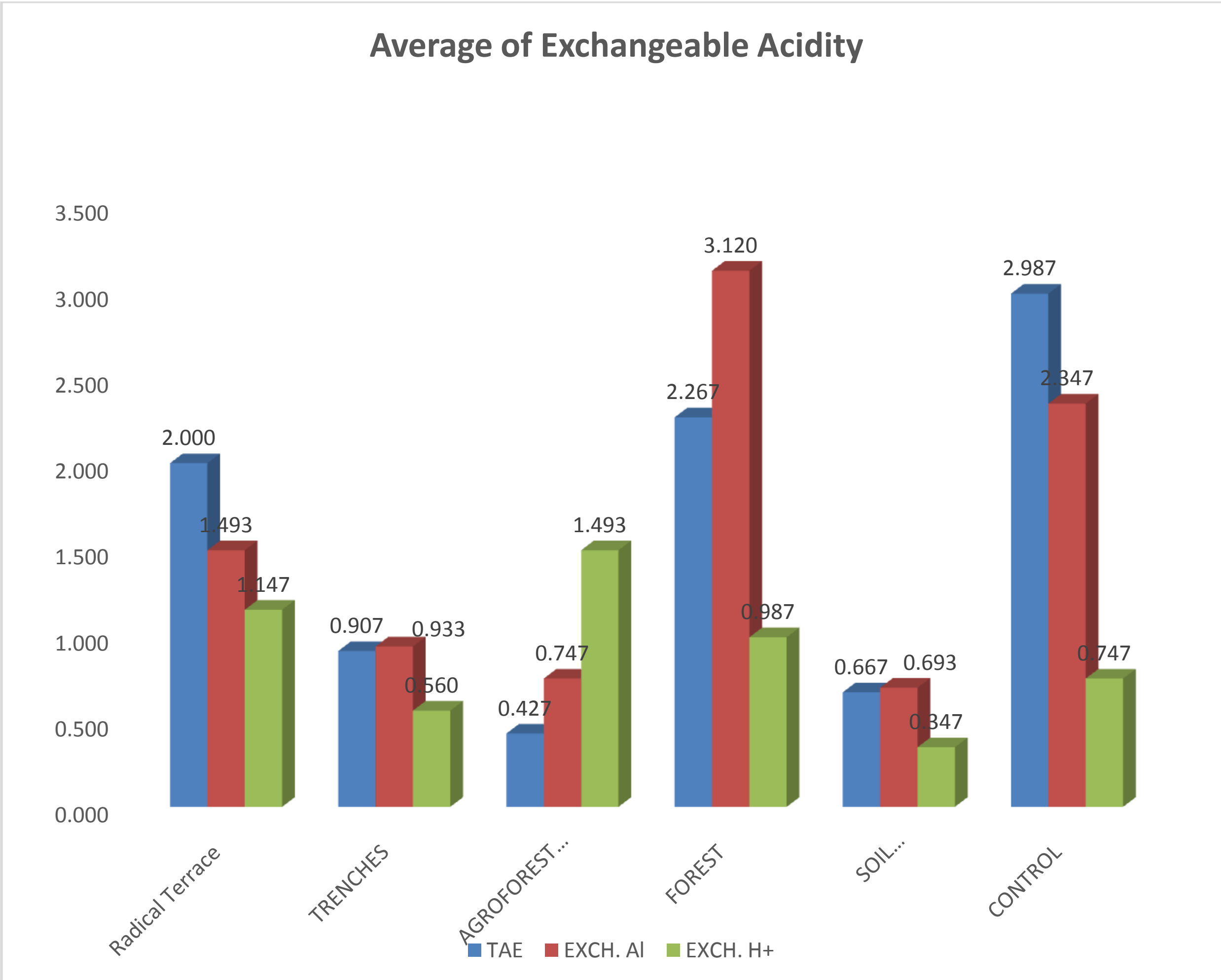


Figure 13: Exchangeable acidity of different land management practices in Migina Catchment

The ANOVA tables (appendix) shows that there is significant difference of land management (P<0.006), (P<0.04) for Aluminium and Hydrogen respectively.

The value presented in the figure above is Total Exchangeable Acidity, Exchangeable aluminium and Exchangeable hydrogen of different land management in Migina Catchment, the exchangeable acidity of the studied area varies slightly along a toposequence in general, (table 2). The figure shows that the acidity is very dominant in control, forest and radical terrace compared to the other land management in Migina catchmen, the exchangeable Aluminium is more than exchangeable hydrogen in study area (figure13).

Generally the Total Exchangeable Acidity of the study area is high (table 3.). The soils irrespective of the physiographic position along the toposequence were varying as this follow respectively exchangeable aluminium and hydrogen values are 1.12 – 2.08,0.96-1.36 meq/100g for radical terraced land; 0.48 – 1.16, 0-1.12meq/100g for trenches; 0.48 – 1.12 ,0.16-3.2meq/100g for agroforestry; 0.8 – 3.04, 0.16 – 2. 32 meq/100g for forest, 0.008 – 1.36, 0.8-0.48 meq/100g for amended soil and 1.12-2.88, 0.16-1.44 meq/100g for control (ILACO, 1993; Landon, 1991; Baize, 1993; Msanya*et al.,* 2001). Referring to toposequence there is no trends of Exchangeable acidity except in control or undisturbed land where Exchangeable acidity is decreasing downward (table1).

Table 4: The results on Soil texture, Moisture content, Bulk Density, Particle Density and Porosity

		Particle size distribution							
Land Management Practice	**Soil Sample Stream**	**% Sand**	**% Clay**	**% Silt**	**Textural classes**	**Moisture content %**	**Bulk Density g/cm^3**	**Particle Density g/cm^3**	**% Porosity**
RADICAL TERRACE	Upper	75.6	16.2	8.2	Sand Loam	9.936	1.276	2.61	52.03
	Middle	73.6	17.8	8.6	Sand Loam	7.917	1.11	2.65	58.27
	Bottom	73.6	22.4	4	Sand Clay Loam	16.18	1.15	2.68	56.77
TRENCHES	Upper	75.6	13.8	10.6	Sand Loam	6.434	1.404	2.52	47.22
	Middle	77.6	14.6	7.8	Sand Loam	3.09	1.233	2.7	53.65
	Bottom	75.6	11	13.4	Sand Loam	10.09	1.113	2.62	58.16
AGROFORESTRY	Upper	69.6	20.8	9.6	Sand Clay Loam	10.213	1.027	2.71	61.39
	Middle	73.6	15.2	11.2	Sand Loam	13.241	1.229	2.68	53.80
	Bottom	77.6	14.8	7.6	Sand Loam	17.276	0.961	2.67	63.87
FOREST	Upper	75.6	17.4	7	Sand Loam	19.3713	1.04	2.72	60.90
	Middle	79.6	10.8	9.6	Sand Loam	18.031	1.243	2.62	53.27
	Bottom	75.6	16.8	7.6	Sand Loam	15.2737	1.248	2.61	53.08
SOIL AMANDMENT	Upper	70	19.2	10.8	Sand Loam	15.594	1.16	2.68	56.39
	Middle	71.6	17.8	10.6	Sand Loam	13.237	1.093	2.7	58.91
	Bottom	77.6	12.4	10	Sand Loam	17.032	1.129	2.66	57.56
CONTROL	Upper	75.6	14.4	10	Sand Loam	7.2309	1.439	2.69	45.90
	Middle	71.6	18.4	10	Sand Loam	13.077	1.281	2.64	51.84
	Bottom	71.6	18.4	10	Sand Loam	12.743	1.303	2.67	51.02

4.2.14. Soil texture under different land management in Migina catchment

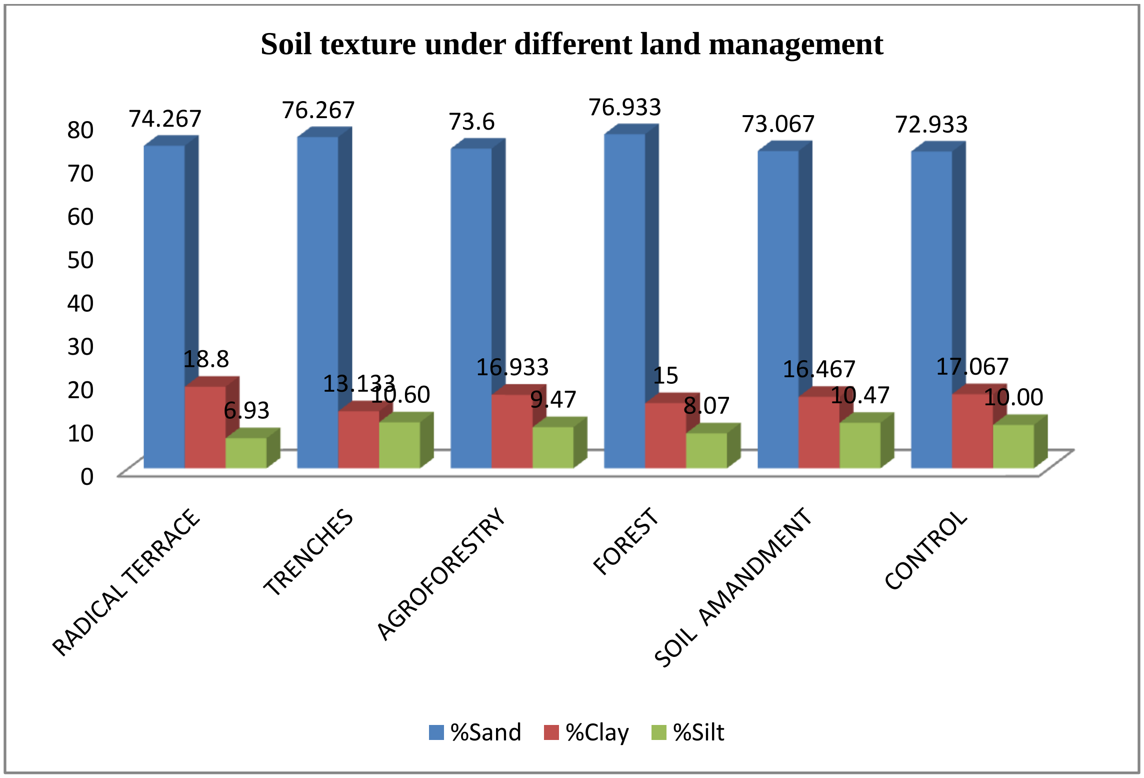


Figure 14: Soil Texture under different land management in Migina catchment

The study site is dominated by sandy loam (table4) except bottom of terraced land and upper land of agroforestry land use. All samples had high content of sand (79.6-69.6 %) than that of silt and clay content. The result (Table 3) of the soil texture showed that percent sand decreased down the slope in terraced and control lands ranging from 75.6 and 73.6 % and 75.6 and 71.6% respectively (figure 14).

4.2.15. Percentage of porosity and moisture content under different land management

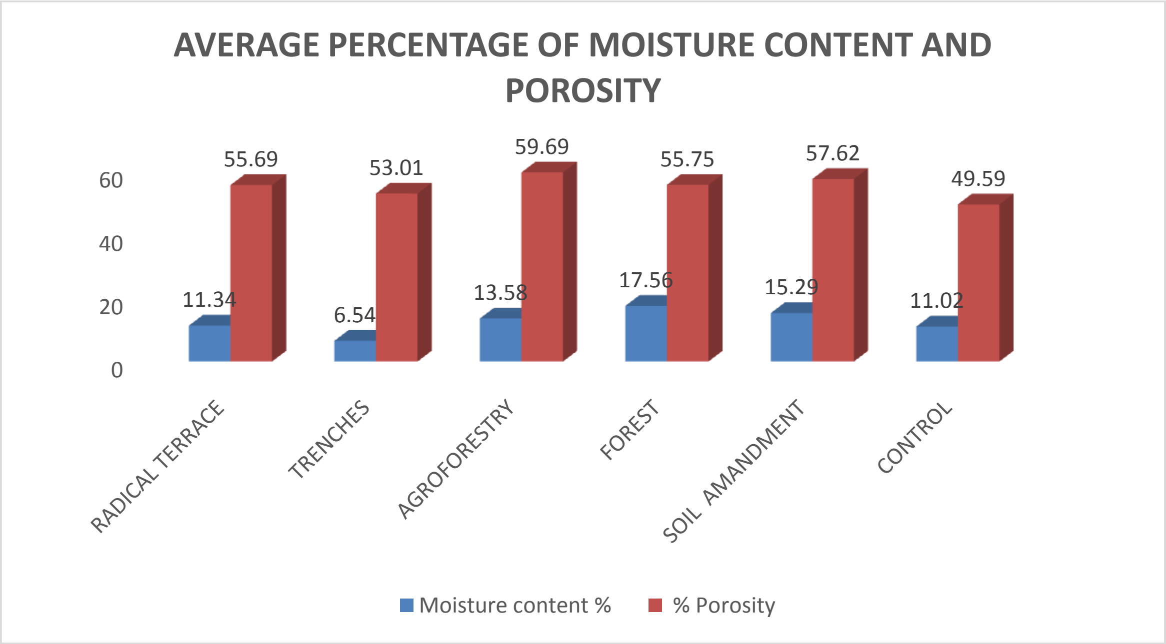


Figure 15: Percentage of porosity and moisture content under different land management in Migina Catchment

The ANOVA tables (appendix) shows a highly significant difference management on moisture content ($P<0.001$).

The values of total porosity ranged between 50.2 and 52.08 in terraced land; 47.2 and 58.16 in trenches; 53.8 and 63.87% in agroforestry; 53.08 and 53.8 % in forestry; 56.39 and 58.9 % in amended soil and 45.9 to 51.84 in the control (undisturbed land) (table 4). There is no trend of increasing or decreasing with slope position in terraced, agroforestry, amended and control land uses. The increases with slope have been found in forest land whereas the increase with slope was in the trenched farm. High porosity was found in agroforestry land use (Figure 15), since agroforestry system increase soil organic matter hence high porosity.

Percentage of moisture content

The values presented in the previous figure shows that in general moisture content varies in range of 6.54% to 17.56% in our study area where forest land has the highest moisture content (17.56%) and the smallest one is trenched land with (6.54%) (figure 15).

The values of moisture content ranged between 9.93 and 16.18 % in terraced land; 3.09 and 10.09% in trenches; 10.23 and 17.276% in agroforestry; 15.27 and 19.37 % in forestry; 13.237 and 17.032 % in amended soil and 7.23 to 13.077% in the control (undisturbed land) (table 3). There are no specific trends of moisture content values variation in our study area except in agro-forestry and forestry where they increase down ward.

4.2.16. Bulk density and particle density under different land management in Migina Catchment

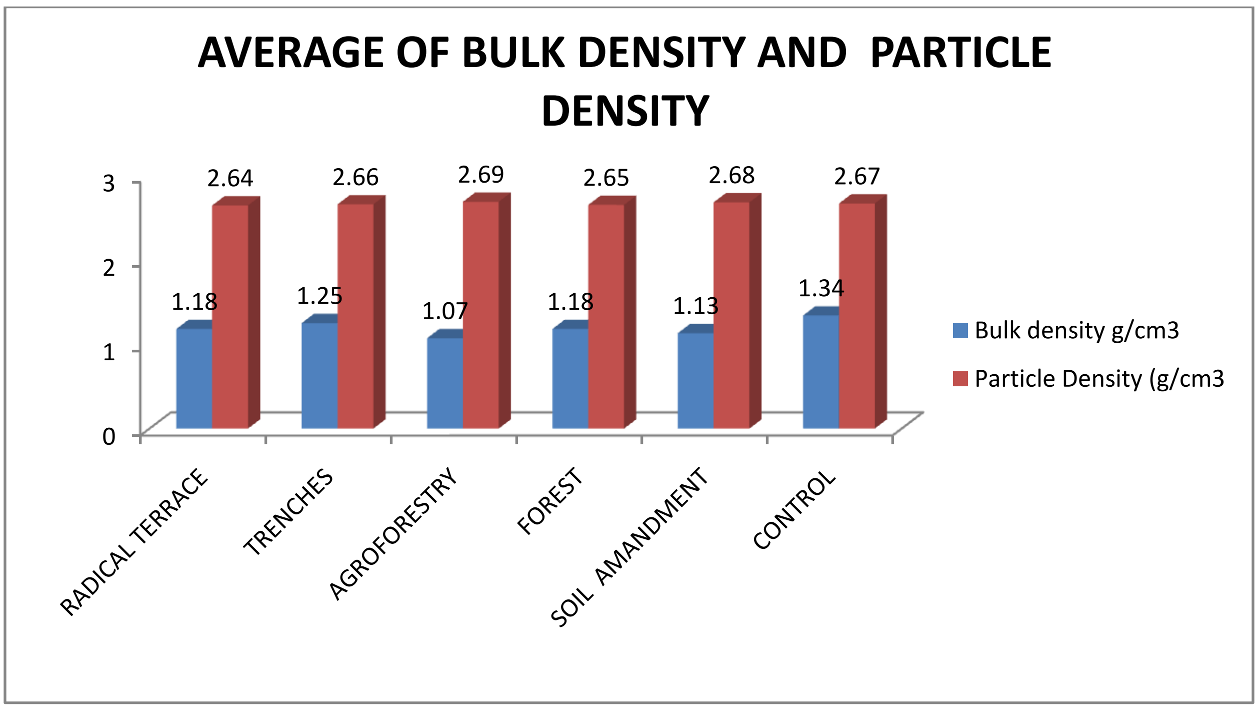


Figure 16: Bulk Density and particle density under different land management in Migina Catchment

The ANOVA Table (Appendix) shows a significant difference between land management ($P<0.01$) on bulk density.

The values presented on figures are Bulk density and particle size distribution and the figure shows that the bulk density is low in terraced, trenches, agroforestry, forestry, amended soil and in control ranging from 0.96 to 1.44 g/cm^3 this is a good range for plant growth. The values presented on the previous figure shows that agroforestry has small value of bulk density (1.07 g/cm^3) compared to the other land management practices while control (non disturbed soil) has a highest value of bulk density (1.34 g/cm^3) but all of them has favorable bulk density for root growth penetration and crop growth in general (figure 16).

CHAP V. DISCUSSION

4.3.1. pH Water, pH KCl of different land management practice in Migina Catchment

The soil reaction level is an indicator of soil acidity, In our study area, especially in agroforestry and amended soil practices, there is high concentration of population settlement on the top and middle who used to amend their land with organic and household waste fertilizers, The rate of pH could be attributed to the intense rainfall (1200mm/year) (Munyaneza et al., 2014). The study area experiences in association to extensive leaching of basic cations due to coarse texture of the soil resulting from high weathering. Low pH in the study area is probably induced by acidifying nitrogen fertilizer, nitrate leaching, exclusion of the bases through crop harvests and the farming practices especially in amended soil, trenches, agroforesty and radical terrace (McKenzie *et al.,* 2004).

Agroforestry systems, the bases deposition above numerous years by growing can influencing the araising of pH of soil, the buffering effects of nutrients leaching (*Sharma et al.,* 2009). Particularly in radical terraces the source of their acidity becomes from their poor establishment and poor management of those terraces where in their establishment used to remove top soil which contain all nutrient elements and put them away, the farmers who used to cultivate this radical terrace, they do not use mulching, liming or other pH restoring strategies for increasing soil pH in soil except in middle area where the farmers are tried to use cattle fertilizers. There is low pH also in forest, the leaves and litters increase soil organic carbon in soil after their decomposition but in this process of decomposition release organic acid in soil which decrease soil pH.

The strongly acid reaction amounts propose potential low accessibility of both the macro and micro plant nutrients for being taken by plant. Low soil pH values below pH < 5.5 have potential to cause toxicity problems (Adamchuk*et al*., 2005). It could also cause dissolution of aluminum and iron minerals which precipitates with phosphorus effectively causing its fixation and further lowering the soil pH (Brady and Weil, 2008).Majority of plants grow well in soils of pH 6.5 to 7.5 (Baize, 1993). Thus, soils studied may present limitations to crop growth because of the low pH values of less than 5.5 which may limit availability of various plant nutrients such as phosphorus and bases (Marschner, 1995). Application of liming materials may be considered necessary to raise the pH to favorable levels of around pH 6.5 and 7.5. Alternatively, crops that tolerate to acidity are recommended for, because plant species and varieties differ in the degree to which they tolerate pH values outside the range, application of more organic fertilizers and application of agroforestry systems are here recommended (EUROCONSULT, 1989).

4.3.2. Electrical Conductivity of different land management practice in Migina Catchment

Electrical conductivity testing is consistent way to evaluate how salts are impacting the growth of plant. The EC of soil and water is improved by decomposition and the concentration of salt which is dissolved. Salts arises the ability of solution to conduct an electrical current, High salinity level is indicated by higher values of EC (Apal, 2014). Therefore our study area does not facing with the problem of salinity. Excessive salt in soil may hinder germination of seed. Excessive fertilization and poor water quality used in irrigation are source of salt (E.S. Marx, J. Hart, 1999).

4.3.3. Percentage of organic carbon and organic matter of different land management practice in Migina Catchment

The high amount of OC observed may be due to fallow period. The area under study has been kept as fallow like our control which does not used for tillage activities Johnsons (2002) observed the higher concentration of OM in the surface soil under no-tillage systems this important reason of %OC sufficient in our control. Greater accumulation of surface carbon is resulted by less disruption because the fodder crops roots and the slower decomposition rate of OM might have contributed to the increase of OM in soil with no tillage. It is also responsible for high water holding capacity and high infiltration rate which may reduce soil erosion by runoff surface water during the rains (Dowuona *et al* ., 2012 and Kebeney *et al*.,2015).

In agroforestry the high values of OM in topsoil than subsoil may be attributed by decomposition of large quantities of plant residues into the soil every season and high population density in top and middle land. Such good climatic condition is favorable for vegetation. Low cropping activity and harvesting lead to the losses of nitrogen and carbon (Dowuona *et al* ., 2012 and Kebeney *et al*.,2015). And also while soil has low soil pH lead to the low organic carbon in soil as that low pH inhibit the microbial activity for decomposing organic matter (Sultana, 2011).

While the ground is covered really generate a great potential and generate soil organic carbon and influencing biological activity and favors soil protection, the high concentration of population settlement in agroforestry and soil amendment is one of proposed reason of OC% increasing in this areas where they used to apply more organic fertilizers, agroforestry species and mulching (Sharma et al., 2009).

4.3.4. General discussion of Nitrate and Ammonium in study area

Nitrate and Ammonium are chemical parameters which show the nitrogen form that are taken up by plan, The level of nitrate and ammonium is affected by rainfall, level of stored water at sowing, time of sampling, depth of taken sample. The high values of nitrate in the study area may be due to fertilizer application containing nitrogen. Ammonium nitrogen concentration values are within the range(2-10ppm) of agricultural soil (Marx E.S., Hart J., 1999)

Ammonium-nitrogen generally does not accumulate in the soil, as soil temperature and moisture condition which is appropriate for the growing of the plant and are ideal for conversation of NH_4-N to NO_3-N. Soil NH4-N level above 10ppm may take place in cold or extremel soil whih is wet, while soil hold fertilizers from a later application, while there is high or low soil pH, and while there is a high soluble salts (measured by electrical conductivity). (D.A. Horneck, D.M. Sullivan, J.S. Owen, and J.M. Hart, 2011). The nitrate level in soil changes widely, basing to the types of soil, rainfall and condition of climate and practices of fertilizing. The normal nitrate level of background in soil not fertilized or rainfall and practice of fertilizing. Level of nitrate ranging from or more than 25to30ppm is enough to the growth of plant in a vegetable garden (Camberato and Nielsen, 2017).

Due to the leaching and heavy rain the sand soils loses its nitrate, then by denitrification also the coarsely textured soil loses nitrates, This might be the cause of low nitrate in the studied area because the soils have sand presence in its soil texture (Brouder *et al*., 2003). Another reason for high amount is that nitrate accumulates more in the soil because in the period of rain season, the temperature of soil is low and the tension of oxygen is also low referring to the saturation with water and this situation decelerate denitrification (Nielsen, 2017).

Agroforestry trees, particularly leguminous trees, enrich soil through fixation of biological nitrogen, addition of OM and recycling of nutrients. The fixed nitrogen may benefit symbiotically to the crops growing in its association and helps in soil fertility improvement. The amount of nitrogen added from the legumes or pruning of trees species taken up by the first crop is reported quite low and large portion is left in the soil organic matter indicating a long term nitrogen benefit than immediate. Different tree components viz., leaf, twigs, fruit and wood have different decomposition rates which helps to distribute the release of nutrient over time.

4.3.5. Available phosphorus of different land management practice in Migina Catchment

The medium values of P may probably be due to continuous cultivation without replenishment of P from different P fertilizers, for this case the application of chemical fertilizer increase availability of phosphorus probably can be the reason of having high values of available phosphorus in some amended soil. The relatively high values of P found in some toposequences may be caused by anthropogenic effects including addition of manure, crop residue and inorganic P fertilizers and low potential for phosphorus fixation. Low available phosphorus may be attributed to low soil pH (<5.8) that could react with iron (Fe) and Aluminium (Al) to make insoluble Fe and Al phosphates that are not readily available to be taken by plant (Hodges, 2007, Raymond and Roy, 1990). Addition of organic matter level can help decrease any P 'fixation' reactions that may be present, by binding Al, Fe and Ca and forming the soluble P which may be available to plants (Hodges, 2007). Then the insufficient soil organic matter in some treatment is another issue of decreasing availability of phosphorus in some treatment of our study area. The mulching is also in order reasons which hinder the leaching of nutrient elements and keeping good physical characteristic of soil, this also another issues of great value of AV.P in trenches, amended soil and agrorestry because same areas of these practice areas, farmers used to apply mulching. Therefore by Defoer et al. (2000) this means that very limited amount of phosphorus are available as pH decrease, and unavailability of phosphorus leads to the low productivity of crops and trees as an essential element for crop growth

4.3.6. General discussion of exchangeable basis in study area

The values of Exchangeable basis show that it is on Low level, this low level of exchangeable bases is probably due to poor practice of cultivation, soil which is poor and conservation of water and insufficient supply of fertilizer to refill nutrients removed with crops. Another reason could be that the parent material on which soil has developed is poor in bases.

Msanya *et al*. (2001) reported that the desired saturation level of exchangeable Mg is between 10 to 15%. Consequently, soils of the study areas don't have sufficient levels of exchangeable magnesium, calcium, potassium for crop production. These low value of exchangeable cations has direct implications on the cation exchange capacity (CEC), soil pH and ultimately plant nutrient imbalances, unavailability and nutrient induced deficiency.

4.3.7. Effective cation exchange capacity of different land management practice in Migina Catchment

The values of ECEC of the soils studied show that it is low; this values are contributed by the kaolinite and sesquioxide or oxidic clays which are dominant clay minerals in highly weathered soils, lacking negative charges. Consequently, they don't retain adsorbed cations and end up with insufficiency CEC due to the nutrient retention capacity which is low (Landon, 1991).

The land management which has more ECEC values in our study area can be credited to higher content soil organic matter (Tomašić *et al*., 2013). Due to the observation in the field, the low ECEC levels in control or undisturbed land observed could also be attributed to low leaching instead strong runoff due to high erosion rate as these sites are steeply sloping area . Erosion causes sediment loss from the upper part (soil truncation) and deposition of new material in the lower part (soil aggradation), this resulted in loss of nutrients in the upper part of the mountains. The ECEC values indicate possible negative influence on the soil buffering capacity and reduced retention of base cations by the soils studied. Consequently, it doesn't have ability to protect soluble cations from leaching out the root zone of plant and helps soils to resist variation in change pH (Barker *et al*., 2007; Brady and Weil, 2008). The rainfall of our studied land is high, this is another reason of ECEC decreasing because many cations are leaching into the soil (Paul & Rattan, 2014).

4.3.8. Base Saturation of different land management practices in Migina Catchment

The values of base saturation of the soils studied are presented in the table 3. The results show that there is a Low base saturation levels in this study area that may be resulted by the level of pH which is very acidic soils and potentially toxic cations such as Aluminium and Manganese from the soil (Hodges, 2007). Poor cultivation practices, poor soil and water conservation and inadequate supply of fertilizer to replenish nutrients removed by crops among others are reported to contribute to low level of bases in most soils (Ellenkamp, 2004; Jones *et al*., 2013)., implying good fertility of soil for production of crops. It is also implies low or no intensive leaching of bases from topsoils to subsoils (Msanya *et al*., 2016).

4.3.9. Exchangeable Acidity of different land management practices in Migina Catchment

These results indicate that the acidity of these soils is mostly contributed by exchangeable Al to a large extent and by hydrogen to a moderate extent. Aluminium ions are released from clay lattices at pH values of about below 5.5 and become exchangeable in the clay complex (Landon, 1991).

4.3.10. Soil texture under different land management in Migina catchment

According to Mc Donald *et al*. (1994), the sand content is very high compared to clay and silt in the study area. The sand nature may probably be attributed by parent material and climate as earlier reported by (Onweremadu et al., 2011; Osujieke et al., 2016).

Soils of high altitude cold desert which have been cames from rock weathered; they are not mature and have higher amount of sand gravels and stones in them showing the presence of sand forming mineral in parent material. Sand is present particle in the hilly soil and they are caming from parent material of sandstones. Clay and silt content have been rated as low. This low values indicates that a soil doesn’t have enough ability for retaining available water for growth of plant due to the unique combination of surface area and sizes of pores (McDonald *et al*.,1994).

4.3.11. Percentage of porosity and moisture content of different land management practice in Migina Catchment

The moisture content is referring to the water content in brief is an indicator of water amount present in the soil (ASTM, 2014). Our study are moisture content varies from 6.54 to 17.56% then according to Bandyopadhyay & Reza (2014), The studied soil result show that there is moderate water retention and referring to Mbaga, Msanya, & Mrema(2017),Tenga et al.(2018) and Uwingabire et al.(2016), the moisture content depend on the soil organic matter, particle size distribution, bulk density and structure of the soil influence the variation of available moisture content in the soil. In fact, the result of soil particle size distribution show that has a good bulk density which implies the high holding capacity of water. And we have an organic matter in generally which is medium to high (table1) even particle size distribution and bulk density determine the distribution of macropores and micropores density are good in our study area (table3), all those factors influence our study are influencing our soil study area to retain water.

No-tillage systems seemed to be more appropriate in maintaining favorable soil porosity by preserving the elongated transmission pores which facilitate good root development. The porosity was > 40% in all Treatement, thus they are not liable to restrict crop growth since they indicate no soil compaction, roots penetration without difficulty, adequate aeration and water storage within the soil (Gachene *et al*., 2003).

4.3.12. Bulk density and particle density of different land management in Migina Catchment

The values of particle density of the soils studied are presented in the table 3. The results show that the texture class of the studied soils was dominated by sand loam and a little sandy clay loam. According to Hazelton & Murphy, (2007), the sand content is very high in the studied soil and there is no trends changes along toposequence of studied area and the figure below shows that in general the value of particle density varies between 2.58 and 2.72 g/cm^3 while normal particle density for plant growth is 2.66 g/cm^3(E.S. Marx, J. Hart, 1999).

The possible causes of decrease of BD in the study area are organic matter addition in the field, if soils are wetter than field capacity, bulk density may increase. Growth of root, in generally start to be restricted when the bulk density reaches 1.55 to 1.6 g/cm^3 and is forbidden at about 1.8 g/cm^3. Bulk density had specific trend by increasing soil depth in the crest and mid-slope but recorded no specific trend in foot-slope. However, bulk density decreased from the crest to the foot-slope and had no significant among the physiographic positions. This is in concurrence with the works of (Aweto and Iyamah, 1993) in the soils of southern Nigeria. Also, some researchers (Gafar et al., 2004; Abrams et al., 1997) have reported similar findings on soil along toposequence. The bulk density was found to be below the critical limit (1.75 – 1.85 g kg-1) as recommended by SSS, (2006) for root penetration.

CHAP V: CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

The assessment on impact of different land management on soil quality in Migina Catchment by using soil laboratory analytical methods was one direction of achieving this research. The physico-chemical properties results already analyzed have shown that the land management practices have a positive impact on soil nutrient availability and also have positive effects in social-economic development of population and agricultural sustainability, good establishment, well monitoring and evaluation of different land management practices are essential factor for land management sustainability and crop productivity.

The main objective of the study was to analyze the impact of land management practices on soil quality in Migina Catchment at Akaboti Cell, Kansi Sector, Gisagara District, in Southern Province of Rwanda, by focusing on physico-chemical properties of soil which are improving soil fertility status, this work was done under different land management practices that are radical terrace, trenches, Agroforestry, forestry, soil amendment and control or undisturbed land.

The laboratory results show that the soil texture was dominated by a Sandy Loam class, the soil bulk density varies 0.96 to 1.44 g/cm^{3}in general, the soil porosity ranges from 50.2 to 52.08 % in terraced land; 47.2 to 58.16% in trenches; 53.8 to 63.87% in agroforestry; 53.08 to 53.8 % in forestry; 56.39 to 58.9 % in amended soil and 45.9 to 51.84% in the control (undisturbed land). The soil pH measured in water ranges from 4.73 to 5.14 for radical terraces land, from 5.79 to 5.29 for trenches; 6.29 to 5.79 for agroforestry land, 4.93 to 4.49 for forested land, 5.11to 6.34 for amended soil, 4.69 to 527 for control. The electrical conductivity is low in treatments ranging from 0.076 to 0.390%, The values of mineral Nitrogen measured in treatments were higher compared to control. Ammonium values range from2.55 to 7.24 mg/Kg while Nitrate values range from 4.36 to 28 mg/kg. Available P values were high in treatments compared to control. The values of available P range from 8.55 to 17.10 ppm. The values of exchangeable bases were slightly high in treatments compared to control. Those values were generally low. Generally the agroforestry land showed high nutrients values compared to the control and other treatments. From the results of this study, it is clear that the land management practices have generally a positive impact on soil properties.

5.2. RECOMMANDATIONS

Considering the output of our research project we put forward the following recommendations to be used for reinforce land management practice and to mitigating the negative impact on the land degradation and soil fertility deterioration, so for to guarantee sustainability of land management in this study area, The farmers should learn the new agricultural technology such as agroforestry system which increase in soil organic matter in order to replenish the lost plant nutrient and to manage their land fertility sustainably as well as environment and also as source of multiple benefits, farmers also must make application of lime for reducing soil reaction acidity of this area, apply sufficient organic manure for improving soil nutrients needed by plant, microbial activity reinforcement and soil physico-chemical parameters availability, To take care on utilization of qualified technicians who are able to establish sustainable land management practices especially terraces and trenches, to select an improved seeds of agroforestry and forestry species which is generating more organic material for producing sufficient organic matter, The farmers should learn how to use efficiently both organic and chemical fertilizers in order to increase soil productivity potential of their land, Soil waste management must be considered because are the source of more toxic elements which decreasing soil fertility status, Soil waste management must be considered because are the source of more toxic elements which decreasing soil fertility status, The acidic tolerant plants should be adopted to be grown in that area, if there is no other possibility to improve soil basicity such as lime application, The government, Agricultural institution and other institution involved in land management activities should invest more research and this research should be promoted across our country in order to enable farmers to adopt appropriate soil fertility management practice and soil quality improvement in general. The main objective of this research work is to identify the impact of land management on soil quality under selected land management practices in Migina catchment by assessing their effect on soil physico-chemical properties and to compare their effective competitiveness in order t know the best to be used for conserving our soil fertility status. It would be better if we could cover the whole country, but once again we had not enough tools and time of this, then this is the reason why our study is spatially, financially and timely limited only in Migina catchment. For that case we invite the researchers to conduct deep research on impact of land management practice by extending their research to all aspects of the complex issues on soil and Environments.

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Appendices

Appendix 1: ANOVA of mean variate of physico-chemical properties of land management practices in migina catchment.

Appendix 1: ANOVA Variate: pH Water

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatements	1	0.296	0.148	3.837	<0.001
Residual	16	3.095	0.773		
Total	17	4.6471744			

Appendix 2: ANOVA Variate:pH KCl

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatements	1	1.51	0.116	4.102	<0.001
Residual	16	2.232	0.446		
Total	17	3.752			

Appendix 3: ANOVA Variate: Elecrtical conductivity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatements	1	0.094	0.030	4.458	<0.001
Residual	16	0.032	0.008		
Total	17	0.1274			

Appendix 4: ANOVA Variate: Organic Carbon

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatements	1	0.347222	0.347222	7.7086	0.006
Residual	16	0.024356	0.001522		
Total	17	0.371578			

Appendix 5: ANOVA Variate: Ammonium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatements	1	9.536	0.112	4.45	0.02
Residual	16	13.390	1.162		
Total	17	22.928			

Appendix 6: ANOVA Variate: Nitrate

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatements	1	176.256	8324.37	29.02	0.006
Residual	16	179.059	34.83		
Total	17	355.315			

Appendix 7: ANOVA Variate: Available phosphorus

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatements	1	57.872	12.855	4.4589	0.02
Residual	16	49.775	12.443		
Total	17	107.658			

Appendix 8: ANOVA Variate: potassium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatements	1	9.842	9.842	32.29	0.04
Residual	16	4.8766	0.3048		
Total	17	14.7186			

Appendix 9: ANOVA Variate: Hydrogen

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatements	1	6.607	0.752	4.4589	0.04
Residual	16	11.770	5.389		
Total	17	18.377			

Appendix 10: ANOVA Variate: Total Exchangeable acidity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatements	1	3.472	2.647	239.02	0.046
Residual	16	21.559	20.632		
Total	17	25.031			

Appendix 11: ANOVA Variate: Sodium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatements	1	9.842	9.842	32.29	0.002
Residual	16	4.8766	0.3048		
Total	17	14.7186			

Appendix 12: ANOVA Variate: Magnesium

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatements	1	6.607	0.752	4.4589	0.042
Residual	16	11.770	5.389		
Total	17	18.377			

Appendix 13: ANOVA Variate: Porosity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatements	1	179.251	29.6694	242.664	<0.001
Residual	16	187.744	46.936		
Total	17	366.996			

Appendix 14: ANOVA Variate: Bulk Density

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatements	1	0.126	0.017	3.837	0.01
Residual	16	0.1328	0.033		
Total	17	0.2596			

Appendix 15: ANOVA Variate: Moisture Content

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Treatements	1	67.266	18.84473	9.4589	0.046
Residual	16	215.485	53.8712		
Total	17	302.741			

Appendix 2: Interpretation norms

Appendix2. 1: Organic matter

	Very low	Low	Medium	High	Very high
Organic matter %	< 1.0	1.0-2.0	2.1-4.2	4.3-6.0	> 6.0
Organic carbon %	< 0.6	0.60-1.25	1.26-2.50	2.51-3.50	>3.5

Appendix2. 2: Soil reaction

Extremely acid	**pH<4.5**	**Neutral**	**pH 6.6 to 7.3**
Very strong acid	pH 4.5 to 5.0	mildly alkaline	pH 7.4 to 7.8
Strongly acid	pH 5.1 to 5.5	moderate alkaline	pH 7.9 to 8.4

Medium acid	pH 5.6 to 6.0	strongly alkaline	pH 8.5 to 9.0
Slightly acid	pH 6.1 to 6.5	very strongly alkaline	pH > 9.0

Appendix2. 3: Available phosphorus and cation exchange capacity

mg/kg	**Very low**	**Low**	**Medium**	**High**	**Very high**
Avail. P (Bray-Kurtz 1		< 7	7-20	> 20	
(CEC) cmol(+)/kg	< 6.0	6.0-12.0	12.1- 25.0	25.0- 40.0	> 40.0

CEC is determined using 1 M ammonium acetate in soils with pH less than 7.5. In soils with pH greater than 7.5 CEC is determined using 1 M sodium acetate.

Appendix2. 4: Electrical conductivity (ECe)

ECe	**< 1.7 dS/m**	**no yield reduction**
ECe	1.7 - 2.5 dS/m	up to 10% yield reduction
ECe	2.5 - 3.8 dS/m	up to 25% yield reduction
ECe	3.8 - 5.9 dS/m	up to 50% yield reduction
ECe	5.9 - 10 dS/ m	up to 100% yield reduction

Appendix2. 5: Exchangeable Calcium

cmol(+)/kg	**Very low**	**Low**	**Medium**	**High**	**Very high**
Ca (clayey soils rich in 2:1 clays) **(loamy soil)** **(kaolinitic and sandy soils)**	< 2.0 < 0.5 < 0.2	2.0-5.0 0.5-2.0 0.2-0.5	5.1-10.0 2.1-4.0 0.6-2.5	10.1-20.0 4.1-6.0 2.6-5.0	> 20.0 > 6.0 > 5.0

Appendix2. 6: Exchangeable magnesium (Mg)

cmol(+)/kg	**Very low**	**Low**	**Medium**	**High**	**Very high**
Mg (clayey soils rich in 2:1 clays) **Mg (loamy soil)** **Mg (sandy soils)**	< 0.3 < 0.25 < 0.2	0.3-1.0 0.25-0.75 0.2-0.5	1.1-3.0 0.75-2.0 0.5-1.0	3.1-6.0 2.1-4.0 1.1-2.0	> 6.0 > 4.1 >2.0

Appendix2. 7: Exchangeable potassium

cmol(+)/kg	**Very low**	**Low**	**Medium**	**High**	**Very high**
K(clayey soils rich in 2:1 clays) **K (sandy soils)**	< 0.13 < 0.05	0.13-0.25 0.05-0.10	0.26-0.80 0.11-0.40	0.81-1.35 0.41-0.70	>1.35 > 0.70

Appendix2. 8: Exchangeable Sodium (Na)

cmol(+)/kg	**Very low**	**Low**	**Medium**	**High**	**Very high**
Na (clayey soils rich in 2:1 clays) **Na(loamy soil)** **Na(sandy soils)**	< 0.1 < 0.25 < 0.2	0.1-0.3 0.25-0.75 0.2-0.5	0.31-0.70 0.75-2.0 0.5-1.0	0.71-2.0 2.1-4.0 1.1-2.0	>2.0 > 4.1 > 2.0

Appendix2. 9: Aluminium saturation

%	Very low	Low	Medium	High	Very high
Aluminium	< 10	10-30	31-50	51-80	> 80

Appendix 2.10: Textural triangle