# INFLUENCE OF SELECTED LAND USE CHANGE AND INDIGENOUS KNOWLEDGE ON SOIL QUALITY IN THE AGRO-PASTORAL SEMI-ARID KARAMOJA-UGANDA

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# DECLARATION

This thesis is my original work and has not been submitted for award of a degree in any other University.

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## DEDICATION

The work is dedicated to my esteemed father and mother Mr Kisuule Kikwalo Asaph (RIP) and Mrs Eseza Namirembe (RIP), my brothers, sisters, my wife Nalongo Ntambi Betty, the children, and friends, for the tremendous support rendered during the process of the entire study from the tender age studies to the current. Further, to the congregation of Anglican Church of Uganda- Lwadda Parish, where I have been serving as the Head of Laity as well as a student; thanks for your prayers.

In a special way, I also dedicate this work in commemoration of my late son Wasswa George Kakembo who passed on, just a few months before the start of this study. May the ALMIGHTY rest him in eternal peace!

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## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| **AMF** | **Arbuscular Mycorrhiza Fungi** |
| **AW** | **Available water** |
| **BD** | **Bulk Density** |
| **FAO** | **Food and Agricultural Organisation** |
| **GDP** | **Gross Domestic Products** |
| **GOU** | **Government of Uganda** |
| **GPS** | **Global Positioning System** |
| **IK** | **Indigenous Knowledge** |
| **KIDDP** | **Karamoja Integrated Disarmament and Development Project** |
| **LULCC** | **Land Use Land Cover Change** |
| **MAAIF** | **Ministry of Agriculture Animal Industry and Fisheries** |
| **MDS** | **Minimum Data Set** |
| **NARL** | **National Agricultural Research Laboratories** |
| **NEMA** | **National Environment Management Authority** |
| **MEMD** | **Ministry of Energy and mineral Development** |
| **NGO** | **Non-Governmental Organisations** |
| **PWP** | **Permanent Wilting Point** |
| **SA** | **Stable Aggregates** |
| **SQ** | **Soil Quality** |
| **SQI** | **Soil Quality Index** |
| **TM** | **Thematic Mapper** |
| **UBOS** | **Uganda Bureau of Statistics** |
| **USDA** | **United States Department of Agriculture** |
| **USAID** | **United States Agency for International Development** |
| **ZARDI** | **Zonal Agricultural Research and Development Institute** |

## GENERAL ABSTRACT

Karamoja agro-pastoral semi-arid zone of Uganda is characterised by rapid land use and land cover change (LULCC), and soil quality (SQ) decline. However, the extent to which these changes have occurred and their impacts on soil quality determinants remained undocumented. The main objective of this study was to contribute towards improved soil productivity in agro-pastoral semi-arid Karamoja, Uganda through integration of indigenous and scientific knowledge for sustainable ecosystem management. Specifically the study, (i) Assessed Land use change in agro-pastoral semi-arid Karamoja for the last 30 years (ii) Assessed the effect of selected land use change in agro-pastoral semi-arid Karamoja on soil physical, chemical and biological properties (iii) Assessed the soil quality indicators of selected Land use change in the semi-arid agro-pastoral region of Karamoja, Uganda. (iv) Evaluated indigenous knowledge-based soil quality parameters for building a local soil knowledge database. Thirty (30) soil samples were collected from all the selected land use (grassland, woodland and farmland) of the study Sub-Counties and analysed for soil physical, chemical and biological attributes. The results revealed pH as one of the major chemical parameter responsible for nutrient availability, hence pH is a key parameter in determining soil quality. Matany soils had the lowest score of soil quality, followed by Iriiri and Rengen. This implies that Rengen soil have intrinsically good soil quality for farming as compared with that of Matany and Iriiri. The percentage soil organic matter of all land uses were significantly different ($p=0.05$) across all sub-counties. The soil OM percentages were for Rengen (0.8, 2.8, and 3.3), Iriiri (2.3, 3.4, and 4.0) and Matany (3.4, 4.5, and 5.2) for farmland, grassland and woodland respectively. Rengen soil textural class was sandy loam while Iriiri and Matany were clay. The drainage rates across all land uses in Iriiri and Matany were not significantly different ($p>0.05$) unlike in Rengen Sub-County which was significantly different ($p<0.05$) with farmland having the lowest drainage rate (1.4) as compared to grassland (2.1) and woodland (2.1). Across all sub-counties studied, fungal and bacteria colony forming unit (cfu) means were significantly lower ($p<0.05$) in farmland top soil than the grassland and woodland. The general decrease in soil attributes values were linked to the soil degradation due to farming/tillage. In order to establish the soil quality index (SQI), the soil samples which were collected from the study sub-counties land use change were analysed for physical; Clay, sand, field capacity, Water saturation point, Available water, permanent wilting point, Drainage rate, soil bulk density and water stable aggregates, chemical; fungi, bacteria and actionomycetes cfus, soil respiration (CO2 mg g-1 of soil), AMF, and nematodes availability diversity and population properties were used. The SQI for different land uses for each Sub-County originated from the above soil attributes using minimum data set (MDS). In order to assess the influence of different land uses on soil soil quality, analysis of variance (ANOVA) was accomplished using SPSS (version 24). To separate the mean value significance and determine the strength of relationships among soil attributes, Duncan's multiple range test and Pearson's correlation coefficients, respectively were performed. Different land uses resulted into different soil quality indices. Hence, there were no universal soil quality index for all land uses. The study took into account the social demographic characteristics of the people, farming enterprises, methods of raising crops, crops yields trends, causes of the perceived yields trends, soil quality indicators. The soil quality perceived parameters derived from the survey were clustered into five categories namely; The relationship between age group and the perceived indicators of soil fertility varied significantly ($p = 0.045$) with the majority stating that they use either soil colour, soil depth or soil texture to rate the fertility of soil. Karamoja farmers use visible features that predict soil quality. In order to establish the relationship between the measurable soil properties and the perceived knowledge, both were compared. Whereas the farmers did not use empirical information, some attributes they use had good hints of soil quality as the measurable parameters. Conclusively, the soil quality in farmland deteriorated as compared to the wood and grasslands. Further, the results suggested that Land use change from woodland to grassland and farmland negatively influenced soil chemical, physical and biological properties in the study Sub-Counties of the agro-pastoral semi-arid Karamoja. The soil texture was more dependent on the soil inherent properties which are mainly determined by the soil forming factors.

# CHAPTER ONE: INTRODUCTION

## 1.1 Background

Dry lands are the areas on the earth surface with an annual crop growing period of 1-179 days (FAO, 2000a). Climatically, they are mainly classified as arid, semi-arid and dry sub-humid zones. Each region is named after its annual crops possible growing season. In this regard, the arid region (1–59), semi-arid (60–119) and dry sub-humid regions (120–179) annual crops growing days. Globally, the dry land occupies 45% of the arable land with 7%, 20% and 18% arid, semi-arid and sub-humid respectively. About two billion people live in the areas of which 90% is in developing countries (FAO, 2000a). Most of the developing countries with semi-arid tropical zones are in Africa along the tropics. Twenty-nine countries of the continent experience semi-arid tropical (SAT) conditions in some parts. For instance, East Africa (Uganda, Kenya and Tanzania) with a total land area of 1,772456 $km^2$ SAT occupies 446710 $km^2$ about 25% of the total land area (Ryan and Spencer, 2001). Out of the Uganda's, total area of 243,050 $km^2$ SAT covers 38,888 $km^2$ equivalent to 16% of the country's area ((Ryan and Spencer, 2001). Most of the semi-arid area in Uganda is a cattle corridor. Uganda's cattle corridor stretches from south western to north-eastern Uganda. The most important activity is cattle keeping (Burnset al., 2013). Although not all the corridor is a SAT, most of the area have similar characteristics that is, highly variable and unreliable rainfall, prolonged drought and over dependence on cattle (pastoralism). On the other hand, the corridor is the main supplier of meat and other cattle bi-products (UIA, 2016).

Uganda's indigenous pastoralists, like everywhere in Africa, have experienced challenges to their traditional livelihood since modernization was introduced during the Europeans colonial era. This started with dividing tribal areas and resources during the partition of Africa into the current countries (Nyariki and Ngugi, 2002). During that time, the Karamoja cluster was sub-divided with some parts being, in Uganda, Kenya, Sudan and the neighbouring countries. The act deprived the pastoralists of their free movement in search for Pasture and water. Thus, to some extent confining them by international countries boarders. Further, land was apportioned by the Protectorate and later by the subsequent governments into game reserves and national parks for instance the Kidepo (Ejeru, 2014), thus denying pastoralists their right of hunting on land they earlier owned. This further culminated into sole survival on livestock. Additionally, the population has been increasing, for instance, from 2002 to 2014 Napak district population raised from 1.5 to 5.3 percentage and Kotido 3.3 to 6.5%, (UBOS, 2014). In respect of that, it led to local communities devise other means of survival, which include, felling tree for commercial firewood, charcoal, bricks making, and sale of grass reducing the land cover (Nalule, 2010; Karamoja strategic resilience assessment, report, 2016). Loss of vegetation cover, led to soil loss through its exposure to degrading agents like runoff and wind erosion, resulting into soil quality decline in the ecosystem.

Declining soil quality (SQ) (the capacity of soil to function) attributable to Land use change remains a serious deterrent to agricultural productivity, inevitably triggering a cascade of environmental and social-economic challenges in Sub-Saharan Africa (Obalum, et al., 2012). This anomaly stems mainly from poor soil management practices such as; over grazing, continuous cropping, low or non-nutrient replenishment, and absence of soil and water conservation practices (Guimaraes et al., 2013; Hansen et al., 2013; Gruver and Weil, 2007; IFPRI/FAO, 1995). On the other hand, with increasing competition between various land uses, SQ is reducing at an alarming rate. Soil properties deteriorate with change in land use especially from intact vegetation to arable agricultural land (Ezeaku, 2011). Unchecked agricultural practices may lead to erosion and leaching of nutrients, which in turn adversely affect the physio-chemical and biological properties of the soil. The soil quality can be determined by measuring soil physical, chemical and biological properties, also known as soil quality indicators (SQI) (Shukla et al. (2006). Soil properties that can be changed in a short time by land use dynamic are considered as SQI (Carter et al., 1997; Ezeaku, 2011).

Soil quality decline (which in most cases referred to as soil degradation) in Uganda has negative effects on land productivity, mainly due to mineral losses (NEMA, 2016; GoU, 2017). Almost 41% of the arable land in Uganda is under degradation, mostly (85%) due to erosion (CIAT; BFS/USAID. 2017). For example, soil quality decline contributes to 50-73% decline in banana yields (Mulumba, 2004). This resulted into growing swallow, hard and low soil fertility tolerant crops such as cassava *Manihot esculanta* and sweet potatoe *Ipomea batatus* in the L. Victoria surroundings (Mulumba, 2004). The cattle corridor, Karamoja inclusive, are the most affected areas with high soil quality degradation due to erosion (CIAT; BFS/USAID. 2017).

Alteration of the natural vegetation has a significant effect on soil quality (Friedman et al., 2001). Therefore, the success in soil agronomy to improve and sustain SQ, rests on understanding its response to land uses (Alekseev, et al., 2018). Over time, SQ alter due to either natural events or anthropological activities. They are improved by suitable agronomic practices and/or land-use decisions which consider numerous purposes of soil. On the other hand, they are impaired by decisions which focus only on single purposes, such as crop growing

(Doran, 2002). Currently, soil quality evaluation has captured a central researchers concern. This is due to recent awareness that soil liveliness is not limited to food and fibre production but the maintenance of local, regional and global environmental quality (Alekseev, et al., 2018). The soil quality index is mainly calculated form the minimum data set (MDS) equation or a formulae by (Doran & Parkin, 1994: Andrews *et al.*, 2004). Where; SQI = *f* (scored MDS)

$$SQ = f\ (K_1SQ_{E1})(K_2SQ_{E2})(K_3SQ_{E3})(K_4SQ_{E4})(K_5SQ_{E5})(K_6SQ_{E6})(K7SQ_{E7})(K8SQ_{E8})(K9SQ_{E9})$$

Where**:** $SQ_{E1=}$ soil structure; $SQ_{E2=}$ aggregate stability; $SQ_{E3=}$ Bulky density; $SQ_{E4=}$ Available water capacity; $SQ_{E5=}$ water filled pores; $SQ_{E6=}$ pH; $SQ_{E7=}$ OM/TOC; $SQ_{E8=}$Active carbon $SQ_{E9=}$Microbial biomass; $SQ_{10=}$ extractable nutrients (NPK); K $_=$ Weighting coefficients.

Enormous efforts like use of fertilizers and conservation tillage practice have been put in place to enhance soil productivity, but with minimum adoption by farmers. The farmers'low adaption and adoption of modern technologies and innovative agricultural systems is linked to the failure to take into account their indigenous knowledge and needs of farmers (Warren, 1991; Grigoras, 2008; Muwanga et al., 2020) advocated for the interaction between different knowledge (local and scientific) for more relevant research. Therefore, there is a need to integrate relevant scientific knowledge with indigenous knowledge to create hybrid knowledge for pertinent research. This in turn may assist in enhancing adaption and adoption of new technologies with potential of maintaining soil quality.

## 1.2 Research problem

Although large scale land use land cover changes and their causes which have occurred for many years in Karamoja have been documented in various studies (Egeru, 2014; Nakalembe, 2017), there is a dearth of information at small scale Land use change and their impacts on soil quality. For instance, household (HH) in small areas like sub-counties are vulnerable to food insecurity partially caused by Land use change which may lead to unsuitable Land use change culminating into poor soil quality, is undocumented (Bezuayehu et al., 2002; GOU, 2010). In line with that, soil losses feature due to Land use change which are observable during the rainy seasons, for instance flooding and accelerated sheet leading to rill erosion at village level are difficult to capture at sub-region level. Likewise, dry season manifest its self differently even within sub-counties. (USDA, 2017). Consequently, culminating into different soil quality degradation at small scale levels and its impacts to the environment. The detailed information at small scale kevel is undocumented. The soil at sub-county levels in the agro-pastoral Karamoja is prone to degradation, mainly caused by LULCC, yet there is either minimum or no deliberate effort by stakeholders to address its conservation practices (Karamage et al., 2017; Cooper, 2018). Perhaps, the minimum involvement in the soil conservation practice is due to lack knowledge of the state of the soil quality in the study area.

Likewise, the indigenous Karamoja farmer’s vast soil knowledge and practical survival skills is neither tapped nor documented for sustainable soil productivity interventions. The studies about the climatic change, vegetation, and household income situation in the zone, do not definitely address soil quality alterations as one of the major components of sedentary farming for sustainable development. The few studies that have been carried on Land use change by Ejeru, 2014; Nakalembe et al., 2017, attempted to address the soil parameters responsible for farmland degradation. However, their research only concentrated on a few commonly measurable chemical and physical properties. This made the studies less comprehensive in soil quality determination. The studies neither clearly addressed the indigenous nor scientific knowledge of soil quality. The major published effort to cover Karamoja traditional knowledge is by Tabuti et al. (2012) which is limited to tradition medicine in Nakapiripirit district. Hence, studies about Karamoja like in most parts of world, indicated no deliberate effort to address soil quality index in its full context (Stefanoski et al., 2016). Therefore, there is no detailed empirical data related to soil quality decline in the region. This makes it difficult to design practical soil conservation interventions.  This research aimed at identifying both the measurable and indigenous farmer’s knowledge of soil quality soas to create a hybride knowledge which can help in enhancing technology adaption and adoption by end users.

### 1.3 Justification and scope of the study

The study elaborate on the extent to which soil quality deterioration has occurred because of human influence (land use change). It provides important information in terms of improving soil quality by farmers, policy makers, researchers, and other stakeholders. After the extent of land use alterations are identified and their influence on soil quality quantified, remedial measures can be put in place to curtail further soil quality deterioration. Understanding and integrating of both indigenous (existing local community knowledge plus experience) and measured soil quality indicators, is essential to arrest soil quality degradation and improve farmers self-reliance. Hybridization of knowledge (scientific and indigenous knowledge) ease adoption of technologies, hence, enhance both environment and soil quality maintenance.

Additionally, by using indigenous terminologies adaption and adoption of soil conservation technologies is ensured. This not only sustainably improve the soil quality and farmers' socio-economic wellbeing, but environmental quality. Further, the study sets a background to the innovative approaches for integrating geographic information data, indigenous knowledge or skills and measurable (physical, chemical and biological) parameters, in handling and maintaining soil quality. It objectively concentrates on a more universal approach to soil quality determination, taking into consideration agricultural soils and its related disciplines.

Due to the fact that it is not easy to estimate the extent to which soil quality is altered by land use change, and the prospective soil degradation impacts, in different areas within the agro-pastoral zone, research interventions are imperative.  Land use land cover changes, have the ability to alter the soil physical, chemical and biological properties. Hence, creating a soil quality degradation viscous circle ranging from low soil productivity, green gas emission, creation of micro gradients in soil climate which lead to further land degradation. It is therefore crucial, to assess soil quality changes.

## 1.4 Study Objectives

### 1.4.1 Overall objectives:

To contribute towards improved soil productivity in semi-arid Karamoja through integration of indigenous and scientific knowledge for sustainable ecosystem management.

### 1.4.2 Specific objectives:

1. To assess Land use change in agro-pastoral semi-arid Karamoja-Uganda for the last 30 years
2. To assess the effect of selected land use change in agro-pastoral Karamoja, Uganda on soil physical, chemical and biological properties.
3. To assess the soil quality indicators of selected land use change in the semi-arid agro-pastoral region of Karamoja, Uganda
4. To evaluate indigenous knowledge-based soil quality parameters for building a local soil knowledge database.

## 1.5 Hypotheses:

1. Land use change have occurred in Agro-pastoral semi- arid Karamoja-Uganda for the last 30 years
2. Different land uses have varied effect on soil physical, chemical and biological properties
3. Different Land use change are having different soil quality indicators
4. Indigenous knowledge-based soil quality parameter can be used for building a local soil knowledge database

# CHAPTER TWO: LITERATURE REVIEW

## 2 .1 Introduction

Soil quality determination is valuable for sustainable agricultural production. Soils are important resources which are fundamental to formation of a host of goods and services essential to ecological systems and the human wellbeing (FAO, 2015a). According to FAO Classisfcation the soils of Karamoja are classified mainly classified as; VERTISOLS, GREYSOLS, LUXIC FERRALSOLS, LUVISOLS, EUTIC REGOSOLS and ACRIC FERRALSOLS for Iriiri Sub-County. The soil productivity in the above classification is regarded as low, medium, low, high to medium for cotton plus cereals, low to medium, low to medium-grazing respectively. The Matany Sub-County the soils are classified as; VERTISOL, EUTRIC REGOSOLS, GLEYSOLS, LUXIC FERRALSOLS, PERTRIC PLITHSOLS; good for food crop with seasonal grazing, and the rest low to good for grazing respectively (Chenery, 1960).

### 2.1.1 Land use change in agro-pastoral areas

Globally pastoralism is undergoing turbulence with a lot of investment taking place in the pastoralist areas (Abbink et al., 2014). East Africa encompasses three types of pastoralist livelihoods; nomadism, transhumant and agro-pastoralism. Majority of the pastoralists in E. Africa practice agro-pastoralism (Gabbert, 2012). Such modes of livelihoods are subsistence but with extensive socio-economic links. Pastoralist's innovations were cornerstones which used to mitigate risks as well as survival in the hostile environment (Mahmoud, 2013). To get the worth of the rangeland, mobile livestock farming was heightened as the best and effective strategy, but is rapidly changing into sedentary farming (Galaty, 2013; Abbink et al., 2014).

Land use means the management and alteration of natural settings or environments into built settings. For example, human settlements, semi-artificial environments, arable farming, managed woodlots and pastures. It is the activities, inputs and preparations people assume in a land cover to produce, maintain or change it (FAO 1997; FAO/UNEP, 1997). The purpose for which land is put to can change from time to time. In order to analyse land use, change two questions must be answered: what are its drivers or causes and the likely impact (Briassoulis, 2000)? According to Lawler et al., 2014 land use leads to changes with can result into large effects on the ecosystem facilities and bio-diversity.

### 2.1.2 Determinants of land use in the agro-pastoral zones, Karamoja ,Uganda

The causes of land use change are mainly, biophysical and socio-economical (Briassoulis, 2000). It could also be caused by processes for instance population and population change, industrialization and technological advancement. In Karamoja perhaps land use change have been marketing oriented advocated for by various public sector bodies like Prime Minister's Office -Uganda, NGOs and the related policies among others (Mwebaza, 2015). According to Golsdorf et al., 2012 and Nakalembe et al., 2017, the main practices which govern Land use change in Karamoja has been basically Government policies, programs and other NGOs instituting advocacy for sedentary agriculture in the area. In line with that privatization advocating for expansion of agriculture is another land use change driving force (Mwebaza, 2015). Other driving forces include population growth, changes in individual social requirements and institutional factors like land use policies formulation (Smith et al., 2010). These lead to soil quality decline due to clearing of new land for farming.

### 2.1.3 Types and extent of Land use change in Karamoja, Uganda

The area of Karamoja, Uganda is categorized into three zones depending on the livelihood practices; pastoral, agro-pastoral and the agricultural. The pastoralists are located in semi-arid areas with prolonged dry spells and unpredictable rainfall (300-500mm) which comes between May and August. This is followed by the dry season which last from September –April. The main pastoralist districts covered here are Amudat, Moroto and Kaabong. The economic activity is livestock keeping in a nomadic way plus some farming. Mainly the area soils are sandy with low fertility and over grazed poor pastures. These areas are typical of the Ethiopia, South Sudan, and Kenya pastoral zone (USAID, 2017).

Agro-pastoralism is practiced in a central Karamoja (Nakapiriprit, Nabiratuk, Napaka, Kotido, some parts of Kaabong and Moroto districts). This zone receives erratically distributed 500-800 mm of rainfall per annum. The soil is mainly sandy and loamy. They main livelihood activities are livestock keeping and crops farming. The common livestock which are kept include steers for ploughing, sheep, goats and bulls. The main crops grown include sorghum, maize, millet, beans, pigeon peas, cowpeas and groundnut. Farmers mainly practice small plots intercropping, around thorn fenced gardens, near their homes (Manyatta). At times farmer practice transhumant herding (USAID, 2017).

The agricultural zone is the most fertile zone with loam soils located in the western part of Karamoja. The zone receives 800-1200 mm of rain fall per year between the months of March and October (USAID, 2017). The common crops grown include maize, beans, simsim, sunflower and cucumber plus fruits like pawpaw, oranges, dessert bananas, and oranges. However, almost all farming is done without clear soil amendment practices.

### 2.1.4 Approaches to assessment of Land use change

Man's trying to understand the existing state or predict the forthcoming condition of socio-ecological landscapes (SELs), as for instance driven by changes in climate, regularly opt to simple, easily inferred alternatives as parts of the entire system complexity. The assumption is that simple options can be easily understood by all stake holders and/or non-scientists to design and appropriate management choices (Yengoh et al., 2015). But since individual indicators reveals only partial information, the total information obtainable from sets SQ indicators cannot match the entire system. In this regard indicator need constant review as researcher get familiar with the system. The varsity number of indicator and their interactions can be reviewed using a few of them depending on the concept of most limiting factor (Rezaei, 2004; Yu-Dong, 2013) and in consideration of the Liebig's law of the minimum.

There are several ways of detecting different earth dynamics. One of the most contemporary ways is the remote sensing which can be defined as the acquirement of material or information about an entity and/or phenomenon without intimate contact as opposed to the on-site observation, particularly on the Earth's surface. Essentially, it is used in geography, military, planning, earth science, survey and other humanitarian applications. It is the use of either satellite or aircraft to detect and classify entities or objects on earth's surface like ocean turbulence, atmosphere changes, land degradation, transpiration (Zurlini et al. 2006; Yengoh et al., 2015; van Dijke, et al., 2018). Remote sensing is a principal information source used in studying dynamics on the earth's surface at both temporal and multi spatial scales. The fundamental of remote sensing is based on logically obtaining information concerning a specific object, place or site without its intimate contact. It describes and quantify natural and anthropogenic land cover changes. There are several techniques for quantifying of land use alterations depending on the details required.

### 2.1.5 Image classification and change detection

One of the the most widely used is the Normalized Difference Vegetation Index (NDVI). A lot of research effort has been done using NDVI in assessing location land cover and land use change (UNEP 2012b; Agone and Bhamare, 2012; Sahebjalal and Dashtekian, 2013). For instance, using NDVI Yacouba et al. (2009), clearly reported Land use change due to agricultural activities in Siomao counties of China. The images can be pre-processed by registering and sub setting using ground control points (GCPS) (Mwavu and Witkowski, 2008). Then images classified by undertaking image starting with unsupervised classification. Further, comparing individual pixel to each discrete cluster to see which one it is closest to in order to derive the available classes then followed by supervised classification using multi-temporal LANDSAT data processing using ENVI 4.7 software for GIS professionals. Under confirmation from ground truthing data the classification results into categories of land use land cover. Then land use and cover change detection analysis are done for each cover class on ArcGIS (ESRI, 2009), to determine the area covered by each land use cover type and change detection. Images for different study year is done by each year images using a confusion matrix the compares the adjacent study periods images. At this stage comparing two classified sets of data, the matrix operation shows all the changes from one class to another. Chi-square goodness of fit is used to test significance in land use cover changes. Finally, Logistic regression is then performed to project land use and land cover scenario for the different classes. Hence remote sensing can be used to determine land use change and drawing inferences for soil quality.

### 2.1.6 Soil quality functions

Functions attributed to soil quality are generally based on three main integrated soil properties and processes namely; biological, physical, and chemical (Carter et al., 2004; Dalal and Moloney 2000; Karlen et al., 2003; Nuttall, 2007; French et al., 2009). These properties and processes are very vital for assessing land degradation. Similarly, they play a pivotal role in identification of sustainable agricultural management practices (Dexter, 2004; Sigh and Khera, 2009). When soil is poorly managed, it is likely to lose its ability to function. This condition is regarded by land practitioners as land degradation or by technocrats as soil quality deterioration. At the point of land degradation, the soil experiences poor water infiltration, low water storage capacity, soil organic matter, fertility, natural nutrient buffer capacity and accelerated soil loss. This is exacerbated by loss of vegetation cover. Furthermore, soil properties and processes are responsive to human use and management decisions. In order to have focused soil maintenance efforts, it is imperative to collect the necessary information which help to determine the trends of soil quality of an area which can help in guiding land users and manager make objective decisions (Hart and Mounton, 2005; Okello-Obura, 2018). Recent reports on soil quality degradation due to agricultural land uses have been well documented. For example, Ayoubi et al., 2011 in Golestan Province, Iran recorded highly degraded soil properties in cleared and cultivated forest lands. In the same study degraded land was reclaimed by reforestation by farmers and government organizations. Severe declining agricultural SQ is wide spread thought the developing countries (Sanchez, 2002). This lead to low and yet declining crop yields which destabilise the farmers ability to invest in inputs, hence, additional SQ declines (Shepherd and Soule, 1998). Antle and stoorvogel, (2006) and Marenya and Barrett (2009) studies reported bio-physical edges in SQ whereby, it is unprofitable to finance amendment of soil. Such studies and efforts are lacking not only in the semi-arid Karamoja, but the whole nation.

### 2.1.7 Soil quality and land degradation

Globally, over grazing, agricultural practices, deforestation, soil exploitation for fuel wood production, and industries, contribution to soil quality degradation stands at 35, 30, 28, 7, and 1%, respectively (Global change, 2014). Soil degradation affects food supply, diminishes agricultural income and economic growth. In Uganda, the primary causes of land degradation are unsuitable farming activities like deforestation, overgrazing, bush clearing, uncontrolled burning (NEMA, 2001; Kazoora, 2002). Whereas soil and land degradation are wide spread in the north semi-arid eastern Uganda, only two districts of Kotido and Moroto are reported to have degradation by MAAIF, cited in NEMA, (2001). However, the extent of soil degradation in the districts is not documented. Soil quality needs indicators which can be determined in a short time for easy periodic soil quality monitoring.

Over time SQ change depending on human or natural events. They are improved by land-use decisions which lead to good soil management. On the other hand, they are weakened by single focused decisions, for example farming (Doran, 2002). Currently soil quality evaluation has captured a central researchers concern. This is due to the current consciousness that soil vitality is not only limited to crops growing, but maintenance of the global environmental quality (Doran and Parkin, 1994). A soil system is sustainable only when it maintains or improves soil quality. In their study in Mediterranean management system, Francavigilia et al., 2014 found a better soil quality under unmanaged than the managed situations. This implies that management has a net negative impact on soil quality, which necessitates periodic monitoring.

### 2.1.8 Soil quality and its management

There are several soil quality definitions which are basically categorized into either soil use or soil functions (USDA,). The definition which depends on soil use clings on its fitness. For example, agriculture and infrastructure without detrimental effect to the environments (Oliver et al., 2013). The most outstanding definition of soil quality is by Doran and Parkin (1994) which puts the two categories together. Hence, defining SQ as the capability of soil to perform its function in ecological land use boundaries in order to sustainably maintain biological productivity, quality of the environment, promote both plants and animal health.

Functions attributed to soil quality are generally based on three main integrated soil properties and processes namely; biological, physical, and chemical (Carter et al., 2004; Dalal and Moloney 2000; Karlen et al., 2003; Nuttall, 2007 and French et al., 2009). These properties and processes are very vital for assessing land degradation. Similarly, they play a key role in identification of sustainable agricultural management practices (Dexter, 2004; Sigh and Khera, 2009). When soil is poorly managed, it is likely to lose its ability to function, hence, reduced soil quality.

### 2.1.9 Types and causes of soil quality degradation

Chemical, physical and biological soil degradation are the three main types of soil quality degradation (Lal, 2015). Soil chemically degrade either decreasing or increasing its pH, cation exchange capacity (CEC), nutrient reduction or increase to toxic levels. Loss of soil nutrients can be through leaching or vaporisation for instance loss of nitrogenous compounds. Additionally, chemical soil degradation is a result of little or no use of external inputs, excessive use of fertilizers and industrial pollutants (Lai, 2015). Soil degrades physically by destruction of its structure attributes like porosity, which include continuity of pore geometry. This in turn subject most tropical soils to compaction, crusting, reduced water permeation, soil loss through erosion. Physical soil degradation is usually caused by excessive tillage, removal of soil vegetation cover like deforestation (Lai 2015).

### 2.1.10 Land use change and their effect on soil quality

Generally, the Land use change which alter soil quality (SQ) include industrialisation, deforestation, human settlement, and agriculture practices. Among the mentioned practices, agriculture is the main practice which alters land cover and SQ by increasing soil erosion and SOM mineralization (Barral et al., 2007). Broadly, agriculture or cultivation include mixed farming, intercrop, mono-culture, pastoral and agro-pastoral systems. These practices influence SQ differently (Habitamu, 2014; Pham et al., 2018). The practices influence soil chemical, physical and biological properties (Tellan and Yerima, 2018).

Several soil chemical properties commonly affected by Land use change include all soil nutrients like, OC, N, K, Ca, P, and Mg. For example, de Assis et al. (2010) detected a decline in SOM stock and emission of OC in soil under cultivation vis-à-vis natural sites. Similarly, Zhu et al. (2012); Dengiz et al. (2015); Kalu et al. (2015) reported higher SOC in forested land than in other land uses. Equally, Jonczak, (2013); Habit, (2014) reported higher SOC in land under fallow. To the contrary, Shi et al. (2010) reported higher SOC in paddy rice. The concentration of N was similar in across arable land, orchard, forested land and grassland except for shrub where N was higher (Zajícová and Tomáš, 2019). Total nitrogen was reportedly higher in forested area than in cultivated land (Moges et al., 2013). The main cause was linked to heightened aeration due to soil disturbance done by tillage (Ayoubi et al., 2014). Land use change like cultivation mostly influence the top soil as compared to the sub-soil. The concentration of OC was less influenced by Land use change in soil layer deeper than 30cm (Qui et al., 2012). Mostly, OM is found in the top soil which makes it easy to decompose and deplete overtime once the soil is disturbed. The OM loss indicates biomass declining, turnover, and enhanced respiration and mineralization particularly in cultivated soils (Six et al., 1998; Katsalirou et al., 2010; Qui et al., 2012; Raiesi and Beheshti, 2014). Conversion of natural vegetation to croplands results into reduced SOM and enhances $CO_2$ emission from soil to the atmosphere (Qiu et al., 2012; Khan et al., 2013). According to Cochran (2007), the reducing SOM in cultivated soils is also due to low or reduced above ground biomass recycling. Hence, recycling SOM input depends on land use with natural vegetation having higher SOM in put vis-à-vis cultivated land. As such, different management practices affect SOM differently (Yitbarek et al., 2013; Bazebih et al., 2014). For instance, Biazin et al. (2018) indicated higher SOC and TN in the upper soil layers of a natural forest as compare to coffee based agro-forestry in Ethiopia, but no difference in the lower layers. The SOM is key in regulating crops yields constraints. This is due to the fact that it has a high CEC which enables retention of soil nutrients, reinforces soil particle aggregation, enhance water holding capacity and soil porosity.

Soil microorganisms as components of SOM play a key role of maintaining not only the soil aggregate or structure, but nutrients recycling. As such, different Land use change influence soil microbial contents at different soil depth (Ayoubi et al., 2014). For instance, in a study which was conducted by Raiesi and Beheshti (2014) in Iran, cultivation decreased microbial carbon pool (MCP) from 1887 to 741 and 1516 to 794 kg $ha^{-1}$ within the surface top 20 cm and 20- 40 cm layers in both range and land crop land respectively. Hence, cultivation reduced MBC by 55% verses range land.

Soil microbial respiration indicate soil biological activity and can be used to determine soil quality changes and carbon dioxide emission to the atmosphere due to land use alterations (Qi et al., 2007). In the same vein, studies by Qi et al. (2007); Aghasi, 2010, reported decrease in the microbial respiration from soil under cultivation than other land uses.

Soil pH is modified by different land use (Fayssa et al., 2015; Bezabih, 2016). Abbasi et al., 2007 reported significant differences between arable land, grassland and forest pH. Similarly, Chen et al., 2016 reported lower pH in crop land as compared with forest land.

Inappropriate cultivation practices influence the level of calcium, TN, available K and P in the soil. For instance, calcium increased in degraded dry land farming (DDF) by 58% over the good pasture (GP) while TN, was low in GP verses DDF (Aghasi, 2010). Aghasi, (2010) attributed the observation to livestock trampling which lead to soil erosion and expose lower calcareous soil layers. To the contrary, Wolka et al. (2011); Alijan and Sarmadian, (2014), attributed the high calcium in the upper soil layer to parental material and climate. On the other hand, P was less affected by land use change. None the less, in their research P was applied, perhaps is might have caused the observation reported. The Mean dry weight diameter of soil aggregate was affected by land use. Bulk density is also affected by tillage and livestock trampling (Aghasi, 2010). Grazing cattle increased BD to 30-40% vis-à-vis no grazed (18-20 %) land causing surface water runoff which led to non- point source pollution to range lands on Oak Savannah rangeland San Joaquin range (Tate et al., 2004). In addition, Bezabih et al., 2016 observed significant differences in sand, clay and silt proportions, soil moisture content and BD in different and uses. Soil texture and compaction can vary with Land use change and soil depth. Farmland is known to contain higher clay content than the protected forest (Yimer et al., 2008).

### 2.1.11 Nematodes and Arbscular Mycorrhizal Fungi (AMF) as indicators of soil quality

The significance of both nematodes and AMF as indicators of soil quality (SQ) are well recognized, but rarely considered in the minimum data set. Nematodes are universary found in all environments on the earth's surface. They have short instars and are sensitive to changes, hence qualifying to be good indicators of SQ alterations (Neher, 2006; Huang and cares, 2006). Nematodes play a vital role in the food cycle. Land use like grazing have been pointed out as enhancers of species diversity. Further, grazing intensity have been reported to be directly proportional to host specific plant feeder nematodes (Hu et al., 2015). The changing vegetation density and, diversity alter soil water and temperature. High temperatures have been demonstrated to compromise some genera while increase plant specific feeders. In line with the above, cultivation disturb soil cover and monoculture reduces plant community diversity which enhances specific crop feeder nematodes (Yan et al., 2017; Asiedu et al., 2017). Whereas the nematodes are key indicators of changing soil quality, there is general lack research related to nematodes as indicators of SQ in the Sub Saharan Africa and in particular Karamoja sub-region of Uganda.

The importance of arbuscular mycorrhizal fungi (AMF) in ecological maintenance cannot be over emphasized as it improves both plant fitness and growth (Klironomos et al., 2011; Moora and Zobel, 2010). Hyphae ramifies the soil and enhance not only plant absorption of P, Cu and Zn which are less immobile, but improving resistance to pest and drought tolerance. However, cultivation and other soil management practices effect the AMF population density and composition differently. In addition, cultivation reduces *Scutellospora spp* abundance (Jansa, et al., 2006). Similarly, the research findings by Lekberg et al. (2008) in semi-arid Zimbabwe revealed agricultural practices differently affecting AMF abundance. Sepp et al. (2018) added that AMF taxon composition are habitat and land use intensity dependant but host plants filters the pool available fungi species. Such studies are missing in Uganda. To the contrary, human soil disturbance has been reported to enhance cultured AMF (García de León et al., 2018). This stands as an entry point towards improving soil SQ using cultured Species of the fungi.

In summary, cultivation denotes the soil mechanical or physical operation or agitation for crops production. The physical operations result in soil structure destruction, compaction and destruction of the soil aggregates. Cultivation enhances aeration which in turn increase the loss of SOM through heightened decomposition. Further, cultivation increases the surface area for SOM microbial attack and alters the redox settings within the soil (Brown et al., 1994; Karuma et al., 2014; Bezabih, 2016). Soil degrades biologically by reduction of soil organic matter (SOM) pool, biodiversity, capacity to sink carbon and enhanced greenhouse gas (GHG) releases from soil to the atmosphere and the ecological loss of biodiversity. Biological soil population, availability and diversity can be altered by agricultural practices. For instance monoculture can lead to reduced SOM availability, which lead to reduction in microbial, substrates, porosity reduction (Marais et al., 2012).

Different land uses affect soil properties differently (Kalhoro et al., 2017). For example, a study which was carried out in the Great Plains by Tarkalson et al. (2006) revealed higher yields in no as compared to the conventional tillage. Similarly, most researchers relate low yields to human tillage and other activities, which lead to loss of soil quality through loss of not only soil nutrients but SOM and moisture retention (Tarkalson et al., 2006; Khresat et al., 2008; Moges et al., 2013; Kalhoro et al., 2017). In line with the above, different land uses may affect different soil nutrient differently. For instance, although total nitrogen and carbon distribution were not significantly different in Moges et al., 2013, south Ethiopia study, the N and C were slightly higher in protected forest than in other land uses.

### 2.1.12 Approaches to soil quality index modelling

Evaluation of the influence of Land use change is of paramount importance for sustainable soil productivity. The varsity of land practices available in different soils under differing ecological states, requires development of proper soil quality index regarding its suitable attributes and crop productivity. Several SQ estimate methods are available but none of them is standard, user-friendly and credible (FAO, 2003). Several inconclusive contributions, cautions and suggestion have been put in place regarding the suitability of each methods for a purpose (FAO, 2003). Currently, the most outstanding technical comparison is that by Murkherjee and Lai, 2014, where three methods namely; the simple additive, weighted additive and statistical model based on the principle component analysis were compared. All the models were found to deliver significantly correlated SQ. Pivotal to this finding, it is justifiable to use any of the three models in the current research.

### 2.1.13 Indigenous knowledge based on soil quality attributes

In Uganda, Hart and Mounton (2005) found out that traditional methods of growing vegetables are near sustainable farming. Indigenous knowledge differs from community to community. According to Okello-Obura, 2018, farmers in Masaka, Hoima and Soroti districts of Uganda are still using traditional knowledge in crops growing. Similarly, Ssali (2010), noted that farmers at times use their traditional medicine and knowledge to treat some livestock diseases. However, Unger (2014) lamented that the knowledge may disappear once it is not well documented and passed to other end users.

Karamoja like anywhere in African agriculture and rural life are closely cohesive. Most people who live in rural areas are socially bound together. They have shared culture plus appreciation for raising crops and livestock. This implies that they have a lot of indigenous knowledge about farming. This knowledge has taken communities through several millenniums. Globally, cultures have established different opinions naturally deep-rooted in their traditional opinions, which indigenous societies use to interpret and appreciate their surroundings' (Iaccarino, 2003). However, this knowledge is unutilized in the contemporary life style. It is erroneously assumed that anything traditional is backward and therefore it must be abandoned. There is a lot of prevailing ecologically healthy traditional practices which we cannot simply reject as satanic, unscientific and backward knowledge or belief systems (Mazzocchi, 2006). The categories knowledge regarded as traditional or ecological, majorly include agricultural, scientific, technical, medicinal plus traditional expressions (Winqi, 2016; Okello-obura, 2018).

### 2.2 Conceptual frame work

The conceptual framework below delineates the soil quality indicators for different land uses. The targeted outcome of this study is presented in Figure 1. Scientifically, soil quality (SQ) starts with the soil inherent properties. It assumed that the intact vegetation (woodland) was near to the ecological balance of the zone than any other land use and any deviation from it is caused by changing land use hence, an indicator of SQ status of study sub-counties. The study took into consideration three mainland use; the woodland, farmland and grassland. The area is undergoing land use and land cover changes. There has been no precise study on the influence of the Land use change on soil quality in the zone. The study puts emphasis on land use activities and its impact on SQ quality using farmers' perception and measurable soil quality indices. The low adaption and adoption of modern technologies in agricultural systems by farmers' is related to neglecting the indigenous knowledge and needs of farmers (Warren, 1991: Hart and Mounton, 2005; Okello-Obura, 2018). Therefore, there is a need to integrate relevant scientific knowledge with indigenous knowledge to create a hybrid of knowledge. This in turn may assist in formulating relevant land use and soil policies which embrace enhancing adaption and adoption of the new soil quality conservation technologies.

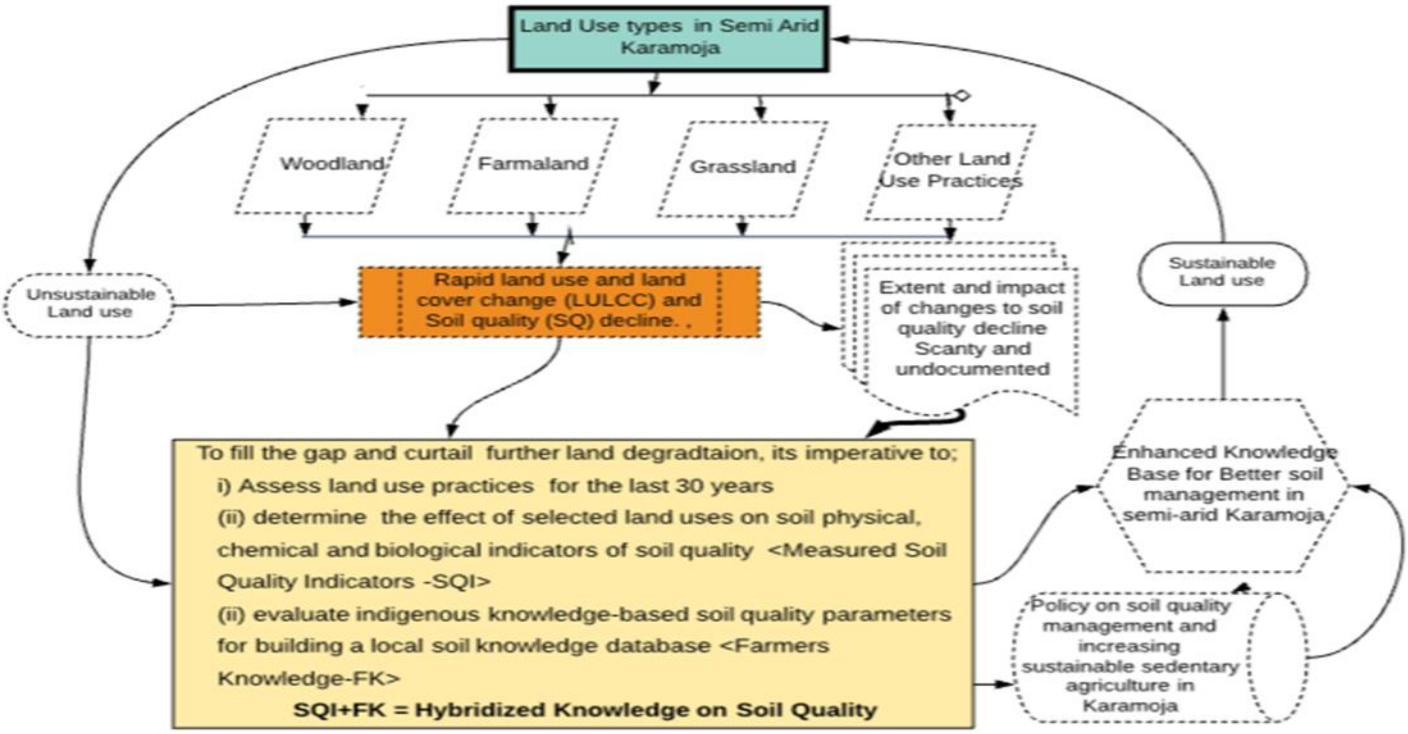


Figure 1: Conceptual framework

The study anticipated to establish the base line information on the soil quality indicator and model the soil quality index for the agro-pastoral zone of Karamoja, Uganda. Further, the study projected to provide farmer-scientific hybrid knowledge to enhance SQ maintenance interventions easy to be adapted and adopted by all stakeholders.

# CHAPTER THREE: INFLUENCE OF AGRO-PASTORAL ACTIVITIES ON LAND USE AND LAND COVER CHANGE IN IRIIRI, MATANY AND RENGEN SUB-COUNTIES OF KARAMOJA, UGANDA


## Abstract

The land use and/or land cover changes (LULCC) caused mainly by human beings for their benefits play a pivotal role in a global environment, resulting in significant ecosystem changes. Iriiri, Matany and Rengen sub-counties in Karamoja sub-region of, Uganda have undergone rapid LULCC in the past three decades. Nevertheless, the extent to which these changes have occurred have not been quantified. This makes it difficult to desidgn practical soil conservation intervention. Establishing the extent of LULCC in the study area between 1986 and 2015 formed our objective. Supervised LANDSAT image classification for years 1986, 1996, 2005 and 2015 was done using ENVI 4.7 software. The classification resulted into six classes; Bare land, Farmland, Woodland, Grassland, Settlement, and Wetland. The area under each LULCC was subjected to a change detection analysis using Arc-GIS (ESRI, 2009) in ten years strata. The results revealed that settlement in Iriiri expanded significantly ($P<0.05$) by 71.3%, while and farmland increased by 45%. Woodland and grassland significantly ($P<0.05$) decreased by 68% and 30% respectively. Bare land increased by 56%, while wetland decreased by 54%. Woodland and grassland significant ($P<0.05$) shrunk by 87% in both Matany and Rengen sub-counties. In Rengen Sub-County Farmland expanded significantly ($P\leq0.05$) by 147% and Woodland shrunk significantly ($P<0.05$) by 79%. Generally, farmland and settlement increased while woodland and grassland shrunk due to increased human population and farming. Expansion of farming is partially due to increased human settlement to pursue agriculture following advocacy by the government of Uganda. The removal of natural vegetation is expected to negatively impact soil quality by exposing it to agents of erosion. However, the extent of these impacts is unknown. Hence, further studies on LULCC and their impact on soil quality at more sub-counties level in the zone are crucial in guiding land use policy and sustainable management practices in the area.


*Keywords: change detection analysis, LANDSAT image classification, land use and land cover*

## 3.1 Introduction

Globally, natural vegetation and grasslands are shrinking therefore leading to profound environmental consequences. Thus, LULCC studies are imperative as the cheapest and quickest way of understanding the current state and predicting the future condition of socio-ecological landscapes (SELs) as influenced by man and nature. Further, studies on land cover changes are crucial as a basis for in-depth socio-scientific re-assessments inform land users, planner, policy makers, and scholars (Sundarakumar et al., 2012). It provides a realistic basis for designing suitable soil conservation technologies.

### 3.1.2 Karamoja overview

Karamoja sub-region is comprised of three agricultural zones namely; pastoral, agricultural and agro-pastoral. The agro-pastoral zone, which run through the districts of Kabong, Kotido, Napak and Nakapiripirit, is one of the three main livelihood zones of Karamoja (USAID, 2017). The zone is mainly composed of the grassland, woodland farmland, and seasonal wetlands (Egeru et al., 2015). The grasslands provide important pasture for livestock and source of thatching material for traditional huts (cluster homesteads Manyata). The less disturbed wood lands usually remain near to their ecological balance for flora and fauna. Islam et al., 2016 and Fox et al., 2017). They provide important ecosystem services, by regulating nutrient cycling, improving water, maintaining the hydrologic cycle and maintaining soil quality (Lawrance et al., 1997; Fan et al., 2007; Hassan et al., 2016; Ozsahin et al., 2018).

The sub-region is characterized by a combination of acute poverty, vulnerability to drought, poor infrastructure, and inadequet basic services delivery combined with limited marketing opportunities. The area has pronounced soil resource degradation, erroneously distributed low uni-model rainfall with one cropping season (GOU, 2009). It worth noting that the people are socially, culturally marginalized, over depend on external aid and the area disposed to permanent insecurity (Musiitwa and Komutunga, 2001; GOU, 2009).

### 3.1.3 Karamoja livelihood zones

Karmoja is subdivided into three livelihood zones namely; the sub-humid agricultural zone, the semiarid –agro pastoral zone with average rain fall ranging between 500-800mm annum$^{-1}$and the arid- pastoral zone (Gou, 2009; FAO and Echo, 2010).

### 3.1.4 The major socio-economic activities of Karamajong people

Pastoralism is the major socio-economic system in Karamoja. The main social economic activities within the system include raiding which is taken by the people of Karamoja as a socio-economic cultural activity. In this regard raiding used to help indigenous people to survive and exchange goods and services in the hostile environment (Knighton, 2003; Stites and Akabwai, 2009; Safeword, 2010). Currently, majority of the Karamajong practice transhumance and optimistic low input cultivation. Other socio-economic activities include; casual labour for cultivation, stone quarry, sand excavation and bricks making (Nalule, 2010). The most commonly grown crops in the semi-arid Uganda are sorghum-legume intercrops, maize Cow pea, ground nut, pigeon pea and green grams are commonly intercropped with sorghum. These crops provide majority of the Karamojan population with food security & cash crops but are characterised by declining yield (Tenywa, 1999; UBOS, 2016).

### 3.1.5 The socio-economic activities of the agro-pastoral zone people

Most of the people's in this area belong to the Jie clan. The people in the study area are mainly engaged in agriculture. Almost all households in Kotido district keep cattle as the main livelihood activity. Majority in the area practice crops growing. The main crops grown are; in order of importance, maize, beans, millet and sweet potato. There are many youth aged between 18-30 who are neither in school nor working. Majority of the youth 10 years and above people own mobile phones. People mainly stay in Manyatta (temporay clustered grass thatched homes) (UBOS, 2016). On the other hand, Napak ditrict is mainly occupied by the Bokola clan. The socio-economic activities are simiral to those found in Kotido distric (UBOS, 2016).

The expansion of farmland, overgrazing by livestock, and human settlement are repeatedly cited as some of the dynamic force behind woodland shrinking in sub-Saharan Africa (Cui et al., 2013; Fox et al., 2017). The Land use change, which human beings often orchestrate, have negative effects to ecosystems, resulting in global climatic changes (Dirmeyer et al., 2010). Currently, LULCC studies are the main ways man can deal with and/or monitor natural resources for better environmental status (Fox et al., 2017). Worldwide, intact vegetation, for instance, forests/woodland and grassland are shrinking in size. Declining trends in the land cover with profound environmental consequences are indicated in several studies (Rugadya and Kansiime, 2013). For instance, deforestation and grassland cover removal for grazing and cultivation in Bangladesh led to a loss of biodiversity, soil quality, escalated global warming and enhanced natural disasters. Some of the negative consequences were unpredictable rainfall patterns, prolonged drought and torrential rainfall (Islam et al., 2001; Islam et al., 2016). The unguided LULCC can be attributed to the increasing population coupled with socio-economic needs and political policies (Sundarakumar et al., 2012).

The magnitude of LULCC within small-ecological settings are neglected. For instance, Iriiri, Matany and Rengen sub-counties have undergone swift LULCC in the past three decades. Therefore, no studies related to LULCC at the sub-counties level. Hence, there is hardly reliable empirical data of Land use change at Sub-County level in Karamoja. In order to bridge this knowledge gap, the objective was set to establish the extent of land use and land cover changes in Iriiri, Matany and Rengen sub-counties, Karamoja, from 1986 to 2015. It was hypothesised that, significant LULCC have occurred in the agro-pastoral, Karamoja for the past thirty years.

## 3.2 Materials and methods

### 3.2.1 Location and description of the study site

The study was carried out in Karamoja sub-region located about 340 km N E of Kampala the capital city of Uganda (Figure 2). The sub-region is made of Moroto, Nakapripirit, Amudat, Napak, Kotodo, Kabong and Abim districts. It lies between latitude $1^{o}$ – $4^{o}$ North and longitudes $33^{o}$ – $35^{o}$ East. Karamoja is mainly made up of three livelihood zones namely, agricultural, agro-pastoral and pastoral zones (Levine, 2010)]. Specifically, the study was carried out in agro-pastoral Kotido and Napak districts. The districts are located $03^{o}$ 31’N, $34^{o}$ 07’E and 02 12’N, 34 18’E respectively. Kotido has a population of 236,900 with a population density of 65.5 /$km^2$ (UBOS, 2016). Napak population stands at 197,700 with population density of 39.7/ $km^2$ (UBOS, 2016). One Sub-County (Rengen) in Kotido and two (Iriri and Matany) in Napak districts were selected for the study. The sub-counties were selected because they were easily accessible and are representative of the agro-pastoral Karamoja. The area receives mono-model rainfall ranging between 500-760 mm minimum and 800-1000 mm maximum per year (Mubiru, 2010 and Kyagulanyi et al., 2016). The average monthly minimum and maximum temperature ranges between 15-18$^{o}$ C and 28-32.4$^{o}$ C, respectively (Mubiru, 2010). It has a very a potentially high evaporation rate, greater than the effective rainfall received (Kyagulanyi et al., 2016). The average wind speed is 12 km per hour with an estimated 10 hours of sunshine a day [hours when the sun is not obscured by clouds (Weather 2, 2018)].

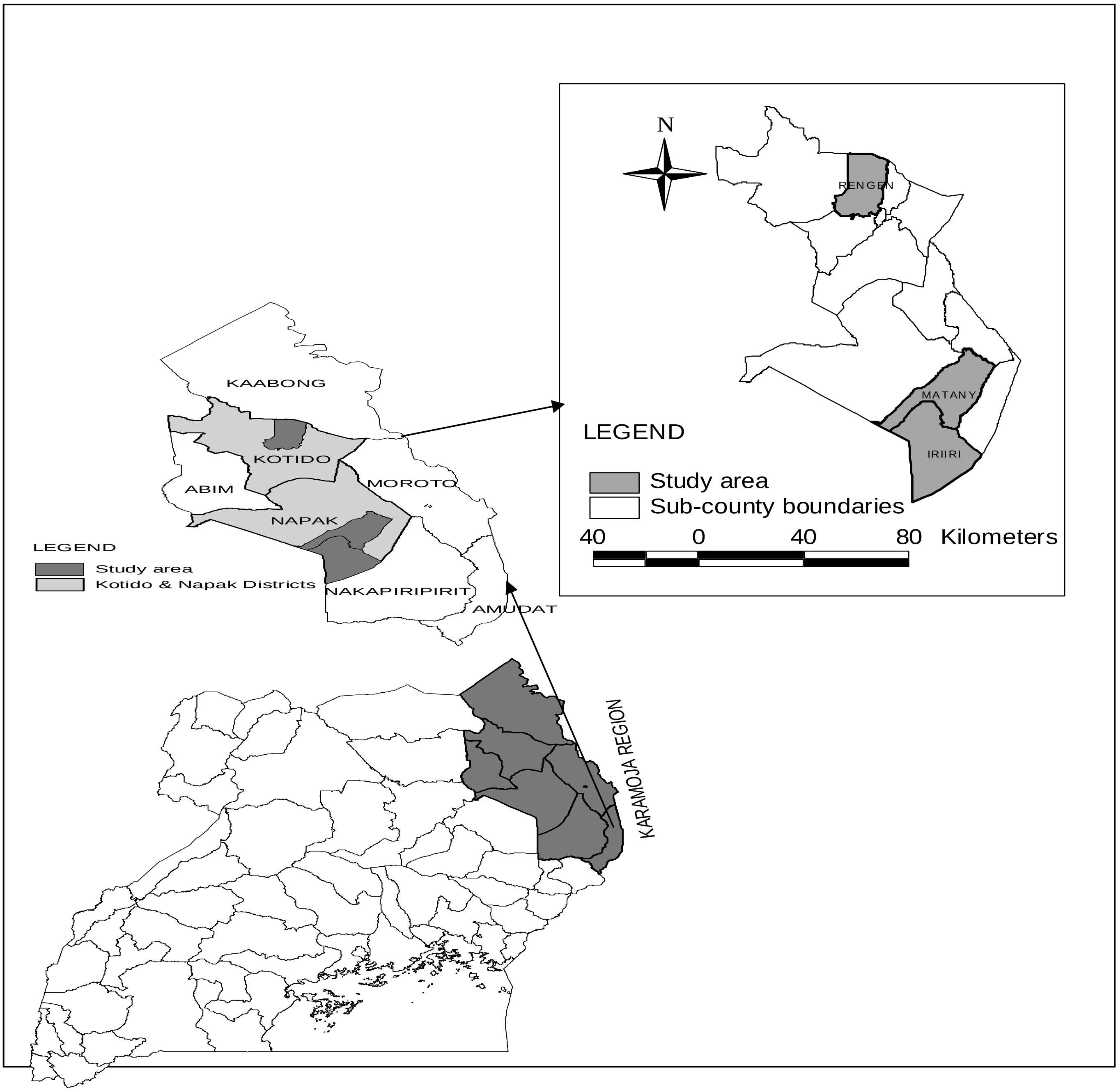


Figure 2: Map of Uganda showing Karamoja sub-region, the districts of Kotido and Napak and the study sub-counties of Iriiri, Matany and Rengen

This study emphasis was done in three sub-Counties of the agro-pastoral zone of Karamoja (Figure 1). In this zone the Karamojong practice a mixed economy of herding and small-scale cultivation, mainly sorghum, maize and Marakwang, pigeon peas and of recent sun flower. Cattle rearing remain the main source of income and dowry. In this area farmer use hand hoes, pangas, and ox- ploughs to till the soil.

Utilisation of modern farm implements and inputs for instance tractors, and fertilisers, pesticides, and high-quality seeds respectively is being introduced by Nabuin ZARDI (based in Nakapiripirit district) staff one of the National Agricultural Research Organisation institutes. The institute come into existence under National Agriculture Research Act, 2005.

### 3.2.2 Study approach

The sites were selected as representatives of the agro-pastoral Karamoja based on the satellite images and a transect drive across the districts with the help of the agricultural extension workers and farmers. The study sub-counties were ground truthed to ascertain the existence of the land use preferred. Characterization included the use of a questionnaire for GPS positioning (Appendix 16). This included crop cultivated, initial land use, the soil types, observable future like erosion, common vegetation species and their relative densities and the check mark next to the land cover being sampled. Three land use types were purposively considered for sampling. These included land under farmland or cultivation or farming for more than ten years, the woodland and the grassland. In each selected land use an initial baseline characterization and assessment of the study site was done (Table 1).

Table 1: Description of the selected land uses in the study area of Agro-pastoral semi-arid Karamoja, Uganda

| District | Sub-County | Land use | Description |
|---|---|---|---|
| Kotido | Rengen | *G L* | According to farmers, this land had been under communal grazing for a long time > than 15 year. The area had rangeland pastures mixed with shrubs. No special management is done here. A rangeland with deep soils. Original vegetation was savannah woodland. Datum slope $1^{o}$ categorized as flat $0.1^{o}$. Azimuth $0\text{-}10^{o}$. Land cover type common plant species are grasses, common trees are sparse Gum Arabic and Cactus surrounded with other scrub vegetation. Common activity is communal grazing. Land use history: *It was classified as savannah woodland.* |

| | | | |
|---|---|---|---|
| | | *WL* | The woodland in the study area was locally referred to as a sacred forest. Indigenous people do not harvest anything, like fire wood, fruits, and mushrooms for fear of evil spirits so it was still in its natural state. By observation soil was compact and stony, with wild pomerina, hypherrenia species, wild simsim species, sodom apples, *Aloevera berbednis and* Agaveceae family species. The land is Physiographically, flat with a gentle slope <0-10$^o$ with Azimuth of 0-10$^o$. Original vegetation *spp* were mainly acacia with a composition of 30%, Cactus are abundant. Land use history: intact vegetation mainly of acacia and cactus (sacred woodland) with omen and taboos to harvest and use its products. |
| | | *FL/CUL* | This land has been under Farmland or cultivation season to season for more than 10 year. The crops commonly grown are annuals; sorghum, maize, green grams, sunflower, millet, bulrush millet and pigeon peas. The area exhibit sheet and rill erosion. The Datum slope is 10$^o$. The slope was physiogarphically flat 10$^o$. The steepness of the slope was <1$^o$ with Azimuth of 0-5$^o$. Land cover type (a check mark next to land cover under study) has acacia trees and other thorny plants. Land use history: it was intact range land for goats and sheep-cleared in 2006 for agriculture. Other observations: weathered crops, soil are sandy, sheet erosion future can be seen in the cropland. Presence of witch weed (*Striga hermonthica)* in sorghum gardens and general purpling and yellowing of sorghum indicating low P and N levels. |
| Napak | Matany | *GL* | The land is flat <10$^o$ with sparse thorny trees and shrubs. Rangeland pasture were mainly a mixture of Sodom apple and other unpalatable pasture species. There were clear livestock path. The area was seldom with thickets |
| | | *WL* | Was not as distinct as in Rengen. The woodland was comprised of mainly thorny, thickets and a mixture of tall grasses. This woodland was difficult to pass through or penetrate due to thorny trees. |
| | | *FL/CUL* | Land is flat (<10$^o$) with rampant wet season flooding. Pastoralists practice dry season grazing. The area has thorny weeds and are very hard soil to work during dry season. During the dry season crack could be seen in most field which were previously under cropping |
| | Iriiri | *GL* | Comprised of taller grass particularly the *Hyparrhenia rufa* (Jaragua grass) |
| | | *WL* | The woodland here had taller trees than in any of the first sub-counties. The trees are sparsely spaced. Soil were very deep with no separate horizons at a depth of 100 cm. |
| | | *FL/CUL* | Land had been under Farmland or cultivation for more than 10 year. Farmers mainly grow annual cereal crops; sorghum, maize and some legumes. They were growing cassava and other perennial crops which were recently introduced in the area by NARO- Nabuin Zonal Agricultural Research and Development Institute. |

Key: *GL* = grassland; *WL* = woodland and *FL/CUL* = farmland/cultivated

### 3.2.3 Data collection for land use land cover changes (LULCC)

In order to extract LULCC change information for the sub-counties satellite data processing was used. The process involved scrutiny of LANDSAT Thematic Mapper (TM) together with the Enhanced Thematic Mapper (ETM) sub-counties images for period from 1986 to 2015, obtained from the United States Geological Survey website (USGS). The imageries used covered a 30-year period in ten years' intervals (1986, 1996, 2005 and 2015). The period of 10 years was considered to be long enough for substantial LULCC in the area. Ground truthing was conducted in order to aid supervised classification of the images (ESRI, 2009).

### 3.2.4 Image Classification and change detection

The Satellite images used in digital image processing and the path rows for Iriiri, Matany and Rengen sub-counties of Karamoja are presented in Table 2. The Images were pre-processed by registration and sub-setting using ground control points (GCPS) (Mwavu and Witkowski, 2008). This was followed by undertaking image classification starting with unsupervised classification through comparing individual pixel to each distinct cluster to see which one was closest to in order to derive the available classes. The supervised land image classification was then done through multi-temporal LANDSAT data processing using ENVI 4.7 software. The classification resulted into six (6) LULCC categories upon confirmation from ground truthing data. The LULCC detection analysis was done for each land cover class on Arc-GIS (ESRI, 2009) to determine the area under each land use or cover type. The LULCC detection analysis was done using the images of (1986, 1996), (1996, 2005) and (2005, 2015). Two images each from different time (1986 to 1996; 1996 to 2005; 2005 to 2015 and; 1986 to 2015), were used to analyse changes for classified LULCC types. The two sets of classified data enabled LULCC matrix operation to show all the possible changes between classes. To test the significance in LULCC, the Chi-square goodness of fit test was performed using the SPSS 24 version and results are presented.

Table 2: Satellite images used for Iriiri, Matany and Rengen sub-counties of Karamoja digital image processing

| Year | Satellite | Path/row | Spatial resolution (m) | Date |
|---|---|---|---|---|
| 1986 | Landsat-5 | 171/58 | 30 | 10-01-1986 |
| | Landsat-5 | 170/58 | 30 | 04-02-1986 |
| | Landsat-5 | 170/59 | 30 | 18-10-1986 |
| 1996 | Landsat-5 | 171/58 | 30 | 19-01-1996 |
| | Landsat-5 | 170/58 | 30 | 08-01-1996 |
| | Landsat-5 | 170/58 | 30 | 10-01-1996 |
| 2005 | Landsat-7 | 171/58 | 30 | 02-2-2005 |
| | Landsat-7 | 170/58 | 30 | 03-03-2005 |
| | Landsat-7 | 170/58 | 30 | 06-02-2005 |
| 2015 | Landsat-8 | 171/58 | 30 | 15-03-2015 |
| | Landsat-8 | 170/58 | 30 | 15-03-2015 |
| | Landsat-8 | 170/59 | 30 | 03-01-2015 |

### 3.3 Results and Discussion

#### 3.3.1 Land cover classification scheme

Variation in the degree of LULCC of Iriiri, Matany and Rengen sub-counties of Karamoja sub-region of Uganda from 1986 to 2015 at 10-year strata. Their mosaics are presented in (Table 3, Figure 3 and insert A,B, C, D), (Table 5, Figure 4 and insert A, B, C, D) and (Table 7, Figure 5 and insert A, B, C, and D).

#### 3.3.2 Land use and land cover change

The LULCC maps for Iriiri, Matany and Rengen for the year 1986, 1996, 2005 and 2015 (Figure 3, 4 and 5 plates A, B, C, and D) were generated following the LANDSAT image analysis and classification. Different land use or cover types in Iriiri, Matany and Rengen sub-counties of Karamoja) from 1986 to 2015 exhibited area coverage variations (Tables 3, 5 and 7).

The magnitude of LULCC and their mosaics in Iriiri, Sub-County of Karamoja, for the period 1986-2015 are presented in Tables 3 and Figure 3, respectively. The results indicated that areas under different land use change exhibited variations from 1986 to 2015 (Table 3).

Grasslands (55.8%) and farmlands (41.4%) comprised the main land uses/cover type throughout the entire study area. The wetlands (swamps) had the least coverage (5%). LULCC Figures for Iriiri, for the year 1986, 1996, 2005 and 2015 (Figure 3 and insert A, B, C and D) show that the Sub-County experienced rapid land use land cover changes between 1986 and 2015 (Table 3). There were high ($p<0.05$) rise in settlement during the period under study. Settlements expanded by 71.3% from 1986 to 2015, while other land uses did not significantly ($p<0.05$) change during the same period (Table 3).

Grassland and farmland comprised the main land uses/cover type throughout Matany and Rengen at (66.8 and 52.0%) and (22.2 and 13.3%), respectively (Tables 5 and 7). The wetland (swamps) had the least coverage and occupied 0.368 and 0.636% of Matany and Rengen, respectively (Table 5 and 7).

The results specified that Matany and Rengen sub-counties have rapidly undergone LULCC from 1986 to 2015 (Table 5 and 7). Significant ($p < 0.05$) land conversion was recorded in woodland in Matany Sub-County. Woodland shrunk by 87% from 1986 to 2015. Other land use conversions were not significantly high ($p > 0.05$). However, in Rengen Sub-County, significantly different ($p < 0.05$) land conversion occurred in grassland, farmland, and woodlands. The grassland significantly decreased ($p < 0.05$) from 20,975 to 12,125 hectares (42%). Farmland expanded significantly ($p < 0.05$) from 5,365 to 13,229 hectares (147%). On the other hand, woodland shrunk ($p < 0.05$) from 5,235 to 1,103 hectares (79%). Other land uses conversion were not significantly different $P < 0.05$.

Generally, grassland, woodland, bare land, and wetlands shrunk while the farmland and settlement were expanding in area, they cover during study period. The final data of the bare land increase in Rengen sub-counties (Tables 7 and 8). To the contrary, the final data of bare land in Matany Sub-County decreased from 2,453 to 303 hectares (87%) (Figure 4; Tables 5 and 6). Perhaps the study specified that settlement and farming were the main causes of Land use change in the entire study area.

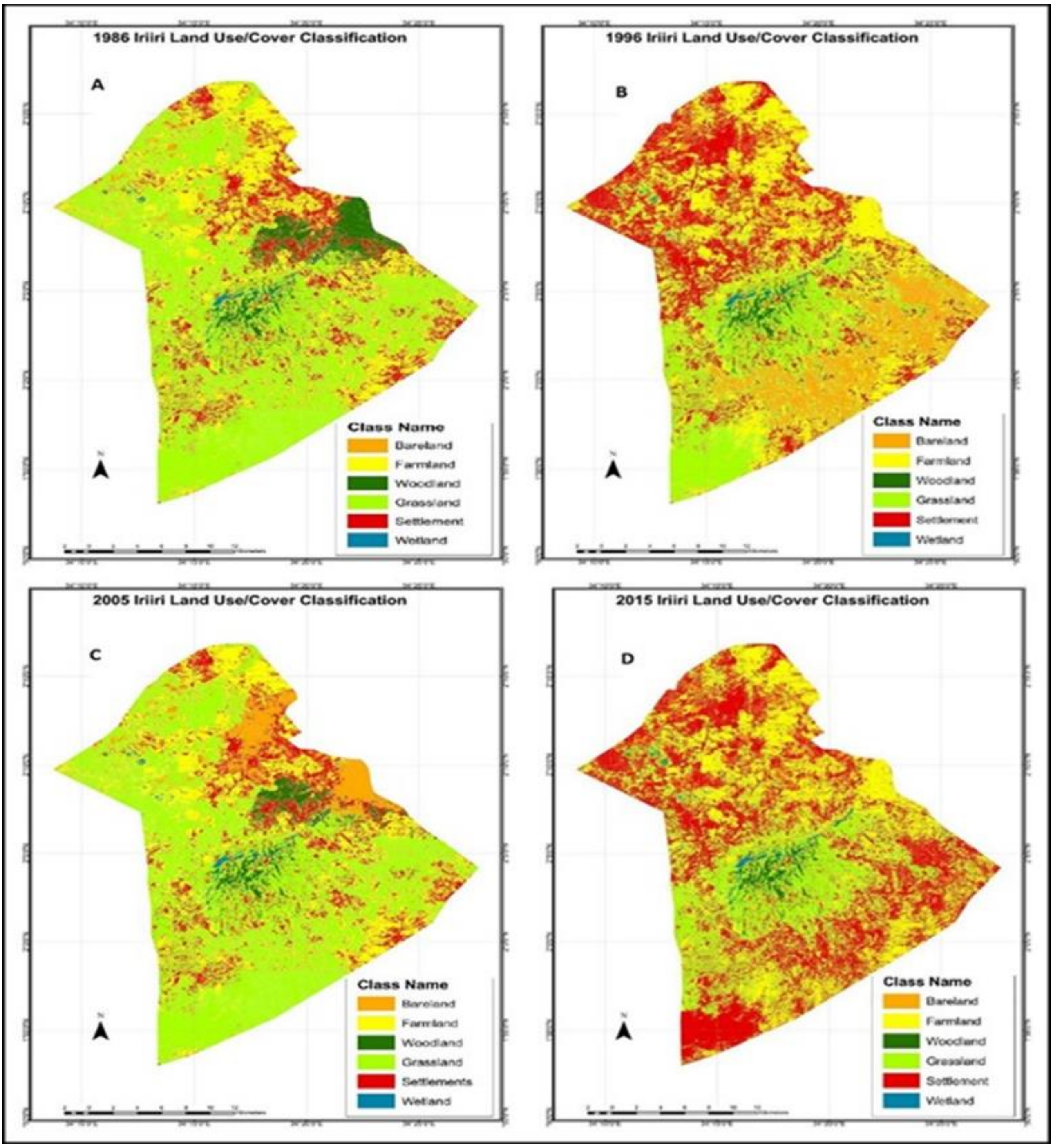


Figure 3 : Land use/ cover Classification Scheme for Iriiri Sub-County for 1986, 1996, 2005 and 2015

[1]Where (in all Figures): **Bareland** = Area without vegetation including overgrazed land, rock outcrops and erosion futures like gullies and rills; **Farmland** = Cropping areas mainly covered by annual crops; **Woodland** = Areas covered by woody plant species with a height of 2-10 meters; **Grassland** = communal grazing land with about 20% bush and mixture of scrub plant species; **Settlement** = Homestead (Manyatta), urban and rural settlements and; **Wetland** = Area covered by seasonal water

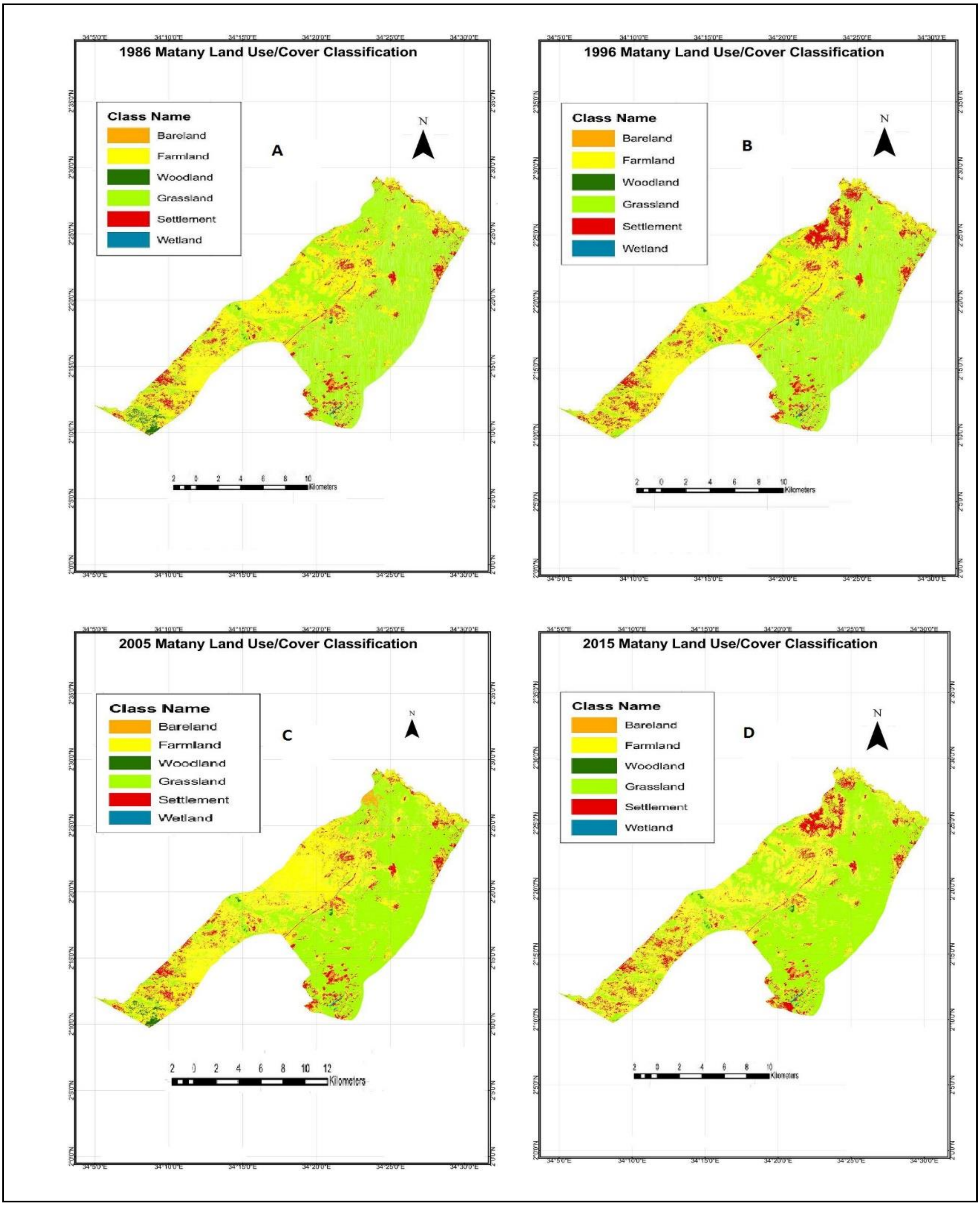


Figure 4: Land use/ cover Classification Scheme for Matany Sub-County for 1986, 1996, 2005 and 2015

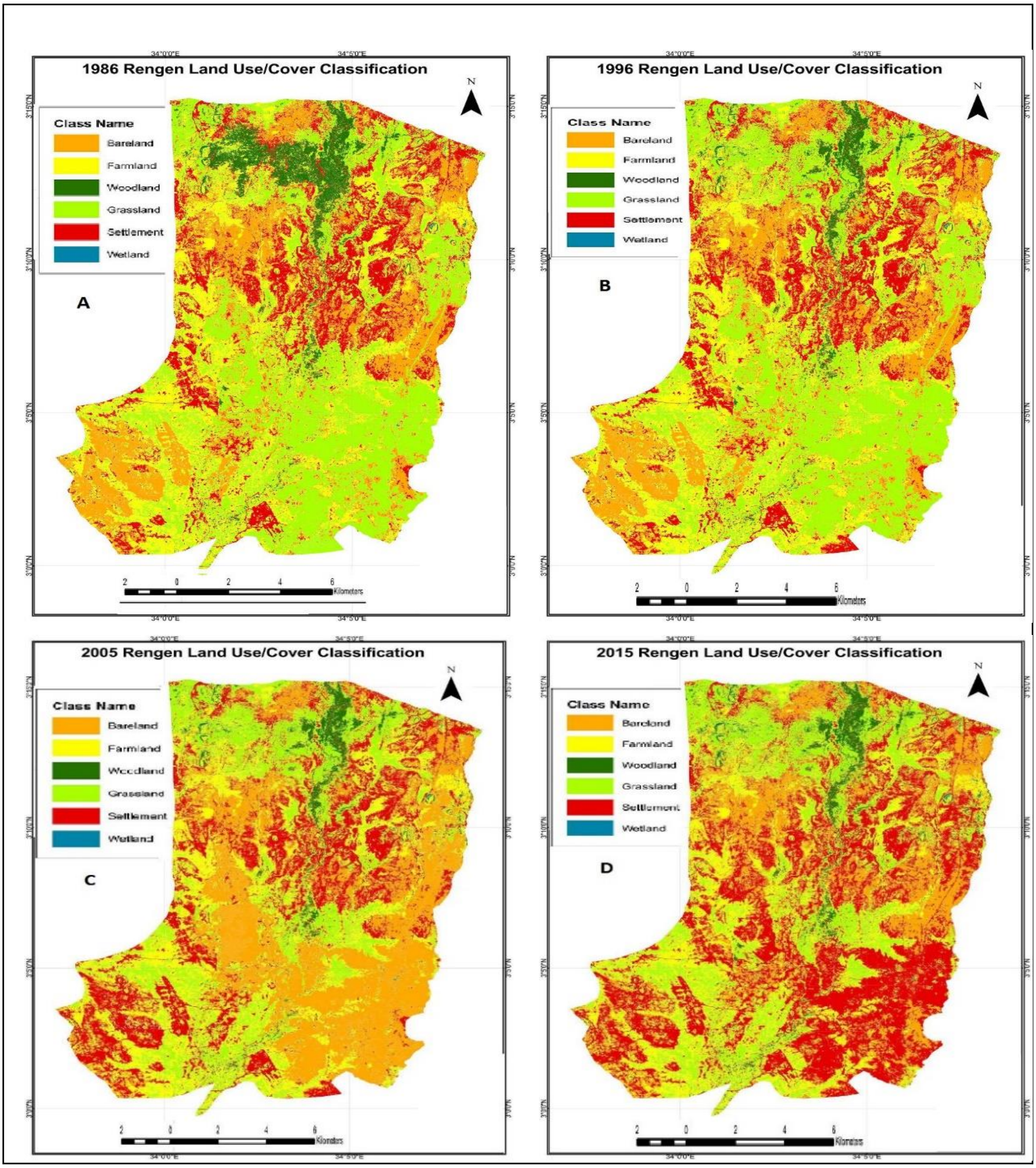


Figure 5: Land classification scheme for Rengen Sub-County for 1986, 1996, 2005 and 2015

Table 3: Thematic Land use change statistics from change-to-change matrices in Iriiri Sub-County

| **Iriiri Sub-County** | **1986** | | **1996** | | **2005** | | **2015** | | **Magnitude of % change** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LULCC category** | Area (Ha) | % cover | Area (Ha) | % cover | Area (Ha) | % cover | Area (Ha) | % cover | **1986-1996** | **1996-2005** | **2005-2015** | **1986-2015** |
| Grassland | 41,949 | 55.8 | 32,543 | 44.8 | 30,259 | 40.3 | 29,276 | 39 | **-22.4** | **-7** | **-3.3** | **-30.2** |
| Farmland | 17,365 | 23.1 | 20,655 | 27.5 | 23,254 | 31 | 25,104 | 33.4 | **18.9** | **13** | **8** | **44.6** |
| Settlement | 9,253 | 12.3 | 13,568 | 18.1 | 14,963 | 31 | 15,853 | 21.1 | 46.6 | 10.3 | 6 | 71.3 |
| Bareland | 2,137 | 2.8 | 4,255 | 5.7 | 3,458 | 4.6 | 3,342 | 4.5 | **99.2** | **-19** | **-3.4** | **56.4** |
| Woodland | 3,542 | 4.7 | 2,365 | 3.2 | 2,625 | 3.5 | 1,146 | 1.5 | **-33.2** | **11** | **-56** | **-67.7** |
| Wetland | 873 | 1.2 | 623 | 0.8 | 561 | 0.8 | 400 | 0.5 | **-28.6** | **-10** | **-29** | **-54.2** |
| **Total** | **75120** | **100** | **75120** | **100** | **75120** | **100** | **75120** | **100** | | | | |

[1.] Where (in all Tables) LULCC = Land Use Land cover class and Ha = hectares

Table 4**:** Chi-Square goodness of fit test for land use and land cover dynamics in Iriiri Sub-County

| **LULCC category** | **Percentage land cover** | | | | **Chi-square Goodness of fit test** | | |
|---|---|---|---|---|---|---|---|
| | 1986 | 1996 | 2005 | 2015 | $\chi^2$ | df | p-value |
| **Grassland** | 55.843 | 44.8 | 40.281 | 38.972 | 4.044 | 3 | 0.257 |
| **Farmland** | 23.117 | 27.496 | 30.956 | 33.418 | 1.974 | 3 | 0.578 |
| **Settlement** | 12.318 | 18.062 | 30.956 | 21.104 | 9.22 | 3 | 0.027 |
| **Bareland** | 2.844 | 5.664 | 4.603 | 4.448 | 1 | 3 | 0.801 |
| **Woodland** | 4.716 | 3.149 | 3.495 | 1.525 | 1.429 | 3 | 0.699 |
| **Wetland** | 1.162 | 0.83 | 0.747 | 0.532 | 0 | 3 | 1 |

[1] Where in all chi-square tables P ≤ 0.05 means significant, p>0.05 means not significant

Table 5: Thematic Land use change statistics from change-to-change matrices in Matany Sub-County

| Matany Sub-County | **1986** | | **1996** | | **2005** | | **2015** | | **Magnitude (% change)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LULCC category | Area (Ha) | % cover | Area (Ha) | % cover | Area (Ha) | % cover | Area (Ha) | % cover | 1986-1996 | 1996-2005 | 2005-2015 | 1986-2015 |
| **Grassland** | 40,185 | 67 | 34,241 | 56.9 | 32,26 | 53.6 | 31591 | 52.5 | -14.8 | -5.8 | -2.1 | -21.4 |
| **Farmland** | 13,359 | 22 | 16,255 | 27 | 18,154 | 30.2 | 20381 | 33.9 | 21.7 | 11.7 | 12.3 | 52.6 |
| **Settlement** | 3,232 | 5.4 | 5,254 | 8.7 | 6,256 | 10.4 | 7730 | 12.9 | 62.6 | 19.1 | 23.6 | 139.2 |
| **Bareland** | 2,453 | 4.1 | 4,173 | 6.9 | 3281 | 5.5 | 303 | 0.5 | 70.3 | -21.4 | -90.8 | -87.6 |
| **Woodland** | 689 | 1.2 | 142 | 0.24 | 109 | 0.2 | 88 | 0.2 | -79.3 | -23.3 | -19.5 | -87.2 |
| **Wetland** | 221 | 0.4 | 73 | 0.12 | 810 | 0.1 | 47 | 0.1 | -67.2 | 9.9 | -42.9 | -79.4 |
| Total | **60139** | **100** | **60139** | **100** | **60139** | **100** | **60138.5** | **100** | | | | |

Table 6: Chi-Square goodness of fit test for Land Use and land cover dynamics in Matany Sub-County

| Matany Sub-County | Percentage land cover | | | | Chi-square Goodness of fit test | | |
|---|---|---|---|---|---|---|---|
| **LULCC category** | % cover 1986 | % cover 1996 | % cover 2005 | % cover 2015 | $\chi^2$ | df | p-value |
| Grassland | 66.820 | 56.938 | 53.641 | 52.530 | 2.126 | 3 | 0.547 |
| Farmland | 22.214 | 27.028 | 30.187 | 33.890 | 2.717 | 3 | 0.437 |
| Settlement | 5.374 | 8.737 | 10.403 | 12.854 | 3.541 | 3 | 0.316 |
| Bareland | 4.078 | 6.940 | 5.455 | 0.505 | 4.667 | 3 | 0.198 |
| **Woodland** | **1.146** | **0.237** | **0.182** | **0.146** | 16.667 | **3** | **0.001** |
| Wetland | 0.368 | 0.121 | 0.133 | 0.076 | 3.857 | 3 | 0.277 |

Table 7: Thematic Land use change statistics from change-to-change matrices in Rengen Sub-County

| **Rengen Sub-County** | **1986** | | **1996** | | **2005** | | **2015** | | **Magnitude (% change)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LULCC category** | Area (Ha) | % cover | Area (Ha) | % cover | Area (Ha) | % cover | Area (Ha) | % cover | 1986 - 1996 | 1996 - 2005 | 2005 - 2015 | 1986-2015 |
| Grassland | 20,975 | 52 | 15,696 | 40 | 13,255 | 32.9 | 12,125 | 29.3 | -25.2 | -15.6 | -8.5 | -42.4 |
| Farmland | 5,365 | 13.3 | 7,174 | 17.8 | 8,263 | 20.5 | 13,229 | 32 | 33.7 | 15.2 | 60.1 | 146.6 |
| Settlement | 4,257 | 10.6 | 6,585 | 16.3 | 7,025 | 17.4 | 7,616 | 18.4 | 54.7 | 6.7 | 8.4 | 79 |
| Bareland | 4,256 | 10.6 | 8,812 | 21.8 | 10,740 | 26.6 | 7,212 | 17.4 | 107 | 21.9 | -32.9 | 69.5 |
| Woodland | 5,235 | 13 | 2,006 | 5 | 1,004 | 2.5 | 1,103 | 2.7 | -61.7 | -50 | 9.8 | -79 |
| Wetland | 257 | 0.64 | 72.4 | 1 | 57.4 | 0.1 | 60.6 | 0.2 | -71.8 | -20.8 | 5.7 | -76.4 |
| **Total** | **40344.4** | **100** | **40344.4** | **100** | **40344.4** | **100** | **40344.4** | **100** | | | | |

Table 8:Chi-Square goodness of fit test for Land Use and land cover dynamics in Rengen Sub-County

| **Rengen Sub-County** | **Percentage land cover** | | | | **Chi-square Goodness of fit test** | | |
|---|---|---|---|---|---|---|---|
| **LULCC category** | **1986** | **1996** | **2005** | **2015** | $\chi^2$ | df | p-value |
| Grassland | 51.989 | 38.905 | 32.854 | 29.326 | 7.915 | 3 | 0.048 |
| Farmland | 13.299 | 17.781 | 20.481 | 31.998 | 9.238 | 3 | 0.026 |
| Settlement | 10.551 | 16.321 | 17.413 | 18.42 | 1.871 | 3 | 0.6 |
| Bareland | 10.55 | 21.842 | 26.621 | 17.445 | 7.026 | 3 | 0.071 |
| Woodland | 12.976 | 4.973 | 2.488 | 2.665 | 11.333 | 3 | 0.01 |
| Wetland | 0.636 | 0.179 | 0.142 | 0.147 | 5.364 | 3 | 0.147 |

Overall, farmland and settlement areas increased throughout the study area of Matany and Rengen Sub-Counties while the grassland and woodland land use areas demonstrated a shrinking trend (Figures 2, 3 and 4). None the less, the wetlands were almost stable throughout the study sites and period. To the contrary, bare land demonstrated unstable trends throughout the entire study area of Matany and Rengen Sub-County. Bare land in Matany shrunk tremendously by the year 2015.

### 3.3.3 Trends for land use and land cover change of the study Sub Counties

The total area, which covered by grassland in 1986, showed a declining trend though the study area. The area will continue declining in the foreseeable future (Figure 6). Woodland cover declined sharply through the study period from and indicating further decline. The bare land increased from 1986 to 1996 then stabilize between 1996 and 2005 after 2005 the area covered by bare land declined sharply. The overall area covered by wetland remained stable through the study period. To the contrary, farmland and settlement demonstrated an upward expansion trend through the entire study period and may sharply increase in the future.

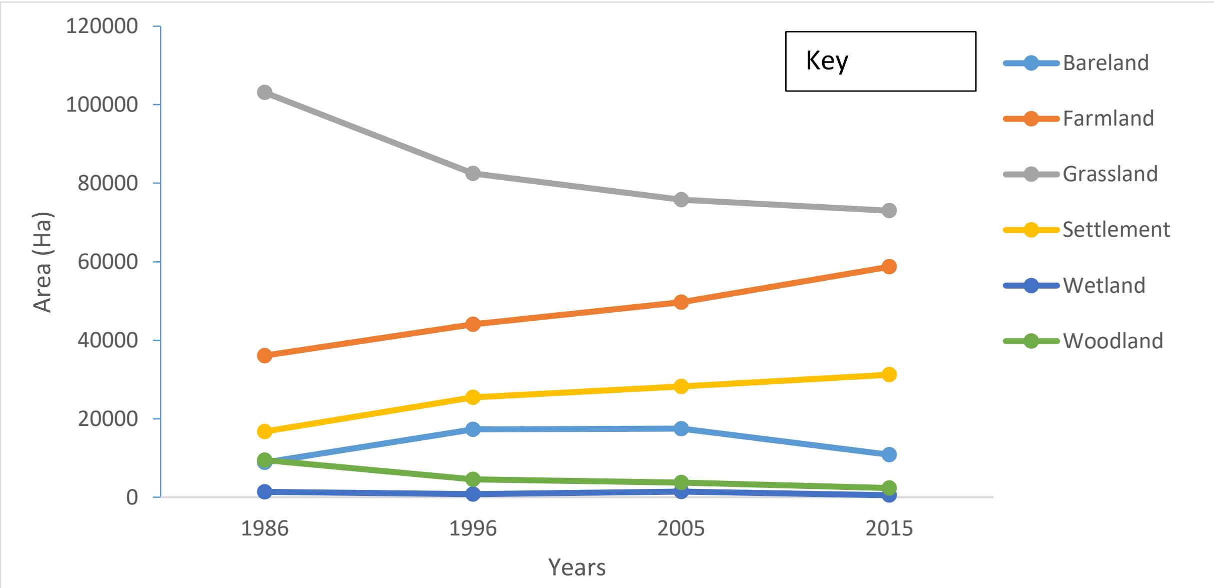


Figure 6 : The trend curves for land use and land cover change of all study sub-counties

## 3.4 Discussion

The main land use and cover changes which were identified in the agro-pastoral Karamoja were; bare land, farmland, woodland, grassland settlement and wetland. The lands have under gone changes in the last three decades. The areas they cover and their changes per each decade are summarise in Iriiri, Matany and Rengen sub-counties are reflected in the six land uses categories allude to above.

### 3.4.1 Grassland

The dwindling of the areas covered with grassland in the study sub-Counties can be attributed to increasing sedentary population, demand for socio-economic requirements likely increased farming. The percentage households depending on agriculture stands at 70.3, 57 and 91.6, 91.2% for livestock and growing crops in Kotido and Napak study district of Karamoja respectively (UBOS, 2014). When more and more Karamajong people settled in the study Sub-Counties, they cleared the vegetation around for other human activities like construction, farming, and firewood. Since currently the Karamajong people practice transhumance nomadic livelihood, it is likely they settled with their animals which over grazed the rangeland grasses around the homes during the favourable weather and reduced the vegetation cover around the settlement. Later during the dry season they moved to far places to graze their livestock which further clear the grasses in the far rangelands. To the contrary, monadic grazing tend to lead to even grazing thought the wet season living no over grazed patches in particular areas. This might have led to the observed reduction the area covered by the grass in the study area. Ebanyat et al., 2010, reported a negative correlation of human population increase with other land uses in a study which was carried out in Parisa district of Uganda. The partial and temporal shrinkage of grassland recorded in this study can also be linked to people's harvesting of grass for the thatching their traditional huts, cover of wood for charcoal production and/or bricks baking in the traditional earth mound kilns, plus uncontrolled rampant bush burning. Similar observations and concussion were drawn by (Rugadya, and Kamusiime, (2013); Nakalembe et al. (2017).

### 3.4.2 Farmland

The observed increase in farmland size throughout the entire study area (sub-counties of Matany and Rengen), could be attributed to the reducing overdependence on livestock in the entire agro-pastoral livelihood zone of Karamoja. Extensive farming for food production started in the year 2005. People in the agro-pastoral zone started practicing agriculture in addition to livestock keeping, this coupled with the increasing population likely led to an expansion of farmland thus removal of the natural vegetation. In addition, the government of Uganda's effort to introduce sedentary agriculture in Karamoja may have acted as a driver responsible for enhanced vegetation clearance to introduce farming. Among the government strategies to introduce more sedentary agriculture is the involvement of the Office of the Prime Minister (OPM), Non-Government Organisation (NGO) and extension workers effort to change the communities. The 2004 Karamoja Integrated Disarmament and Development Program (KIDDP) resulted into induced increase in crops growing for enhanced food production in Karamoja sub-zone (MAAIF, 2010). Similarly, Bushby and Stites (2016) studies indicated increased crops production as a result of KIDDP introduction in Karamoja. In addition, the year 2002 population density of Karamoja area was as low as 12 persons compared with 2014 which puts it at 35 persons per $km^2$ (SUBO, 2014). Implying that previously relatively smaller population nearly solely depended on livestock for survival, but due to the increase in population, people seek alternative ways of survival. Therefore, they might have encroached on grassland and woodland for cultivation and settlement. Mainly the changes are driven by human alteration on ecological covers for socio-economic gains (Maitima et al., 2010; Ebanyat et al., 2010). Perhaps, this led to grassland and woodland decrease in hectares. In a study, which was done by Nakalembe et al. (2017) in Moroto district, Karamoja, it was revealed that there was a direct competition between pasture grasses and cropland. In their study, the main drivers of the major Land use change were farming/cultivation increase, enhanced sedentary settlement, over-harvesting of wood for construction of Manyatas and the enclosures, charcoal production, bricks baking and firewood for both domestic plus household income generation. Other underlying factors are probably population increase and poverty. Zziwa et al. (2012), Kenya Ministry of Forestry and Wildlife, 2013 and Egeru et al. (2015) drew similar conclusions of Land use change.

### 3.4.3 Human settlement

The expansion in the settlement was probably, in part due to human population increase. For example, the human population of Rengen Sub-County stood at 18,373 in 2002. In 2014, it stood at 36,977- an increase of 101% (UBOS, 2014). Perhaps, similar trends happened in Matany Sub-County whose population was 22,810 in the year 2014. Another driving force for increasing settlement may be attributed to the improved exposure of the people of Karamoja to other communities. Karamoja, which used to be inaccessible due to rampant cattle rustling and vehicle ambushes by warriors, is now accessible because of the government’s effort to disarm the local people. In addition, the ever-increasing levels of formal education of the peoples of Karamoja has enabled them to change to modern livelihood. Brown et al. (2017) recorded an upward trend in education dynamics of Karamoja, which required an increase in sedentary population. Human settlement (sedentary population), may account for LULCC in areas surrounding their homes. When people settle, their population increase and turn into the small urban centres or trading areas. The population in the trading centres requires more fuel in form of firewood, charcoal, and timber for the construction of more houses as reported by FOSA report-Uganda, 2018. Farmers mainly harvest the above items from the surrounding woodland. Perhaps, this led to the shrinking of the natural woodland and grassland covers recorded in this study.

### 3.4.4 Bare land

The largest area of bare land observed throughout the entire study area in 2005 as compare to other study years, coincided with the introduction of KIDDP, which restricted livestock to protected kraals (OPM, 2010). This could be attributed to livestock restriction in protected kraals, which resulted in reduced areas for grazing as protected rangeland pastures for security purposes, hence the population of animal grazing per unit area increased. Restricted animal grazing areas not only reduce animal movement, but also increase the number of livestock beyond the rangeland vegetation carrying capacity. Herbivores are known to severely reduce the above vegetation in dry area woodland (Sämuel et al., 2011). In so doing, animal tend to overgraze the available range pastures leading to bare patches. In addition, perhaps the appearance of larges bare lands were enhanced by livestock over trampling of the restricted kraal and grazing areas which lead to bare lands indicated in the Figures of the study Sub-Counties. This study was in line with studies in sub-Saharan Africa by Cuit et al. (2013) and Foe et al. (2017). Similar observations in other parts of Karamoja were made by Burns et al., 2013.

### 3.4.5 Woodland

The overall great shrinkage of woodland throughout the study area can be attributed to the increased human activities like expanding farming or cultivation, wood harvesting for construction of Manyatta, charcoal making, bricks baking, sale to earn a living, to mention but a few. This is in agreement with other studies by MacOpiyo, (2011), MEMD, (2015) and Nakalembe et al. (2017), which indicated farming and other human activities as drivers of Land use change in Karamoja. Woodland slight increase in area between the years between 2005 and

2015 can be attributed to other rather unrelated causes which led to temporal change. Perhaps, the sequence of rejuvenation of woodland, included abandoning of exhausted land for fresh land by farmers and recovery of wood tree species from human wood harvesting for houses construction, charcoal, and firewood. Similarly, woodland increase in area from the years 2005 to 2015 can be related to vegetation recovery from the previous overgrazed land due to previously restricted grazing from the protected kraal era and the vegetation recovery from army clearance of the vegetation for clear vision. When the protected kraal era ended the livestock were left to graze from large area which allowed tree regrowth. This is in line with a study, which was done by Islam et al. (2001) in the tropics of Bangladesh where an increase in exotic shrubs and grasses were recorded after deforestation.

### 3.4.6 Wetland

The wetland changes could be attributed to seasonal variations and unpredictable rainfall, other than human encroachment. The area covered by seasonal water depends on the availability, the amount of rainfall received during the season, and the drought experienced in the area. Prolonged dry season might have manifested its self in a reduced area covered by the wetland and the reverse is true. Similarly, Mubiru, (2010) attributed the water shortages to seasonal rainfall variability.

Overall, agriculture or farming increased at an alarming rate. Although Karamoja is lightly populated, most of them are clustered near urban centres for security purposes. In this regard, areas near urbanizing centres were likely to be more vulnerable to loss of vegetation due to human settlement and their subsequent requirements. These might have culminated into changing natural forests, grassland covers, and hence environmental degradation, which requires further studies. Nakalembe et al. (2017) recorded a high increase in crops production in Lotome Sub-County Napaka district of Karamoja. The study results indicated that there was a sharp decline in woodland hectares. This may be ascribed to increased human demands for survival leading to over cutting of trees for use in charcoal production, firewood, bricks baking, huts building, thatching and bush clearing for crop production. The study was in agreement with earlier studies, which were conducted in Ethiopia by Berhanu et al. (2016).

### 3.5 Conclusions and recommendations

1. The results of the study have shown that substantial land use dynamics occurred between the years 1986 and 2015.

2. There was significant land use change due to human agricultural and settlement practices in the entire study area.

3. The study further established that in each of the sub-counties (Iriiri, Matany and Rengen) farmland was the major expanding land use, followed by the settlement.

4. The grassland, woodland and bare land were decreasing while wetland remained unaffected. Thus, human activities are the major causes of land use change in the agro-pastoral Karamoja. Perhaps, advocacy for sedentary farming coupled with population increase in the area, were the main drivers of LULCC in the agro-pastoral zone. The farmland increase seriously influence the soil quality to perform it specific functions. As such, it is imperative to understand the negative consequences of the expanding land use and determine the possible remediation. Hence, studies on LULCC and their effect on soil quality at sub-counties level are crucial in guiding land use planner, policy makers and other stakeholders for sustainable management practices in the area.

5. Further studies on LULCC and their impact on soil quality at more sub-counties level in the zone are crucial in guiding land use policy and sustainable management practices in the area.

# CHAPTER FOUR: INFLUENCE OF SELECTED LAND USE CHANGE ON SOIL MEASURABLE (PHYSICAL, CHEMICAL AND BIOLOGICAL) PROPERTIES IN THE AGRO-PASTORAL KARAMOJA, UGANDA


## Abstract

There is inappropriate Land use change in Karamoja agro-pastoral zone which can lead to soil quality (SQ) degradation. However, the levels and rates of soil quality (SQ) detoriolation in the zone received little or no research attention. Hitherto there has been no efforts to establish the indicators of SQ in this study area. Accordingly, it has been difficult to design appropriate interventions to minimize the SQ deterioration. This study aimed at asssessing the effect of selected Land use change on soil chemical, biological, physical properties of the agro-pastoral Karamoja, Uganda. The hypothesis was that different land uses have varied effect on soil physical, chemical and biological properties.

Ninety soil samples were collected from Iriiri, Matany and Rengen Sub-Counties of the agro-pastoral livelihood zone and analysed for the chemical and physical properties attributes using standard methods. The results revealed that most of the parameters were affected by land use alteration. Farming led to decline trends of both chemical and physical soil attributes. The findings indicated that farming or cultivation led to substantial damage of the chemical and physical attributes throught the study area. As such, necessitating soil conservation practices and management ultimately contributing to the maintenance of the unique, fragile semi-arid system and its related ecological services.

To determine the soil biological properties, five soil monolith (25 x 25 x 30 cm) samples per land use were taken and kept under aseptic conditions. The objective of the study was to assess the influence of Land use change on the biological activities as components of soil quality indicators in the agro-pastoral semi-arid zone of Karamoja, Uganda. The sample were analysed for bacterial, fungi and actinomycets cells (cfu), Mycorrhiza, and nematodes availability, and abundance and carbondioxide emission plus soil biological attributes using standard methods. The results revealed low population of abscural mycorrhiza fungi (AMF) in farmland. Overall, the respiration and actinomycets were highest in Rengen grassland. Grassland had the highest number of nematodes spece. However, Rengen farmland recorded the highest plant pathogenic nematode *Aphelenchoides spp.* The high respiration rate was attributed to the presence of AMF indicating less degraded soil, while low respiration could be due to the reduction in soil organic

matter as substrate for microbes. Therefore, microbial properties can be used to determine soil quality.

*Key words: soil attributes, agro-pastoral, Abscural mycorrhiza fungi, Colony forming units, Minimum dataset, principal components, and soil quality indicators*

## 4.1 Introduction

Different Land use change are responsible for the disturbance of the world environment leading to different catastrophes, like global warming, erroneous rainfall leading to loss of organisms' species diversity (Sanaullah et al., 2016). In order to meet the increasing population of the world, encroaching of agriculturally related activities into the ecological systems has been ranked highest (Lambin and Meyfroidt, 2011). This has resulted into soil quality deterioration through loss of biological, physical and chemical attributes. The loss of soil quality (SQ) is mainly a result of clearing natural vegetation, ploughing or tillage and replacing it with inappropriate agricultural practices. Hence, several researchers have reported declining fertility in cultivated land vis-à-vis ecological systems. Mainly this is indicated by sub-optimum crops yields (Nakalembe et al., 2017). Attempts to ameliorate the declining crops yields have been advocated for in soil fertility amendments packages but with limited but received limited application. Whereas the soil physical chemical and biological attributes are intertwined in nature, soil managers mainly employ the soil physical and chemical attributes and just draw inferences to the soil micro biological activities as indicators of soil quality. Majorly, the challenge is to identify the most limiting indicators of soil quality. Sustainability of Karamoja soils productivity lies in intensification of farming activities. Unfortunately, as farming activities intensify, the measurable attributes of the soil are neglected and compromised.

The role played by soil microorganisms in SQ maintenance are extensively documented, but seldom utilised as SQ indicators (Sowerby et al., 2005). Microorganisms affect nutrient recycling in the soil, by converting biomass and mineralize several compounds. They are also part of the soil organic matter. Therefore, they affect the soil chemical and physical properties. They regulated soil water properties like erodabilty, infiltration, water holding capacity. In in addition to soil microorganisms are important attributes which are essential in SQ determination. The population of those organisms which are well adopted to the soil environment will proliferates. Hence, SQ can be assessed by microbial activities. As such, enumeration of soil microorganisms is key in understanding the soil quality status. The objective of the current study was to assess the influence of Land use change on the measurable propeties as soil quality indicators in the agro-pastoral semi-arid zone of Karamoja, Uganda.

There are inappropriate Land use change and intensification of agriculture throughout the sub-Saharan Africa (Geissen et al., 2009b). Land use change are the actual long-term conversion of the land cover into varying activities implemented by man for his benefits (Noble et al., 2000). The permanent or semi-permanent changes from ecologically balanced ecosystems to other land uses like cultivation and grazing can significantly affect the soil chemical, physical and biological properties. Hence, altering the soil quality properties and their contribution to the environment and agriculture sustainability. Soils are of high quality when they can sustain environment quality, high crop productivity, human and animal health. According to Karlen et al. (1997), soil quality is the ability of a definite kind of soil to function within ecological or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. According to Mantel and Engelen, 1994; Scherr and Yadar, 1996; Lemenih, 2004 and Aghasi et al., 2011, the capacity of a soil to remain agronomically sound and produce good crops (SQ) may decline with inappropriate Land use change.

The Land use change are attributable to farmers attempt to increase production by increasing cropping area to cater for the rising population and increased food demand (Eswaran et al. 2001). Concomitantly, soil chemical, biological and physical properties are degraded.

Karamoja sub-region of Uganda is predominantly made up of three livelihood zones namely, the pastoral, agro-pastoral and the agriculture livelihood zone (USAID, 2017). Firstly, the pastoral zone lies mainly in Nakapiripirit, Amudat. Moroto, south East Kabong and South East of Abim districts. In the pastoral zone, the main livelihood activities include livestock herding, periodic cultivation of crops, hunting and gathering of wild edible plants. The second zone was the agro-pastoral, which stride from middle Nakapiripirit through Napak, Kotodo and Kabong districts. The main activities are cattle grazing in a transhumance manner, small scale farming and gathering of wild food. The third is the agricultural zone, which run on the western strip of the entire Karamoja on the western, side of Amudat, Nakapiripirit, Nabilatik, Napak, Abim, Kotido, Kabong and Karenga districts (USAID, 2017).

The agro-pastoral livelihood zone is cited as a dynamic and high-income generating strip in Karamoja (Levin, 2010). This is mainly due to the government advocacy for sedentary agriculture in Karamoja sub-zone. The inhabitants of this zone were mainly involved in both small sale cultivation, transhumance livestock keeping, gathering of wild food and income generating products (Burns et al., 2013). Land under natural vegetation cover was converted into grazing and farming crop cultivation. The main common Land use change and land cover of Karamoja in general and in particular, the agro-pastoral zone were forestry (woodland), grazing land or grassland and farmland or cultivation. Hence, these were selected as the essence of the study.

### 4.1.1 Woodland

There are rapid changes of wood and natural grasslands to farmland or cultivation in the agro-pastoral Karamoja (Filipová and Johanisova, 2017). Agricultural activities and deforestation have negative impacts on soil organism like earthworm (Brirang et al., 2003). Karamoja woodland had been changing into grazing and farmland or cultivation (Rugadya and Kamusiime, 2013; Egelu et al., 2016). According to Nampindo et al. (2005), the woodland in the entire Karamoja sub region, is reducing at an average of 19.7% per year annum. Elsewhere, woodland which is known to be ecologically balanced in the semi-arid environment is reducing at an alarming rate, yet little scientific data is collected on its ecological composition for future reference (Fries, 1991).

### 4.1.2 Farmland or cultivated land

Homann-Kee Tui, (2016), reviewed some of the benefits of farmland or cultivation in the dry lands including, enhanced food security, income source, better integration of livestock and crops. The latter, lead to high agriculture productivity, which is known to be key for sustainable smallholders farming and high agricultural production (Burns et al., 2013). Conversely, human activities like farming is perceived for many negative soil quality changes (YBQI, et al., 2011). In the Karamoja, Uganda, the main viewpoint included, but not limited to, farming impacting negatively by enhancing temperature rise, decrease in rainfall and the frequency of the extreme events recur (Nakalembe et al., 2017). The role of farming, include clearing of natural vegetation, planting crops and limiting animal movement over the cultivated land. The threat to soils quality degradation, results into the need to use a high number of external inputs in order to sustain crops yields (Scherr and Yadar, 1996). Opening of land for cultivation had been known for a long time by scientist to expose the bare soil to rainfall impact on top soil leading to soil aggregates destruction and the eventual increase in runoff, thus, soil loss through erosion. During the dry season, soil is lost through wind erosion. Cultivation accelerate the rate of SOM decomposition through increased aeration. Cultivation also led to nutrients loss through harvesting and enhance leaching, hence leading to SQ deterioration. According to Mishra et al., 2017 cultivation, influence significant alterations to the soil physical, chemical and biological properties. In turn, this can affect SQ either positively or negatively. The negative impacts of land use can further result into emission of green house gases to the atmosphere, thus, contributing to global warming, escalating climatic changes and reduce soil productivity. Land use change alteration are viscous circles, which not only alter the soil cover and SQ, but also the ecosystem biodiversity and the consequential land users' decisions (Qin et al., 2017). Considering the above, the inhabitants who are highly dependent on the fertile soils for their livelihood are progressively reduced by SQ decline (Beyene, 2011).

Various research findings have indicated that farming or cultivation without appropriate soil conservation practices lead to SQ decline (Hudson, 1987; Unger et al., 1991; Gicheru et al., 2004; Aghasi et al., 2011; Lahmar et al., 2012; Tittonell et al., 2012). This is because dry land soils like that of Karamoja are prone to degradation and less resilient to changes. As such, Land use change can lead to soil quality (SQ) deterioration, hence, eventual crops yield decline.

### 4.1.3 Grazing land

Soil quality decline due to grazing impact in Karamoja, is viewed as one of the main causes of crops yield decline (NEMA, 2007). Conversely, grazing and dry season grass burning for pasture rejuvenation are over criticized as causers of soil degradation (Papanastasis, et al., 2002).

The effect of overgrazing in the land use conversion include limited vegetative regrowth, due, excessive trampling of plants and soil compaction (Nature, 2005). This in turn, lead to bare soil patches, observable in various parts of the agro-pastoral zone, hence soil is exposed to soil eroding agents. Scientists view soil quality measurements in different land uses as a reliable approach to determine its potential to sustain a highly productive soil (Karlen, et al., 1997). However, Karamoja sub-region of Uganda has receved limited research work related to soil and its other functions. Soil degradation mainly stems from practicing improper management practices. Management options, which are appropriate in a particular place, may not be suitable to another. As such there is need to identify appropriate soil management options for each location. Most research use only crop yield, to determine soil quality, whereas it is the soil quality and other environmental factors, which determine crop yields. Hence, crops yields are sub-components of living organisms a necessary factor in soil formation. When the soil quality studies are limited to a particular crop/s without due consideration of the total functions of soil, then it becomes biased only that crop, hence the demand for redefining SQ to much the purpose. Soil quality should be handled in a brood manner to encompass most of the functions, which are clearly stated in Karlen et al. (1997) definition. For a soil to function well there must be a unique balance of the processes (Doran and Parkin, 1994). Hence, any soil management strategy should target the physical, chemical and biological factors equilibriums.

#### 4.1.4 Soil degradation

Soil degradation have caused great concern to scientist, policy makers, farmers and other stakeholders globally. The main reason being the escalating human population and consequential demand for agricultural goods and services from a deteriorating soil quality (FAO, 2005; Gelfand et al., 2013), which seems to follow Malthusian theory of population growth alluded by (Harley, 2019). The soil quality decline is reportedly high in sub-Saharan Africa in general and in particular, Uganda where more than 75% of the population depends on subsistence farming. The main cause being the removal of soil nutrients through continuous cropping without external input (Tully et al., 2015). Hence, the major cause of soil quality deterioration is tillage and other farming practices.

Land use alterations with improper soil management can enhance soil degradation. There are several studies which have indicated soil quality loss through lack of soil erosion control structure, nutrients removal by continuous agriculture with no nutrient recycling, bush clearing and deforestation (Tenywa et al., 1999: Tilhun, 2015). Soil disturbance through tillage may improve or destroy the soil top layer Jabro et al. (2010), which may pulverize the top soil, enhance OM decomposition, and leaching of nutrient to soil lower layers.

Nonetheless, assessing soil quality quantitatively can offer essential evidence required to ameliorate soil degradation in the study area. However, in the past the levels and rates of SQ degradation in the study area received little or no research attention. There was no deliberate effort to establish the indicators of SQ in the Agro-pastoral Karamoja, Uganda. This made it difficult to design appropriate interventions to minimize the SQ deterioration. Knowing the soil quality of the area, would enable farmers, scientists, policy makers and other stakeholder to make reliable soil management decisions. As such, there is great need for the farmers of Karamoja to adapt and adopt sustainable SQ maintenance practices. It was therefore imperative, that research in different land uses is done to fill the knowledge gaps of SQ indicators, hence the study design and objective.

This study aimed at determining the effect of selected Land use change on soil chemical, biological and physical properties of the agro-pastoral Karamoja, Uganda. The hypothesis was that, different land uses have diverse effect on soil chemical, physical and biological properties. Identifying and monitoring changes in SQ is a critic step in designing sustainable land management packages for countering land degradation.

In Karamoja sub-region of Uganda the soils are prone to degradation particularly by erosion once exposed to the soil erosion agents. Contrary, Kamajong have been shifting from over dependence on livestock to cultivation which is promoted by the Government. Nonetheless, crop yields are low compared with the on station. The main causes are linked to farmer's lack of adequate knowledge concerning cultivation, poor weather condition, and light texture soil with low inherent fertility and less soil management skills. On the other hand, farmers have been overgrazing the range land by over stocking surpassing the optimum carling capacity. Worse still the population of the zone is increasing. The sedentary farming was advocated for before the status of soil quality was determined Nakalembe et al., 2017). The status or trend of soil degradation in the agro-pastoral Karamoja was unknown. Therefore, carry out a study related to soil quality attributes is imperative. Hence, the objective of the study was to assess effect of selected land uses in agro-pastoral Karamoja, Uganda on soil physical, chemical and biological attributes.

## 4.2 Materials and Method

### 4.2.1 Study location

For the location and description of the study site, study approach are as ascribed in Chapter Three-Materials and Methods.

#### 4.2.2 Sample collection for soil physical and chemical properties

Soil samples were taken in a zig-zag manner along three parallel grids with an inter-row spacing of 75 meters, within each land use under study. Each grid was laid along vegetation mosaic which best predict each Land use change under study (Grass, wood and the farmland/cultivated lands). In addition, the vegetation mosaic within the Land use change were put into consideration during sampling, taking care to sample from each naturally and botanically unique vegetation along the grids (vegetation mosaic). Soil samples, were taken from both 0-15 cm and 15-30 cm from each land use (grassland, woodland and farm/cultivation land) using a 5 cm diameter soil auger. Composited sample were made for each sampling site by homogenizing 4 auger samples, removing roots, mixing the samples and quarter sampling in a basin. Care was taken no to mix samples from different layers. A total of five top and five sub-soil composited soil samples, for both physical and chemical properties were collected from each land use. Finally, thirty (30 samples were taken from each of the three study areas (Iriri, Matany and Rengen sub-counties). The samples were bagged in clean polythen bags, labelled, packed in boxes and transported to the National Agricultural Research Laboratories (NARL) Kawanda for analysis.

Two soil profile pits were dug between parallel grids at 50 m a part within each land use. From the top and bottom soil layers (0-15 and 15-30 cm) within each pit two core samples were taken for bulky density, using a core sampler. The 30 cm layer was considered because it is the main root domain for most crops grown in the area. The samples were sealed, labelled, packed in polythen bags and transported to Kawanda NARLs, where soil bulky density was determined.

#### 4.2.3 Soil laboratory analysis for physical and chemical properties

The composite samples were air-dried, ground in a mortar and sieved through a 2 mm mesh. Soil samples were analysed for P, K, Ca and Mg content using the Mehlich 3 Double Acid method (Mehlich, 1984). The soil texture was determined using hydrometer method described by Black et al., 1995. Total N was determined by Kjeldahl digestion methods by Black et al., 1965, Anderson and Ingram, 1993. The soil pH was measured in 1:2.5 soil: water suspension. Soil Organic Matter (SOM) was determined using modified Walkley–Black oxidation method (Walkley–Black, 1934).

Soil bulk density was determined by oven-drying the core samples to constant weight at 105° C and bulk density calculated as described by Klute, 1996. Soil water properties were calculated using a textural triangle as described by Saxton et al., 1986. Soil stable aggregate were determined using wet sieving methods (Van bavel, 1950). The formulae used was stable aggregates SA = dispersed material retained - NaOH 0.2/ the sum of the weights obtained in the dispersing solution cans + distilled water cans (Eijkelkamp, 2018). Particle size analysis was determined using the Bouyoucous hydrometer method (Dane and Topp, 2002).

### 4.2.4 Sample collection and analysis for soil biological properties

Soil biological samples were taken from woodland, grazingland and farmland of Iriiri, Matany and Rengen study Sub-Counties. To determine the soil biological properties, five soil monolith (25 x 25 x 30 cm) samples per land use were taken by driving a monolith into the soil using a sledgehammer. The soil bulk samples were extracted in layers of 10 cm and each placed on a separate clean, dry and sterile polythen sheet. From the centre of each layer a biological soil samples of about 500g was taken and put into dry sterile polythen sleeves, labelled, then kept into a cool box. From one land use to another the polythene sheets which was used in the previous land use change were sterilized by cleaning and spraying the bag/container with 75% alcohol and then dried under sunshine. All soil biological samples, which were collected from all study sites, were transported in cool boxes to Microbial Resource Centre MIRCEN laboratory, University of Nairobi. Samples were kept under a fridge at 4° C for 2 weeks and later analysed for soil microbial activities, fungi, actinomycetes and bacteria colony forming units (cfu) or population. Sub-samples were taken to Muguga Kenya Forestry Research Institute biological laboratory where nematodes and arbuscular mycorrhiza fungi (AMF) were isolated.

#### 4.2.4.1 Determination of the number of bacterial, fungi and actinomycets cells (cfu) per gram of soil

There are several methods which are used in determining microorganisms that are available in a sample of soil. Among them are the spectrophotometer which is used to measure the optical density of the mirobial population, the directly counting of microorganisms by using a haemocytometer, or the serial dilution of the organisms and plating them on a media that supports their growth. In the current study, a serial dilution plate technique as described by Somesegaran et al., 2012 was used. It was deemed as the most perfect for enumerating microbes in a soil sample as it identifies the living organism population. Biological soil samples were analysed for cfu, population densities, diversity and respiration/microbial activity.

#### 4.2.4.2 Mycorrhiza isolation

In order to isolate mycorrhiza spore, fifty grams (50 g) from the soil samples were weighed in Kenya Forestry Research Institute laboratory. Then, the samples were pre-soaked to soften the soil clods for the fungi dispersion. The soil was then mixed with water and stirred thoroughly. The mixture was decanted through a 710mµand later 45mµ sieve. The residue from each sieve was examined. All the sediments from the 45mµ sieve were washed in three 50ml centrifuge tubes. Equal weights of the tube were obtained by weighing. The tubes centrifuged for 5 minutes at 1750rpm. Later, the water was decanted from the tube and the floating residues removed. A sucrose solution of 48% was obtained by mixing 227 g of sucrose in 50mls of water (assumption the density of the spore equals that of the solution). The mixture was weighed in centrifuge tubes equal each other, then thoroughly mixed and centrifuged for 15 seconds at 1750rpm (Schenck and Perez (1990).

After centrifuging the sucrose solution was, decant through a 45mµ sieve. The retained spore on the sieve were rinsed thoroughly with water to remove sugar. The spores from the 50 mµ were transferred to small petri dishes and examined under a dissecting microscope at X 20 magnification. Further, the spores were transferred to the electronic microscope mounted with a camera for photographing. Later the spores were characterized for spore development, colour, aggregate contents, subtending hyphae.

#### 4.2.4.3 Nematodes isolation

From the biological soil samples which were taken from the study sites using a monolith' 100g were weighed and Nematodes extracted according to methods by EPPO, 2013 also known as modified Baermann Funnel Technique or Bucket Sieving Technique.

The weighed samples were, placed on Hanan or soviet paper tissue, which was supported by the sieve and placed on a plate. Water was introduced on a plate and care taken not to over flood the soil samples. Then the units with sample were left undisturbed for 24 hrs. After 24 hrs the total volume of water was measured and 25 mls were pipetted from the volume collected and then transferred to the counting dishes. Pipetting and counting were done twice. The observed nematodes were photographed using an electronic microscope. Further, the nematodes were identified by observation up to genera level.

The organism numbers were calculated using formulae below: -

Extrapolated no. of organism /100g soil = No of organism counted in pipette A+ No. of organism counted in pipette B * total volume of water collected from the plate (C) (20ml)/25ml.

A= 25 meals of 1st pipette water

B= 25 ml of 2nd pipette water

#### 4.2.4.4. Statistical data analysis for soil chemical and physical properties

Statistical analysis of data on the soil chemical and physical properties was done using Analysis of Variance (ANOVA). ANOVA was applied to determine significant differences between the study sites. For each soil sample, depth analysis was done separately to see whether the different land uses have significant differences on the soil attributes. Mean separation was done by Tukey HSD using GENSTAT 19-edition computer package. Column graphs were used to compare the mean difference between the different land uses in the different sites for all the physical and chemical factors.

#### 4.2.4.5 Statistical data analysis for biological properties

In order to determine significant differences between the lands uses studied, data on the biological properties of soil were statistically analysed using 2-way ANOVA. For each soil sample, depth analysis was done separately to see whether the different land uses have significant differences on the soil biological attributes. Mean separation was done by Least Significance Difference (LSD) using Gen stat 19 computer package.

## 4.3 Results

### 4.3.1 Soil pH and soil organic matter

Soil pH values were not significantly different ($p>0.05$) across land uses in Iriiri and Matany sub-counties. Overall, pH values in Matany were significantly higher ($p < 0.05$) than in other sub-counties across all land uses. In Rengen, pH values were significantly lower ($p = 0.05$) in grassland sub-soil than in other land uses. There was no significantly different pH in both farmland and woodland top and sub-soil (Figure 7).

Overall SOM values were significantly ($p < 0.05$) lower in Iriiri farmland top soil than in its other land uses (Figure 8). Sub-soil OM values were not significantly ($p > 0.05$) different in Iriiri sub-soil across all land uses. Iriiri had significantly high OM in farm land and glass land sub than in top soil. Both Woodland layers indicated balanced levels of high OM. Contrary, Matany had higher (4.5 % and 5.2%) levels of SOM in both layers but with top having more than the sub-soil across all land uses. Woodland in Matany had more OM 5.2% in top soil than in all land use in the entire study area. In Matany, farmland had significantly lower OM than the grassland and woodland in both top and sub-soil (Figure 8). In Rengen, farmland had the significantly lowest OM values in both top and sub-soils, than its grassland and woodland. Farmland and woodland had more OM in the sub than in top soil. To the contrary, grassland top soil had significantly ($p < 0.05$) higher OM values than the sub-soil. In woodland top soil hand significantly lower ($p<.05$) OM values than its sub-soil (Figure 8).

Generally, Iriiri and Matany sub-counties had significantly ($p < 0.05$) higher OM than Rengen across all land uses. On the other hand, farmland in Iriiri had more OM in top than the sub-soil. On average farmland OM values were lower than other land uses across the study area. Rengen Sub-county in grassland top soil but in farmland and wood land top soil.

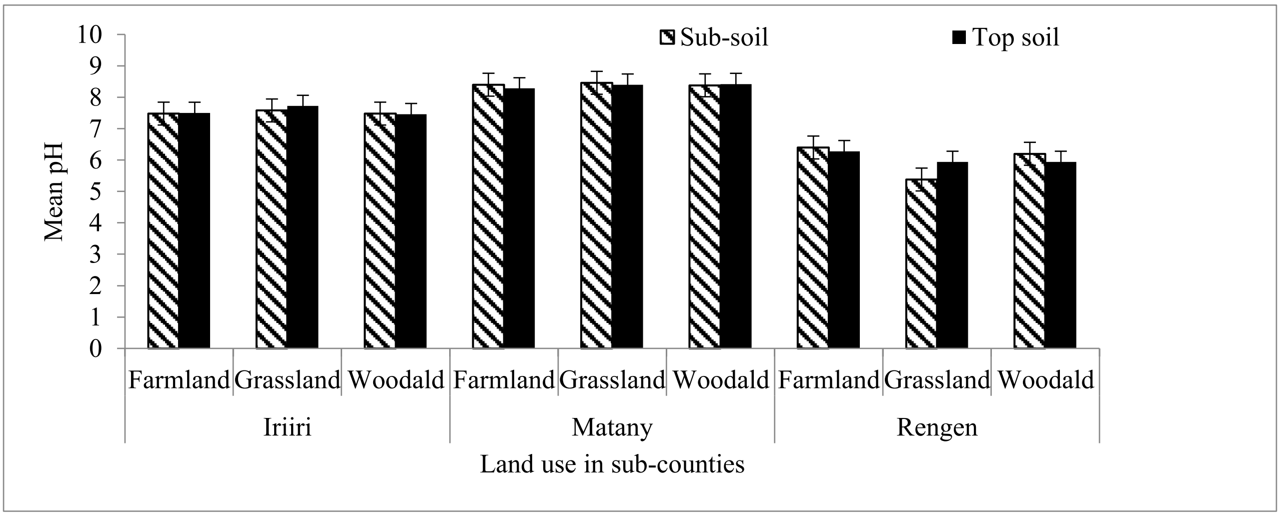


Figure 7: Shows Mean pH of iriiri, Matany and Rengen Sub-Counties

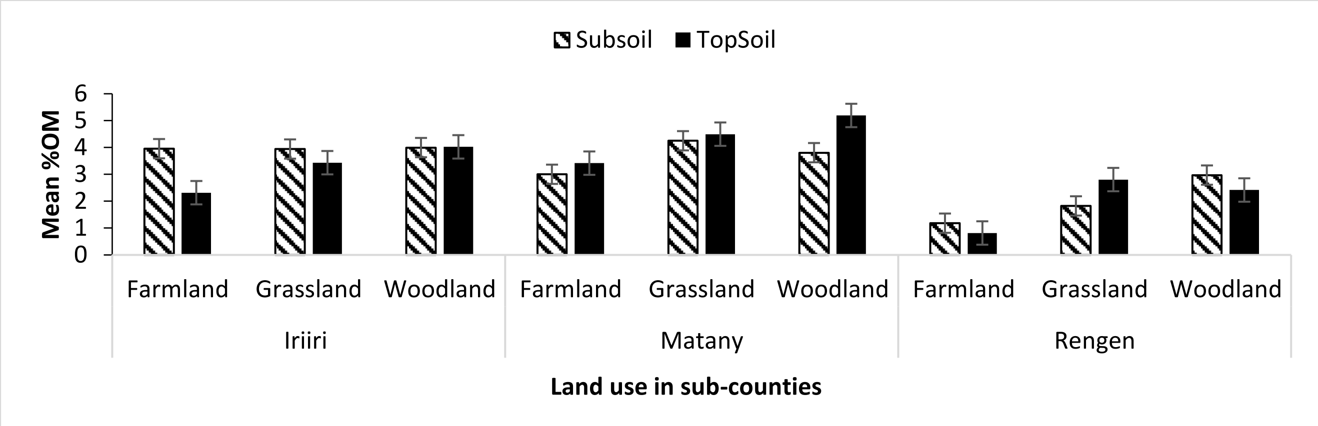


Figure 8: Shows Mean % OM of Iriiri, Matany and Rengen Sub-Counties land uses

### 4.3.2 Soil phosphorus and Nitrogen

Soil N was significantly ($p<0.05$) lower in both Matany and Iriiri than in Rengen across all land uses (Figure 9). There were not significant differences in N values grassland uses in both Iriiri and Matany sub-counties. The grassland and woodland values were not significantly different in Rengen. However, farmland top soil had significantly higher N than other land uses in Rengen. The levels of N in Rengen sub-soil were not significantly different.

Iriiri Sub-County farmland sub-soil, had significantly ($p < 0.05$) high P values in sub-soil than top soil in both farmland and woodland. To the contrary, grassland top soil had significantly higher P than the sub-soil. To the contrary, grassland had significantly ($p < 0.05$) more P in top than sub-soil. However, Matany significantly lower P in both top and sub-soil of farmland as compared with grassland and woodland. Grasland had significantly lower P in sub-soil than its top soil. A smiral trend was recoded in woodland.

Likewise, Rengen, farmland had significantly lower P in both top and sub-soil than both its grassland and woodland. Woodland in Rengen had the significantly ($p < 0.05$) highest P in top soil than sub-soil across its three Land use change. Matany and Rengen had significantly higher P in top than in the sub-soil (Figure 10). Overall Iriiri had significantly higher P in the sub soil than Matany and Rengen across all landuses in the entire study area (Figure 10)

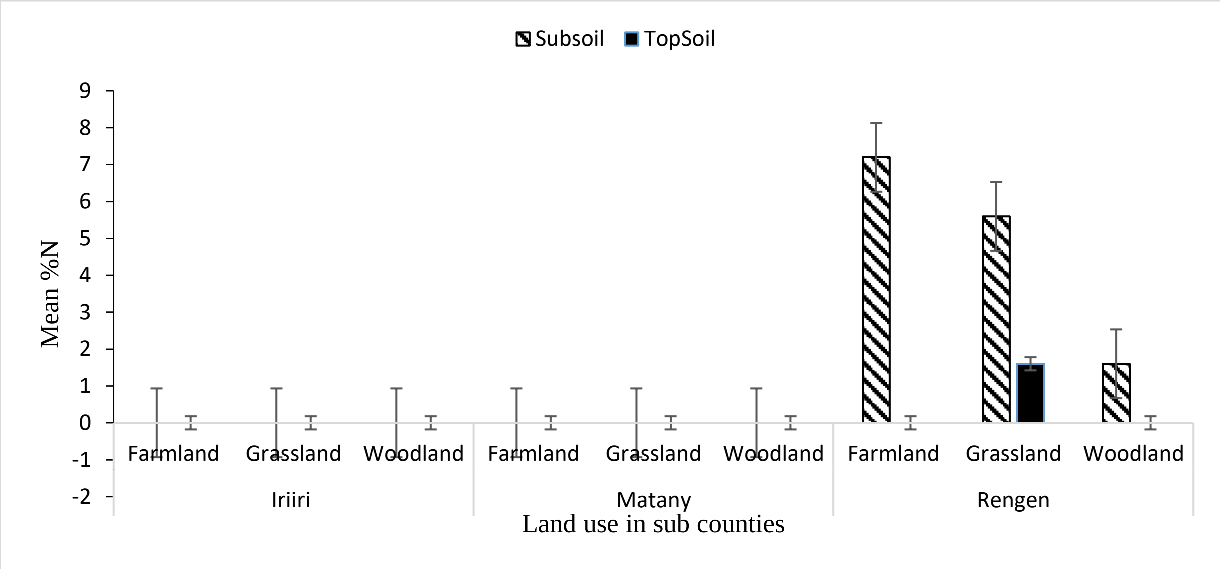


Figure 9: Shows the Mean % N of Iriiri, Matany and Rengen Sub-Counties land uses

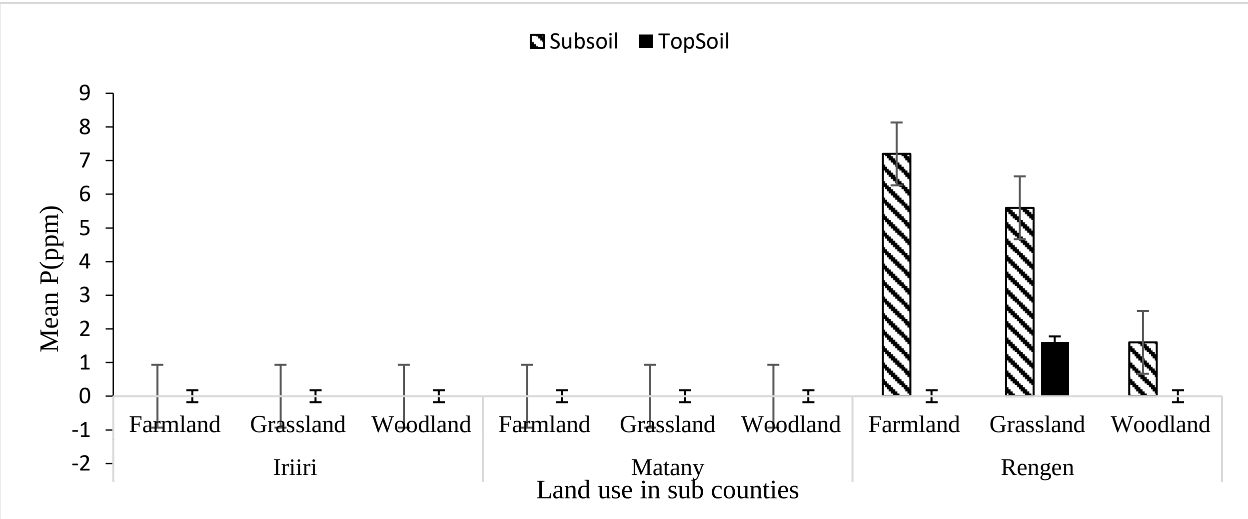


Figure 10: shows the Mean P values of Iriiri, Matany and Rengen Sub-Counties land uses

### 4.3.3 Soil calcium and magnesium

Farmland in Iriiri and Matany sub-counties had significantly lower values of calcium ($P < 0.05$) in both top and sub-soil than in its other land uses (Figure 11 ). Grassland and woodland had significantly higher Ca in the sub than topsoil. Significantly higher Ca in both top and sub-soil was recoder as compared with both the woodland and farmland of Iriiri. Matany had the significantly highest exchangeble calcium in grassland than all other land uses. The sub soil of Matany in all study land uses had the significantly higher Ca than its top soil. To the contraly, grassland had the lowest values of calcium as compared to other land uses in Rengen Sub-County. Farmland had significantly higher calcium in sub-soil than other land uses in Rengen. Woodland calcium values were higher in top than sub-soil. Rengen had the lowest calcium values in grassland. Generally, Matany had significantly high levels of calcium ($p < 0.05$) followed by Iriiri and Rengen Sub-County with the lowest (Figure 11).

Magnesium was significantly lower in farmland and woodland in Iriiri Sub-County than in grassland (Figure 12). Magnesium level were significantly higher in sub-soil that the top soil of Iriiri. Matany had significantly high Mg in all land uses and soil depth than other land uses in other study Sub-County. The significantly highest level of Mg for Rengen was recorded in its farmland sub-soil. Grassland had the lowest values of Mg compared with both its farmland and woodland. Rengen had the significantly lowest level of Mg across all land uses and study sub-counties (Figure 12).

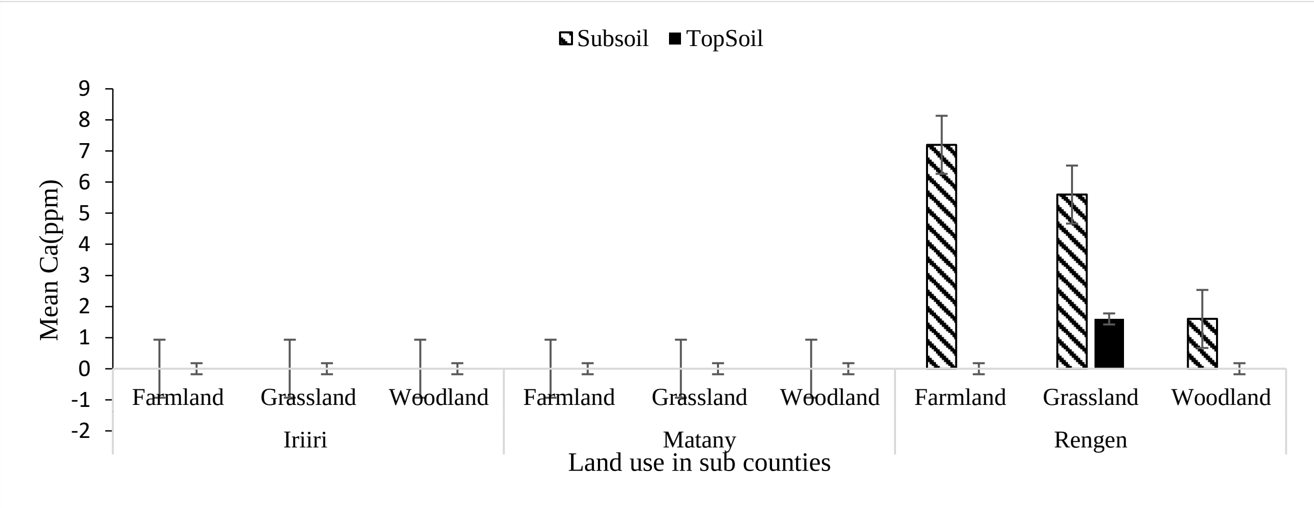


Figure 11 : Mean Calcium values of Iriiri, Matany and Rengen Sub-Countie land uses

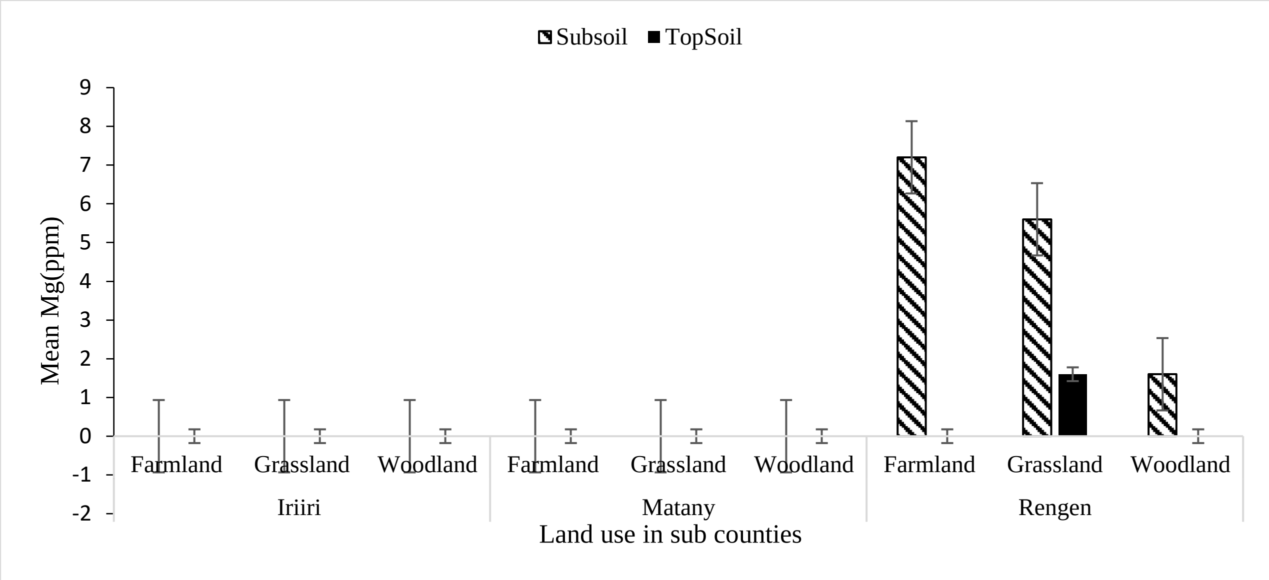


Figure 12: Mean Mg values of Iriiri, Matany and Rengen Sub-Countiesland uses

### 4.3.4 Mean Soil potassium (K ppm) of Iriiri, Matany and Rengen Sub-Counties land uses

In Iriiri sub-county, had significantly higher levels of K in the sub-soil than the top soil. While in the grassland and woodland the recorded significantly higher K values were in topsoil. Oveall, Iriiri woodland top soil had the highest levels of K. For Matany sub-soil had the lowests levels of K as compare to the topsoil across all land uses. While Rengen farmland had the significantly lowest levels of K in the farmland top soil, grassland and woodland had higher levels in the top soil.

In contrast, Iriiri and Rengen farmland had significantly higher $K^+$ in sub-soil than topsoil. The values of $K^+$ in Matany were significantly lower ($p < 0.05$) than those of Iriiri and Rengen. Farmland in Rengen and Iriiri had higher values of K in sub than its topsoil. Mostly, the Potassium values revealed significantly ($p <0.05$) high potassium levels in the top than the sub-soil, in both grassland and woodland throughout the entire study area (Figure 13). Overall, woodland had significantly ($p< 0.05$) higher $K^+$ than other land uses in the study area.

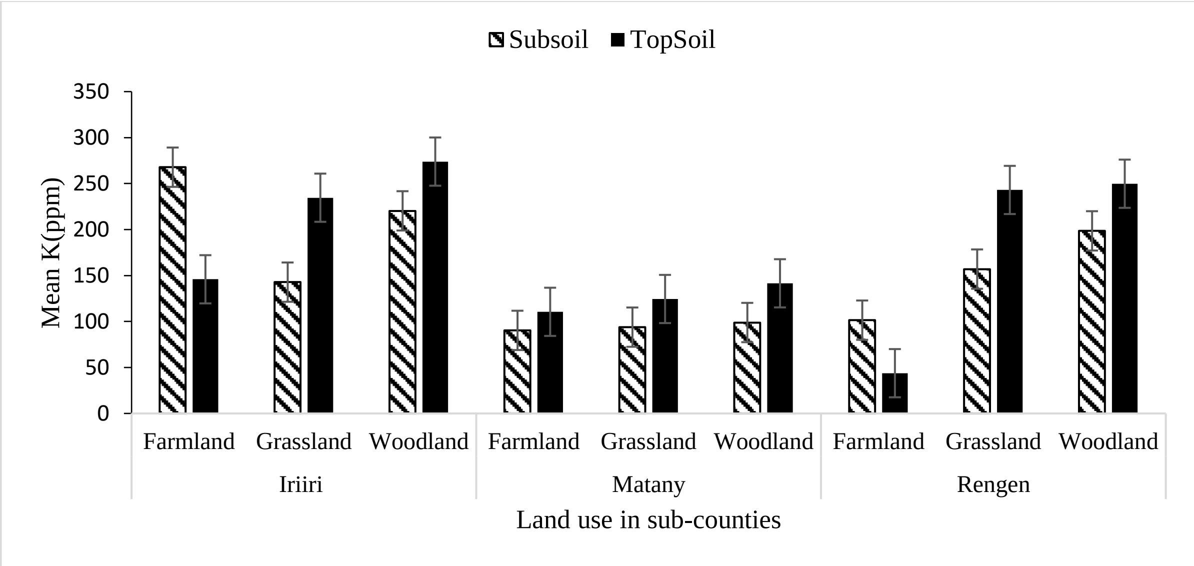


Figure 13: Shows the Mean K of Iriiri, Matany and Rengen Sub-Counties land uses

### 4.3.5 Sand and clay contents in different land uses

Farmland in Iriiri had the significantly lowest clay in both the top soil and sub-soil than its grassland and woodland. While grassland and woodland Clay content was not significantly different in both layers (Figure 14). For Matany there were no much difference across all land uses and soil depth. Rengen sub-count had no much differencein farmland layers while grassland and woodland had significantly higher clay percentage in the sub-soil than in the top soil. There were no significantly different clay percentage between grassland and woodland sub-soil. Simiraly, woodland and grassland topsoil cla content was not significantly different. Overall, Rengen had significantly lower clay percentage in both layers than Iriiri and Matany across all land uses.

Rengen soils contained a significantly high ratio of sand to clay ($p < 0.05$) than Iriiri and Matany. The ratio of clay to sand in Matany was not significantly different across all land uses. However, Iriiri had slightly higher sand in farmland than in other land uses. To the contrary, Iriiri and Matany soil had more clay percentage than Rengen (Figures 15). Percentage sand values where significantly higher ($p<0.05$) in Rengen than in Iriiri and Matany. However, for clay both Iriiri and Matany had a significantly higher amount of clay than in Rengen where soils were mainly sandy loam. Generally, the soils of Iriiri and Matany are clay while that of Rengen are sandy loam (Figure 14 and 15).

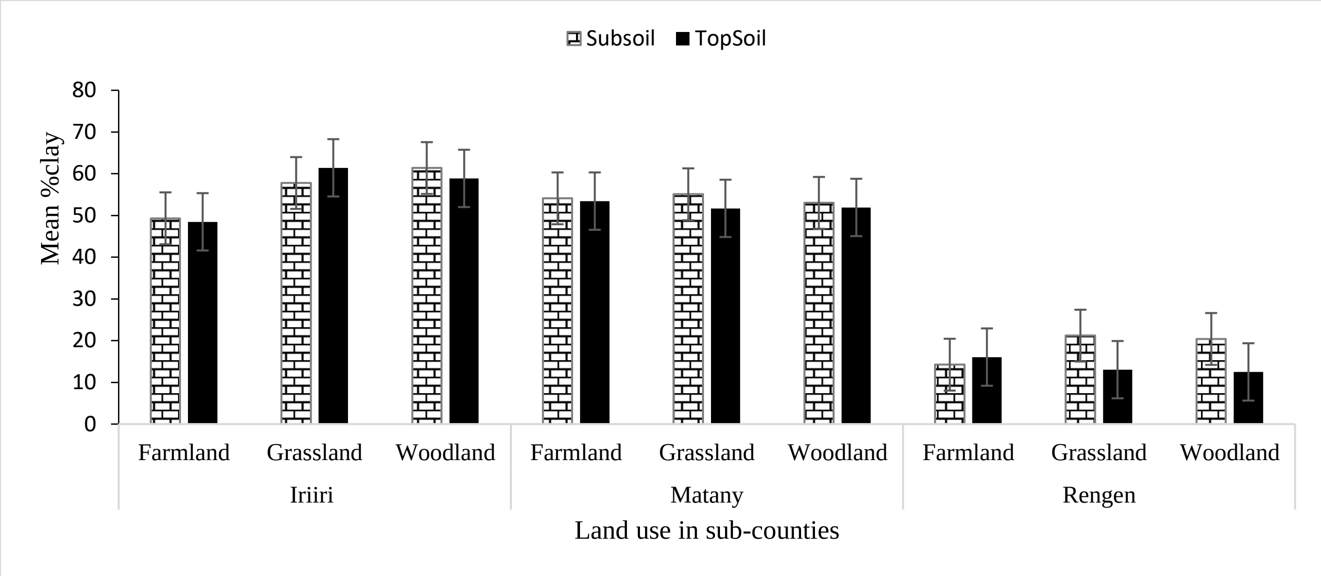


Figure 14: Mean % clay composition of Iriiri, Matany and Rengen Sub-Counties land uses

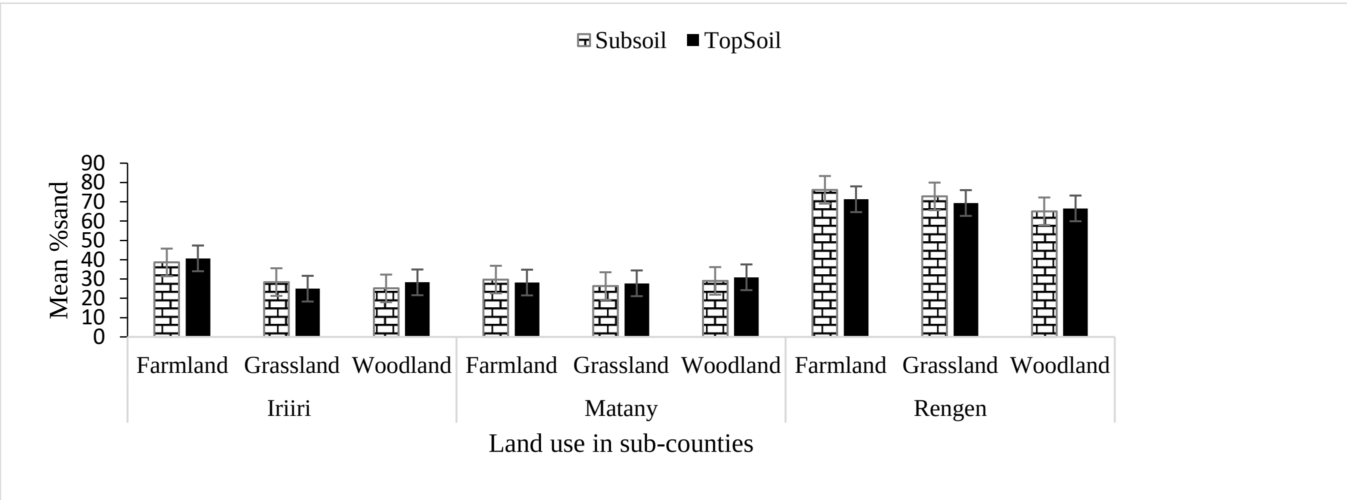


Figure 15: Mean % sand composition of Iriiri, Matany and Rengen Sub-Counties land uses

### 4.3.6 Field capacity and Saturation point

In Iriiri farmland field capacity was significantly lower than in grassland and woodland. Farmland sub-soil had slightly higher field capacity than its top soil. To the contraly, grassland sub-soil FC was slightly lower than its top soil, while woodland sub-soil had higher FC in its top soil. In Matany, there were no significant differences between either sub-soils or topsoil under different land uses (Figure 16. Farmland FC was the same in both soil layers while grassland and woodland had slightly higher FC than the top soil. In Rengen Sub-County, farmland indicated low field capacity in the sub-soil than in topsoil. While grassland and woodland sub-soil had higher FC than the top soil. Overall farmland in Rengen had lowest field capacity across the entire study area.

Rengen had a significantly ($p<0.05$) lower field capacity than both Iriiri and Matany across all land uses and soil layers (Figure 16). There were no significantly ($p>0.05$) different volumes of water required to saturate a volume of soil between land uses in both in Iriiri and Matany sub-counties (Figure: 16). However, Iriiri farmland had a lower filed capacity than other land uses in both top soil and sub-soil. Rengen soil had a significantly lower water saturation point vis-à-vis Iriiri and Matany. Nonetheless, there were no significantly different water saturation points between land uses in Rengen Sub-County. There were a significantly high field capacity and water saturation point in both Iriiri and Matany than in Rengen. There were no significantly different field capacity and water saturation point in land uses within sub-counties (Figure 17).

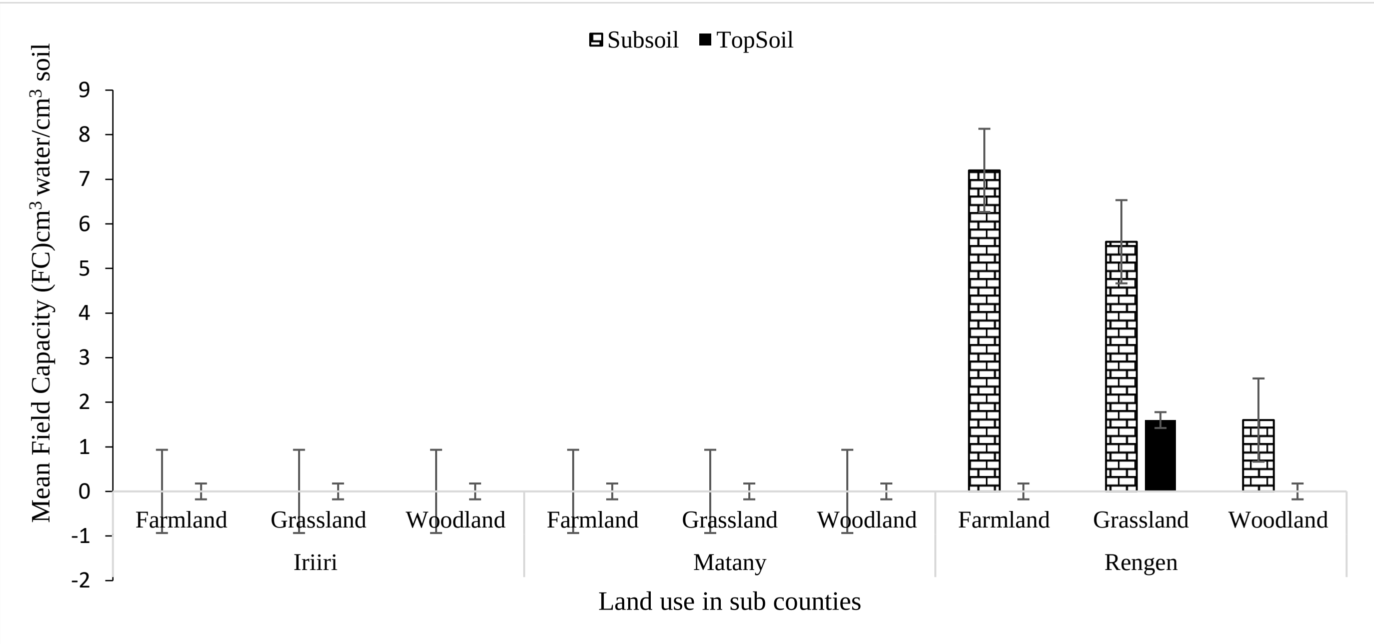


Figure 16: Field capacity of Iriiri, Matany and Rengen Sub-County land uses

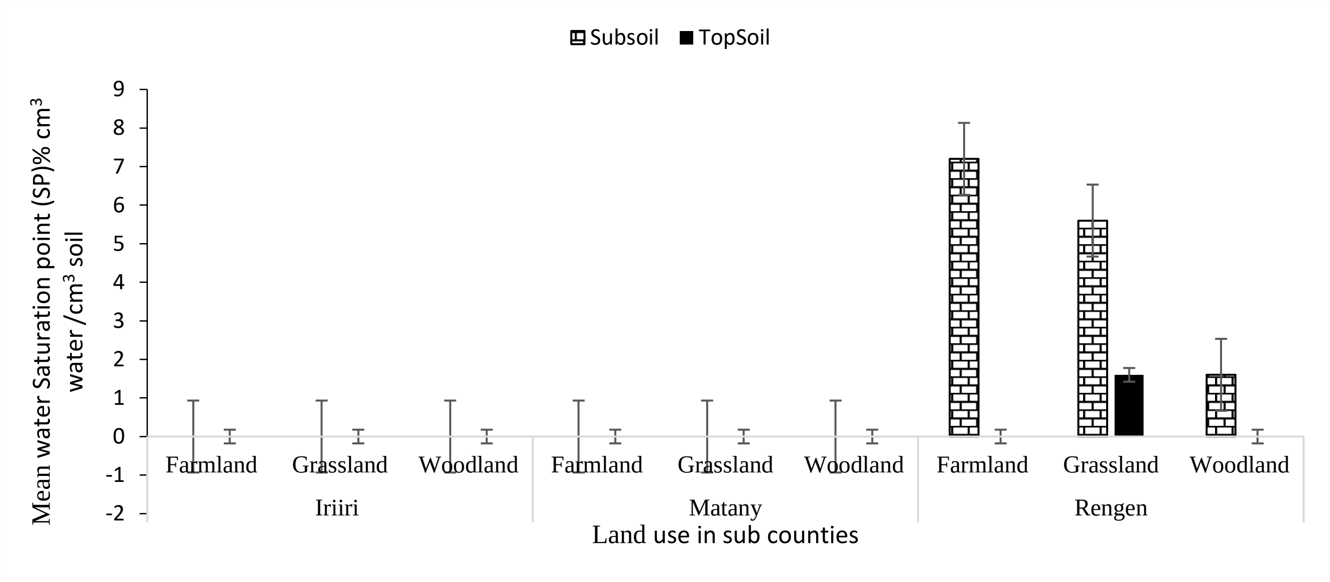


Figure 17: Soil water saturation points of Iriiri, Matany and rengen Sub-Counties land uses

### 4.3.7 Available water and permanent wilting point under different land uses

Farmland in Iriiri had significantly lower amount of soil water available for crop use than other land uses in both top and lower soil layers of Iriiri and Matany sub-counties. Overall, Rengen Sub-County had significantly lower volume of available water than Iriiri and Matany across all land uses and soil depth (Figure 18). Farmland in Iriiri had the lowest PWP than its grassland and woodland. Here were no significant differences between top and sub soil of farmland. Grassland PWP was slightly higher top soil than sub-soil. While woodland topsoil had lowrPWp than the sub-soil. Simirarly, Matany farmland recorded no significant difference between farmland soil layers. To the contraly, grassland top soil had no significant difference in PWP water levels between the two soil layers. Rengen woodland had the lowest PWP in sub-soil closely followed by its top soil. There was no significant difference between grassland soil layers PWP. Farmland in Iriiri had significantly lower wilting point ($p < 0.05$) as oppose to other land uses in Iriiri and Matany. Generally, Rengen had the lowest wilting point across all sites, soil depth than other study sub-counties. Woodland had the significantly lowest wilting point ($P<0.05$) in Rengen (Figure 19).

The permanent wilting point values were significantly higher ($p < 0.05$) in Iriiri and Matany than it was in Rengen. Similar results were recorded for field capacity, soil porosity and drainage rate. Available soil water was significantly different ($p<0.05$) in all study sites.

Overall, Rengen had significantly lower percentage of the available water vis-à-vis other study sub-counties (Figure 18).

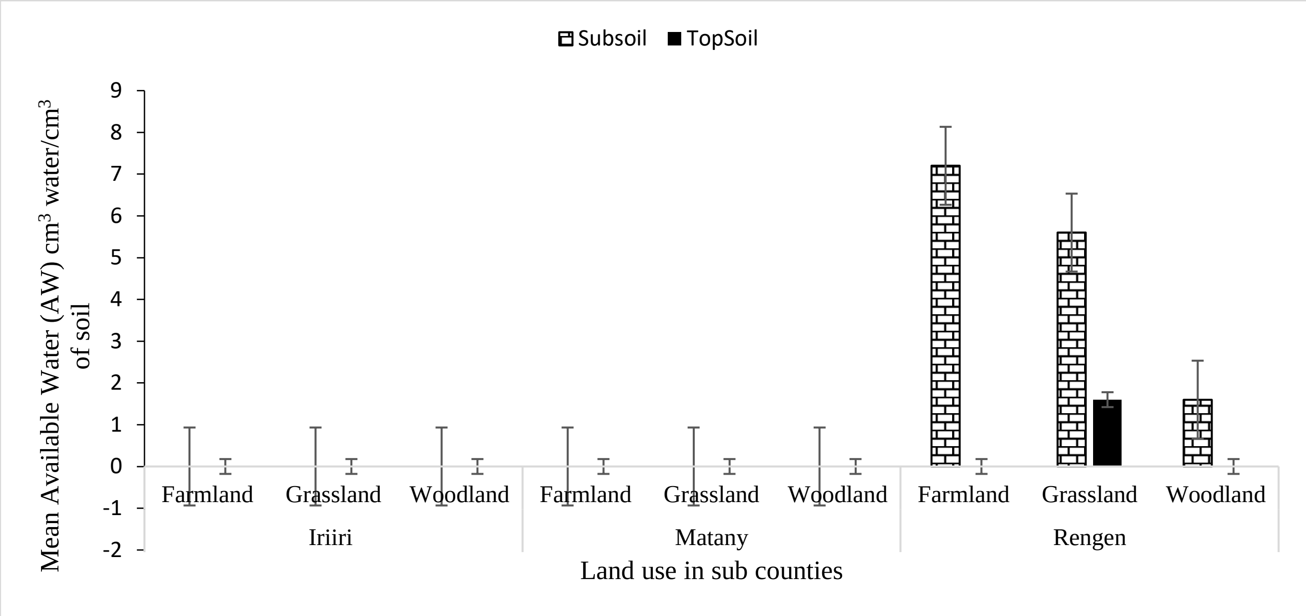


Figure 18: Available water in of Iriiri, Matany and Rengen Sub-Counties land uses

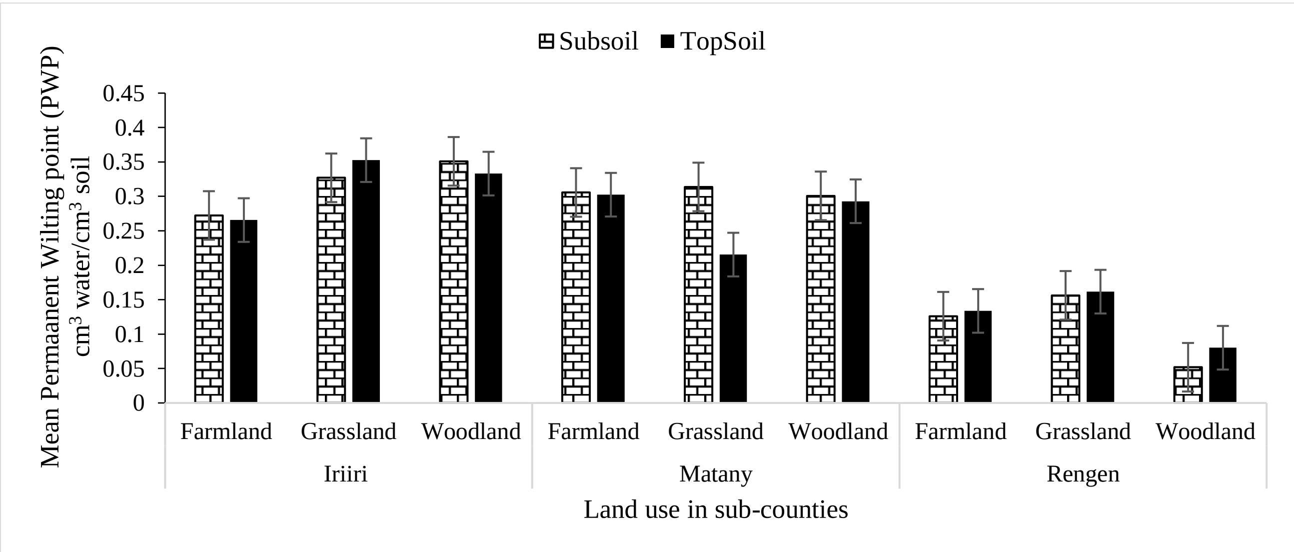


Figure 19: Permanent wilting point of Iriiri, Matany and Rengen Sub-Counties land uses

#### 4.3.8 Mean drainage rates and soil bulky density (BD under different Land use change in the study area

The water drainage rate (DR) in Rengen was significantly higher ($p < 0.05$) in both grassland and woodland than in the farmland top soil (Figure 20). The sub-soil DR was significantly lower in grassland and woodland than in the farmland. The top soil had a significantly lower drainage rate ($p < 0.05$) than the sub-soil in farmland use. There were no significantly different drainage rates ($p > 0.05$) across all land uses in Iriiri and Matany.

Soil bulky density was significantly highest in the grassland soil than in other land use. There were no significantly different in BD ($p = 0.05$) in both woodland and farmland across all study sites (Figure 21).

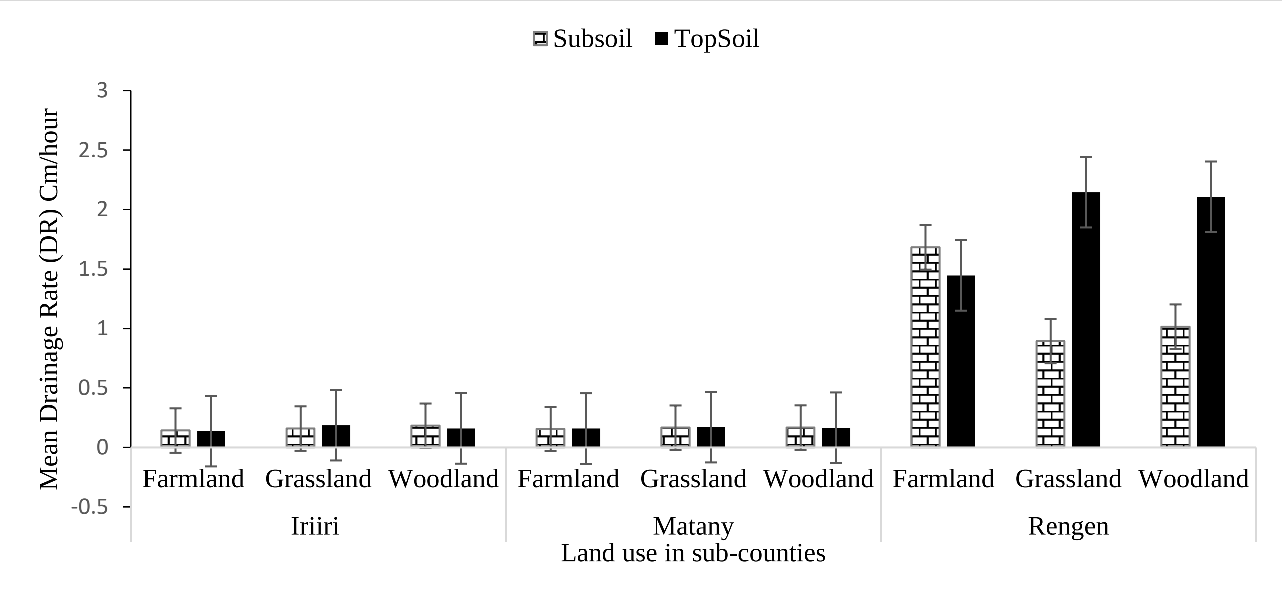


Figure 20***:*** Water drainage rates of Iriiri, Matany and Rengen Sub-Counties land uses

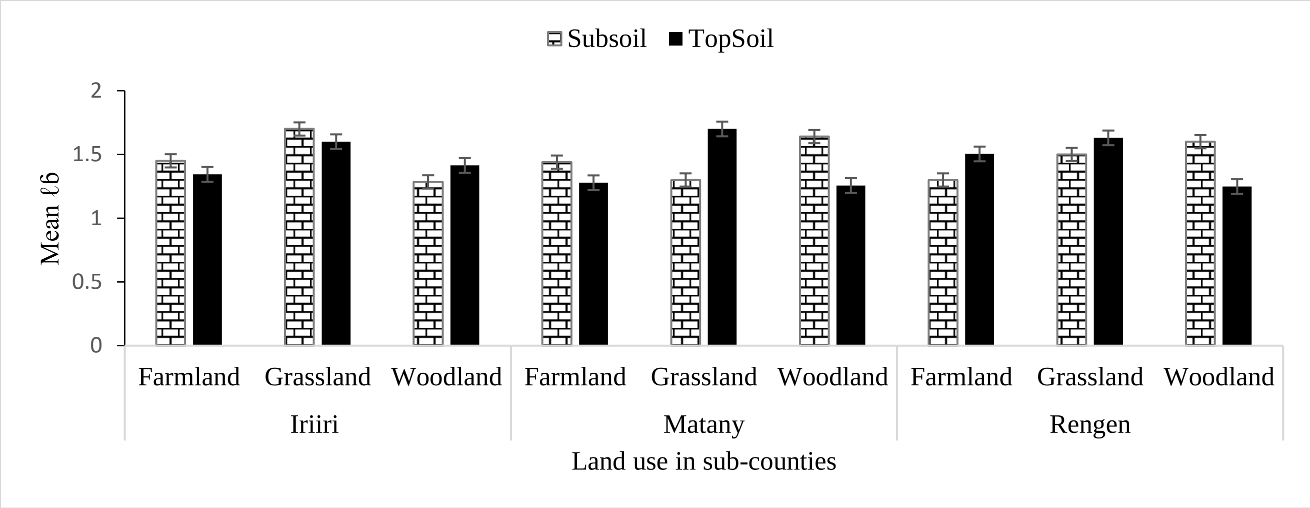


Figure 21 : Soil bulk Densities of Iriiri, Matany and Rengen Sub-Counties land uses

### 4.3.9 Water stable aggregates of Iriiri, Matany and Rengen Sub-Counties land uses

Grassland had significantly lower percentage of the stable aggregates ($p<0.05$) followed by farmland in both Rengen and Iriiri. Woodland had the highest stable aggregates across all land use in the study area (Figure 22).

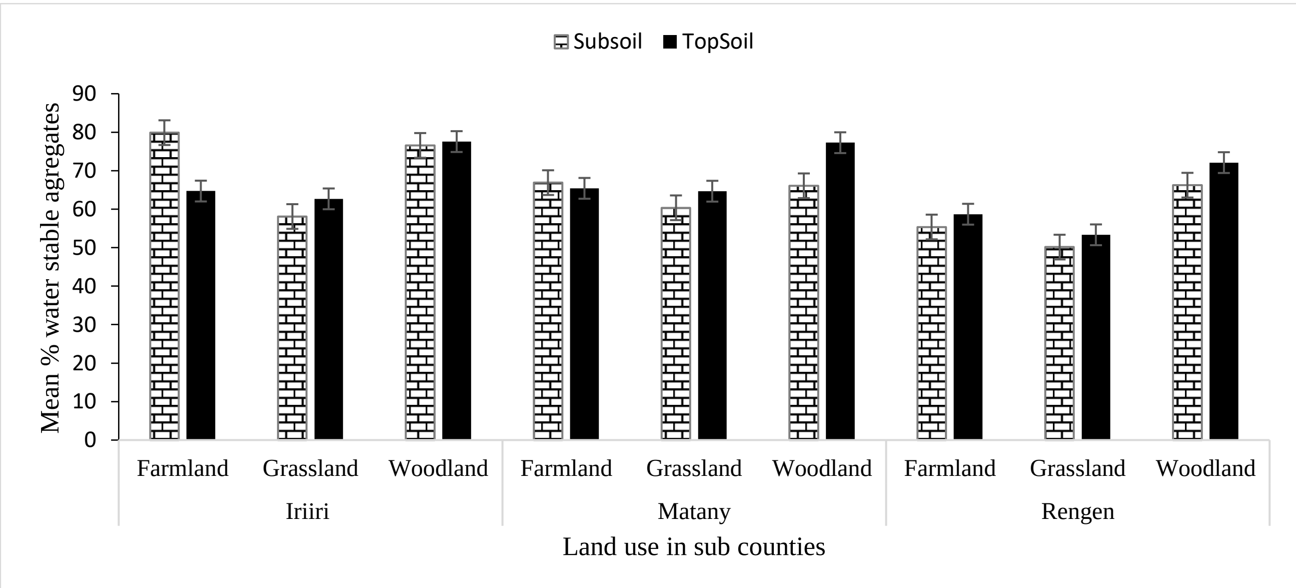


Figure 22: Water Stable aggregates of Iriiri, Matany and Rengen Sub-Counties Land uses

**4.3.10 Influence of Land use change on the number of fungi, bacteria and actinomycetes colony forming units (cfus) in Iriiri, Matany and Rengen Sub-Counties.**

Both the fungi and bacteria cfu were significantly lower ($p < 0.05$) in Rengen than in Iriiri and Matany (Table 9). The actinomycetes population were significantly higher in Rengenthan in other study ub-Counties. The fungi and bacteria cfuwere higher in Rengen than in Matany and Iriiri Table 9.

The soil respiration was significantly higher in Rengen than in other Sub-Counties.
The data for fungi colony forming units (cfu) is presented in Figure 23. Woodland had significantly highest ($p < 0.05$) number of the fungi cfu in both top and sub-soil than grassland and farmland in Rengen. The farmland number of fungi cfu were significantly lower ($p < 0.05$) in top soil than in sub-soil. Farmland had a significantly lower ($p < 0.05$) fungi cfu than grassland and woodland. There were no significantly different ($p > 0.05$) numbers of fungi cfu in all land uses in Iriiri and Matany.

The data for bacterial colony forming units is presented in the Figure 24. Woodland had significantly high bacteria colony forming units (cfu) than grassland in Rengen Sub-County. However, grassland had significantly high ($p < 0.05$) population bacteria cfu in top soil than the top soil of woodland in the Sub-County. There were no significantly different ($p > 0.05$) in the bacteria cfu numbers in grassland and woodland of both Matany and Iriiri. Nevertheless, farmland in Iriiri had significantly higher numbers of bacteria cfu than any other land use in the study area.
The results indicated declining trends for both bacterial and fungal cfus from woodland through the grassland and the farmland. The population of the fungi cfu were lower in Iriiri and Matany sub-counties. Rengen Sub-County had the significantly highest fungal population ($p < 0.05$) in woodland followed by grassland and lastly farmland (Figure 23).

Population of bacterial cfu was highest in farmland of Iriiri. There were no other significantly ($P > 0.05$) different bacteria population in other land uses both Iriiri and Matany (Figure 24). Whereas farmland had the lowest population of bacteria, grassland and woodland were not significantly different.

Table 9: Microorganisms population and their activities as soil quality indicators in different sub-counties.

| Microbial population and activities | Sub county | | | Test statistic |
|---|---|---|---|---|
| | Rengen | Iriiri | Matany | |
| cfu_Fungi | 32587 b | 5417 a | 4118 a | Lsd=4756.0 |
| cfu_Bacteria | 3225333 a | 5563000 b | 4562667 b | Lsd=948349 |
| cfu_Actinomycetes | 630800 a | 512700 a | 503367 a | Lsd=198019.9 |
| CO2 mg $g^{-1}$ of soil | 0.326 b | 0.2052 a | 0.236 a | Lsd=0.0748 |

Means followed by same superscript letter are not significantly ($p \leq 0.05$) different within rows cross study sites

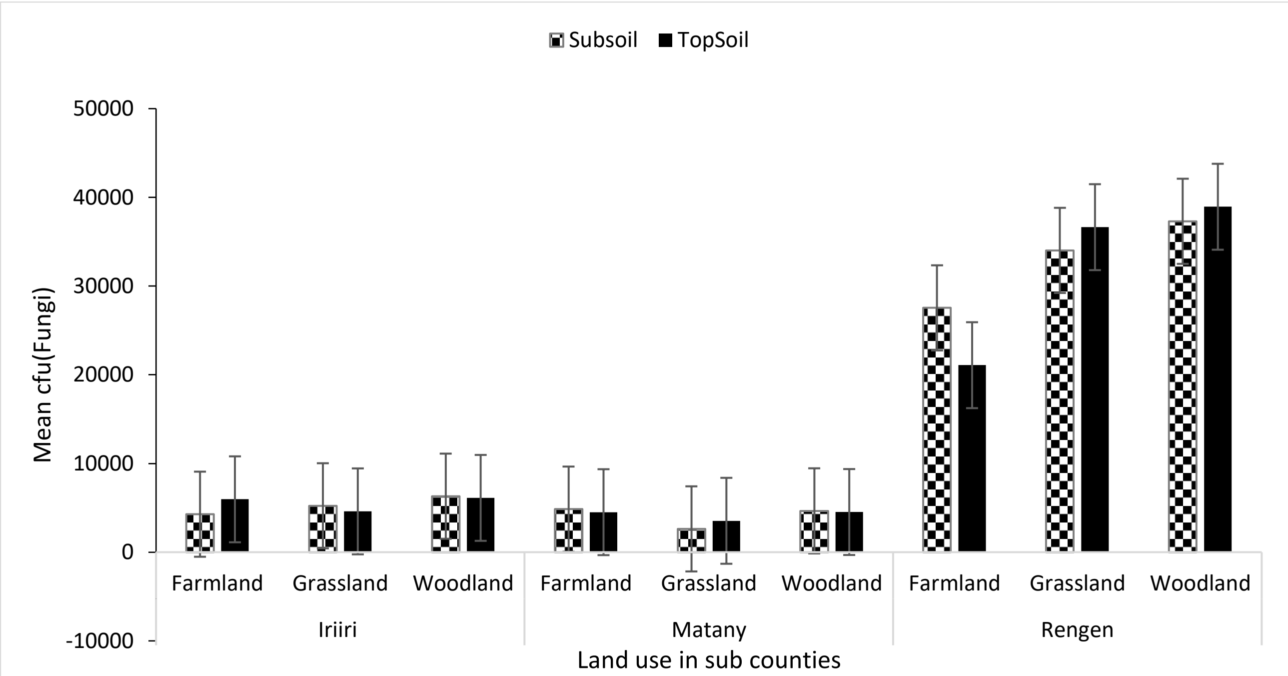


Figure 23: Mean fungi cfu in Iriiri, Matany and Rengensoils under different land uses

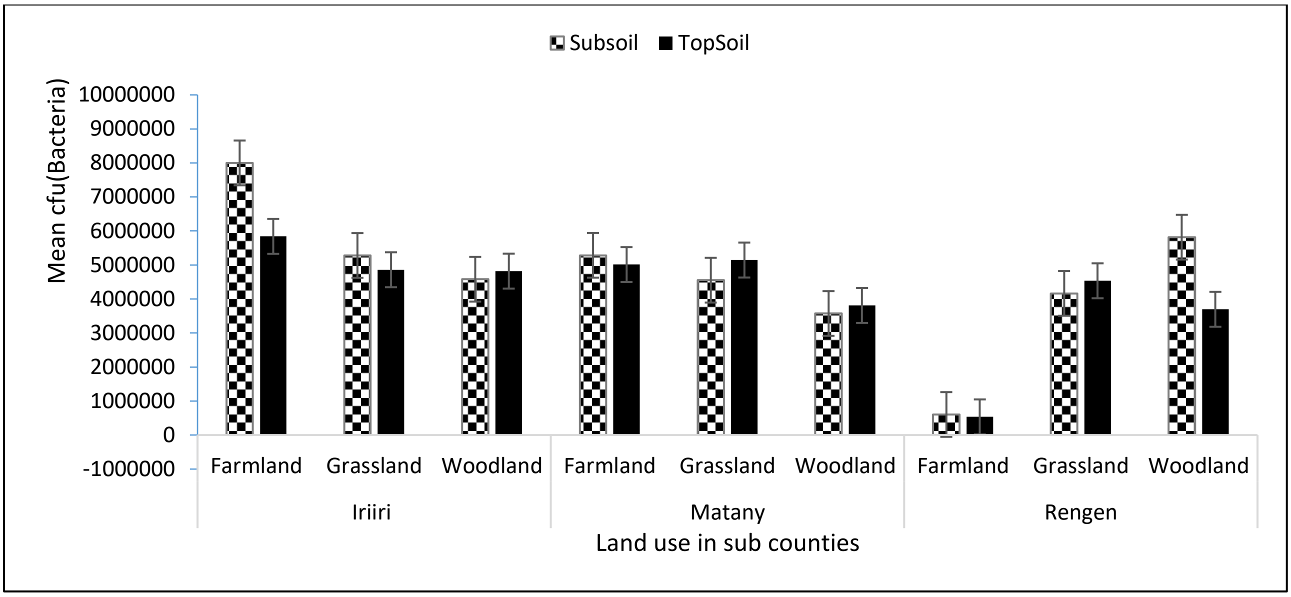


Figure 24: Mean bacteria cfu in Iriiri, Matany and Rengen Sub-Counties soils under different land uses

### 4.3.11 Actinomycetes colony forming units

There were no significantly different in the actinomycets population across almost all the study area land uses. However, Rengen grassland subsoil had the significantly higher population of actinomycetes than other land uses (Figure 25).

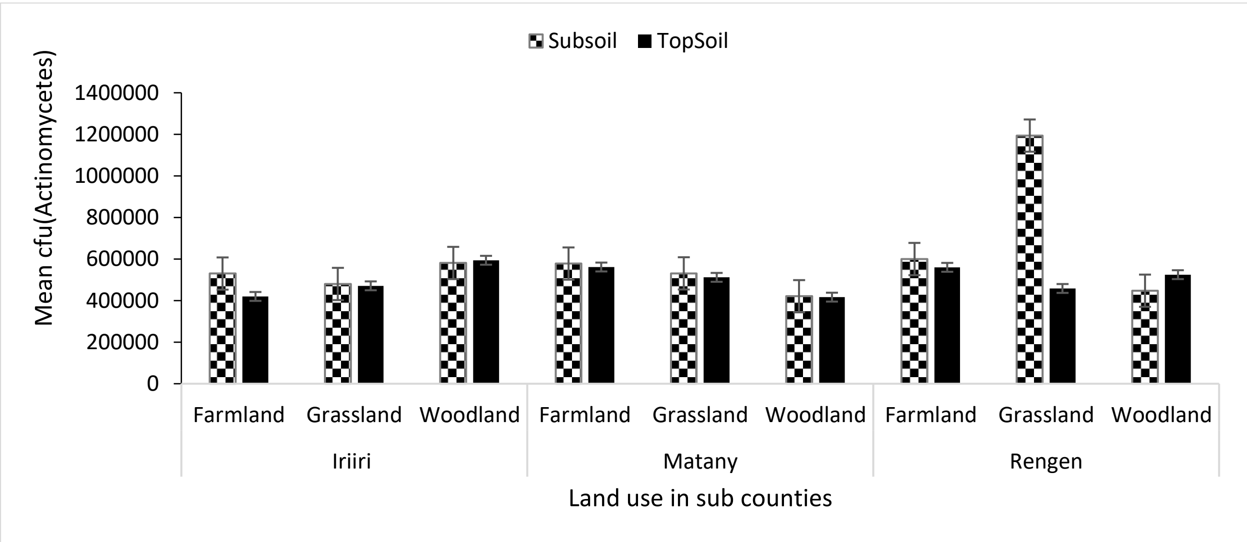


Figure 25: Actinomycets cfuin Iriirii, Matany, and Rengen Sub-Countis soils under diferent land uses

### 4.3.12 Soil respiration

Grassland of Rengen Sub-County had the significantly ($p < 0.05$) highest respiration followed by woodland and farmland (Figure 26). In iriiri farm land sub-soil revealed significantly high respiration rate than top soil. Likewise, respiration trends were recorded in Iriiri grassland and woodland layers. In Iriiri, woodland had the lowest respiration grassland and farmland having no significant differences. In Matany, woodland had the highest respiration rate followed by farmland. Wood land top soil had significantly higher respiration rate than sub-soil. To the contraly, farmland sub-soil had significantly higher respiration rate than the sub-soil.

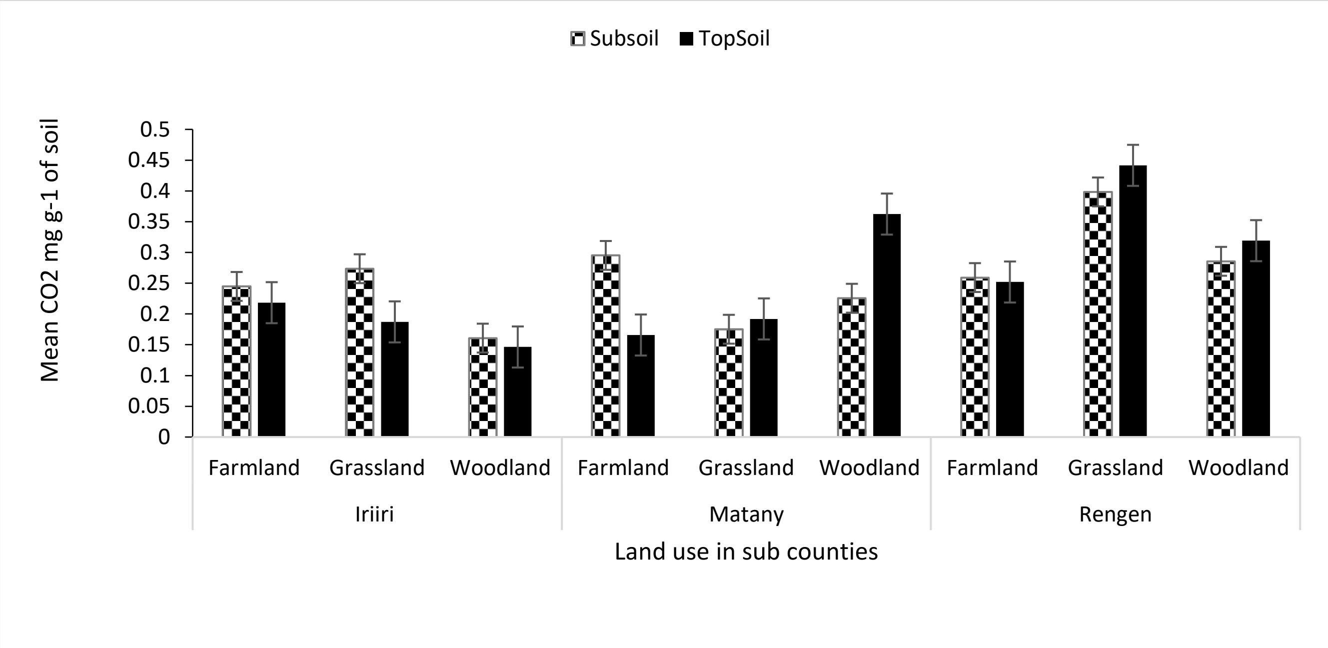


Figure 26: Soil respiration in different land uses of Iriiri, Matany and Rengen Sub-Counties

### 4.3.13 Influence of Land use change on AMF as soil quality indicators in the different Land use changen (Plates 1-4)

The Glomus mycorrhiza species are presented in the plate A. The Glomus mycorrhiza species (*spp*) populations were significantly highest ($p<0.05$) in woodland top and subsoil as compared to other land uses thought the study sub-counties (Figure 27). Significantly higher population of the mycorrhiza was higher in top soil as opposed to the sub soil in all land uses and sub counties. Similarly, grassland top soil in Rengen Sub-County had significantly high population of Glomus spp. Farmland had significantly lower population of the mycorrhiza than other land uses in Rengen. There were not significantly different population of the mycorrhiza in both Iriiri and Matany (Figure 27).

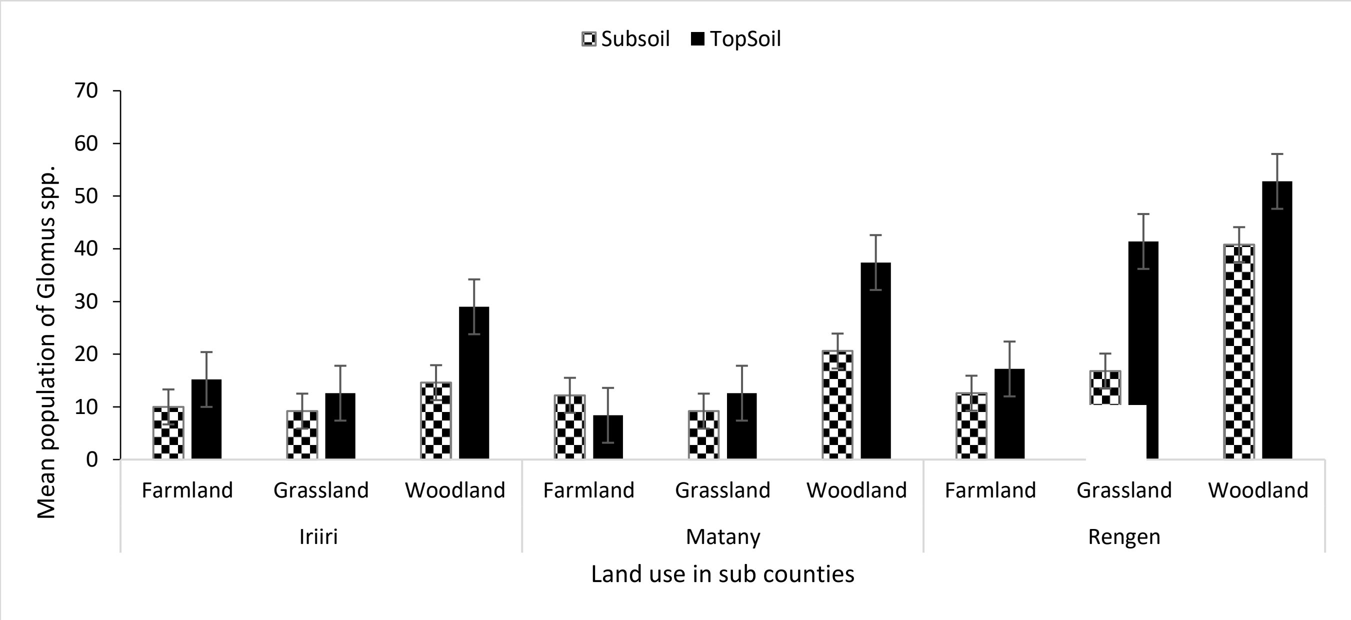


Figure 27: Influence of Land use change on the population of AMF sppin Iriiri, Matany and Rengen Sub-Counties

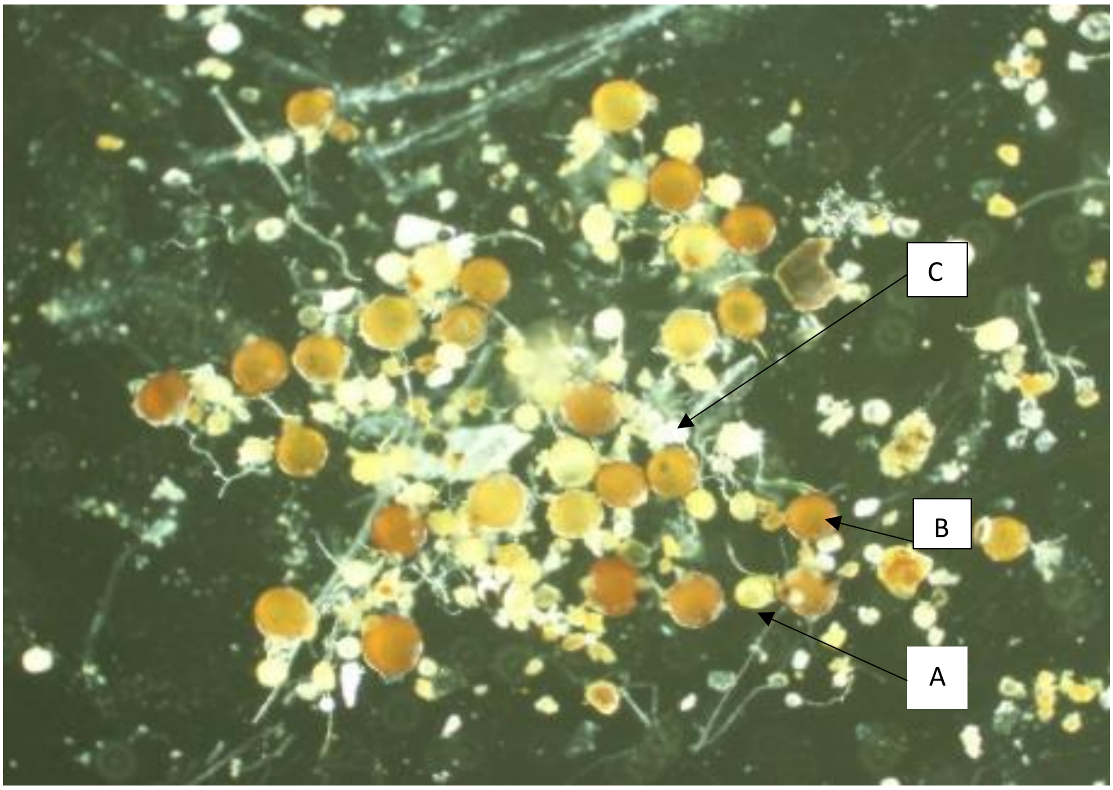


Plate 1:  Different spece of Glomus AMF found in the the study area

A = Glomus mosseae, B = Glomus intraradices and C = Scrutellospora verrucosa

**4.3.14 Population response of AMF Scutellospora spp to different Land use change in Iriiri, Matany and Rengen sub-counties.**

Woodland data for *Scutellospora specie* indicated a significantly higher population (p <0.05) in Rengen and Matany in both top and sub-soil of all land uses (Figure 28). Mainly, top soil had significantly higher population of the myccoriza fungi than the sub soil throughout the study area. Iriiri had a significantly higher population of Glomus species in grassland top soil than in its farmland and woodland. On the other hand, farmland populations were significantly lower in Rengen farmland than other land uses. Overall, the populations of the myccoriza *spp* were significantly low in both Iriiri and Matany's other Land use change than in Rengen and Matany woodland. Woodland had significantly higher population of Glomus spp than other land uses in the study area.

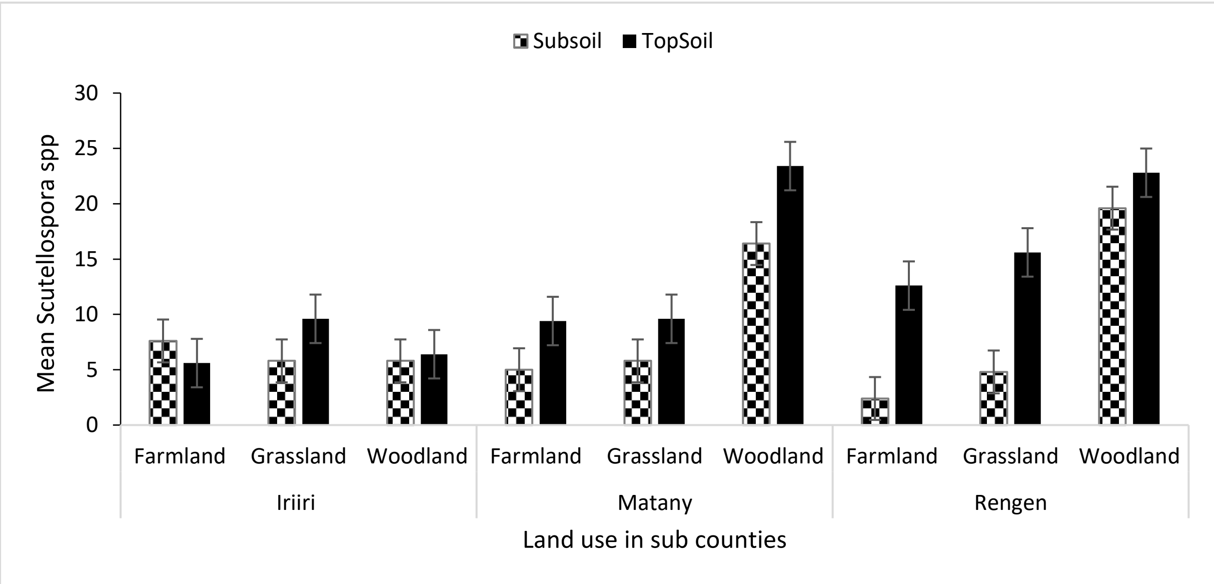


Figure 28: Effect of Land use change on the population of AMF Scutellospora spp in Iriiri, Matany and Rengen Sub-Counties

Plate 2 : Spece of Scutellospora spp AMF found in the the study area

#### 4.3.15 Population response of AMF *Acaulospora specie* to different Land use change in Iriiri, Matany and Rengen sub-counties

The *Acaulospora specie* population were significantly high ($p < 0.05$) in grassland followed by woodland and lastly farmland in Rengen Sub-County (Figure 29). Woodland in both Iriiri and Matany sub-counties had higher population of the *Acaulospora spp*. Overall Iriiri and Matany had significantly lower population than Rengen.

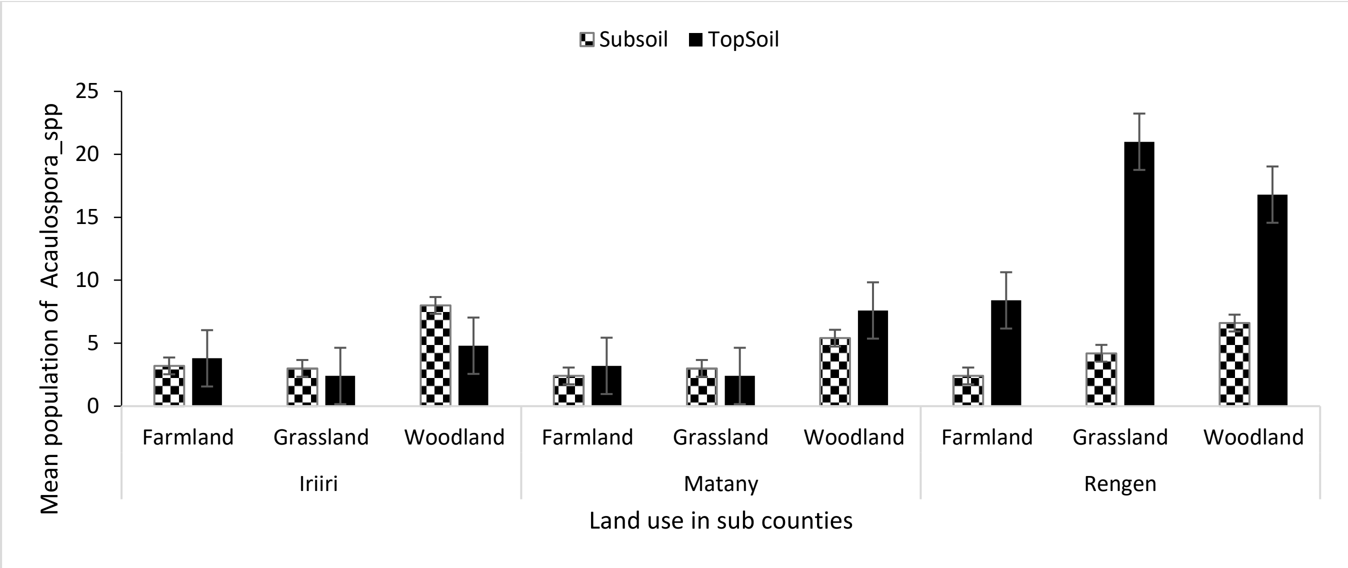


Figure 29: Effect of Land use change on the population of AMF Acaulospora spp in Iriiri, Matany and Rengen sub-counties.

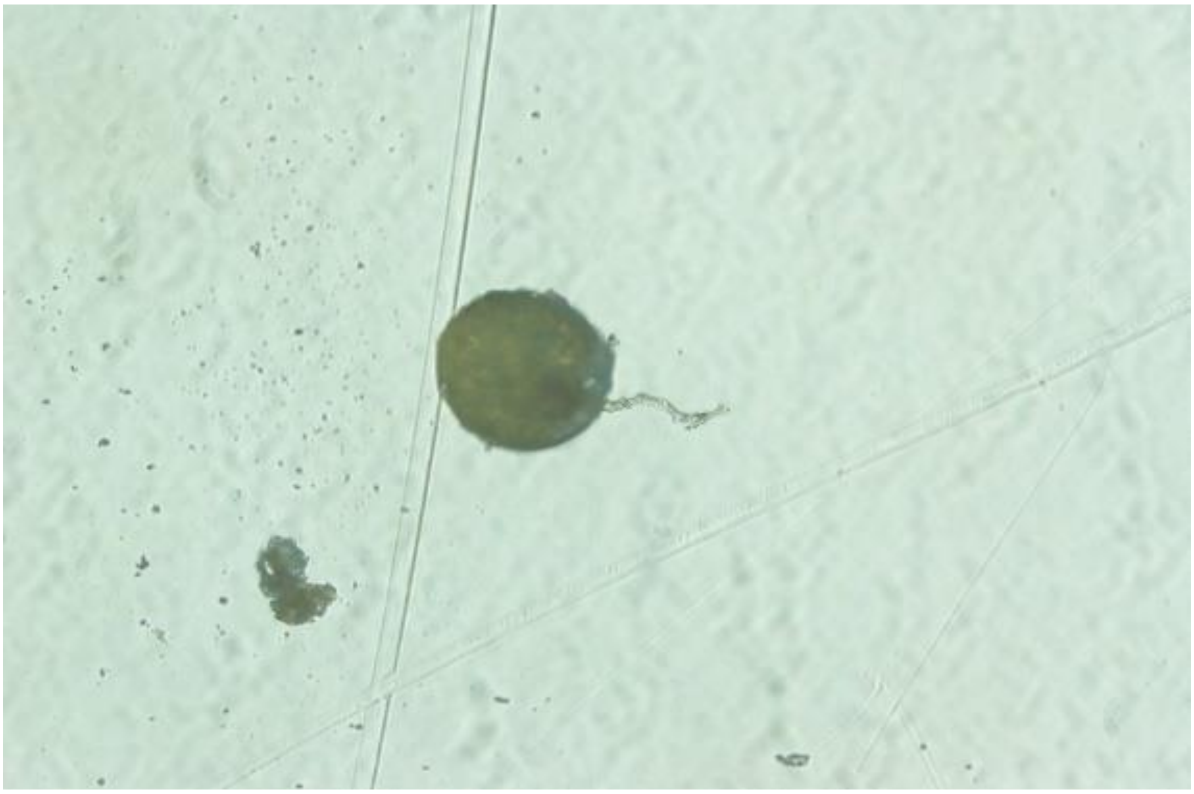

Plate 3 : Species of Acaulospora AMF found in the the study area

#### 4.3.16 Effect of Land use change on the population of AMF Gigaspora spp in Iriiri, Matany and Rengen sub-counties.

Woodland and grassland had a significantly higher population of *Gigaspora specie* ($p < 0.05$) than in Rengen and Matany (Figure 30). In Iriiri woodland and grassland top soil had a higher population of *Gigaspora specie* than other land uses. Top soil had significantly higher population as oppose to the sub-soil.

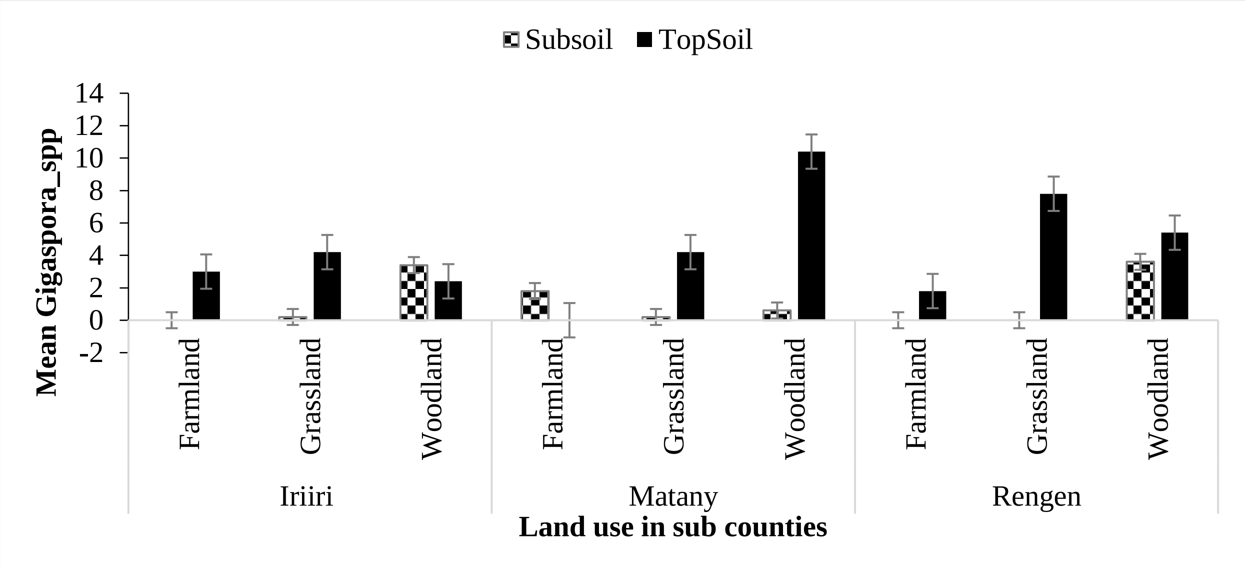


Figure 30: Effect of Land use change on the population of AMF Gigaspora spp in Iriiri, Matany and Rengen sub-counties.

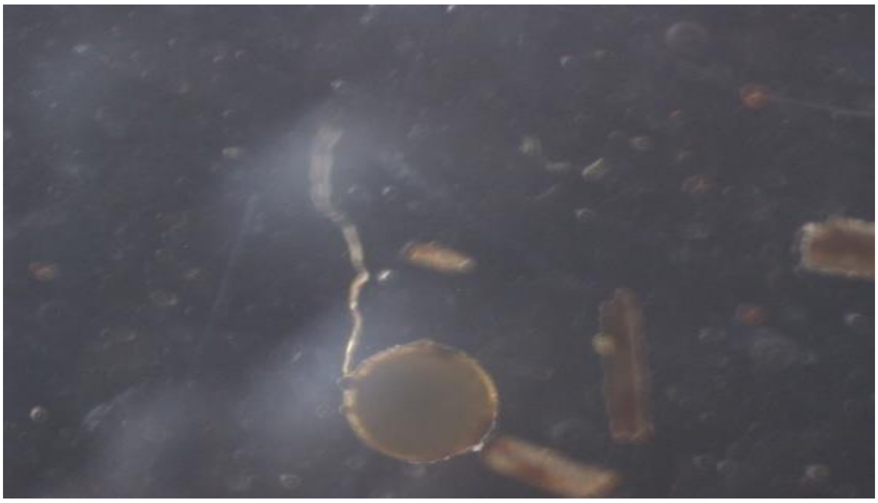

Plate 4: Spece of Gigaspora AMF found in the the study area

### 4.3.17 Nematodes availability and diversity as soil quality indicators in different sub-counties Land use change (Plates 5-8)

The data presented in Table 10, indicated that there were no significantly differences between the population of Scutellonema specie ($p<0.05$) in Rengen and Matany. There were significantly high ($p \leq 0.001$) population of Scutellonema specie in Iriiri than Rengen and Matany study sub-counties. Nonetheless, *Dorylaimus* and *Criconemela species* populations were not statistically significantly different ($p>0.05$) across all study sub-counties. The *Hemicycliophora specie* populations were significantly higher ($p \leq 0.001$) in Iriiri than in other sub-counties. The *Aphelenchoides specie* populations were significantly higher ($p \leq 0.001$) in Rengen than in both Iriiri and Matany.

Table 10: Nematodes availability and diversity as soil quality indicators in different sub-counties Land use change

| Nematodes characteristics | Sub county | | | Test statistic |
|---|---|---|---|---|
| | Rengen | Iriiri | Matany | |
| *Scutellonema* | 0.4764 a | 1.2745 b | 0.2 a | Lsd=0.5698 |
| *Dorylaimus* | 1.154 a | 1.124 a | 0.794 a | Lsd=0.7407 |
| *Hemicycliophora* | 0.1155 a | 0.965 b | 0a | Lsd=0.403 |
| *Criconemela* | 0.27642 a | 0a | 0a | Lsd=0.2564 |
| *Aphelenchoides* | 0.8414 b | 0a | 0a | Lsd=0.4218 |
| *Rhabdites* | 3.759 b | 1.725 a | 1.825 a | Lsd=0.7799 |

The data for *Scrutellonema*, *Dorylamus and Hemicycliophora species* indicated significantly high ($p < 0.05$) population in Iriiri grassland as compared with other land uses across all study sub-counties (Figures 31,32 and 33). Farmland had a high population of *Hemicycliophora* in both top and sub soils. The *Criconemela specie* populations were significantly high ($p < 0.05$) in farmland and woodland of Rengen Sub-County (Figure 32). Farmland had significantly higher population than woodland and other Land use change. In other land use population were very low and not significantly different ($p>0.05$).

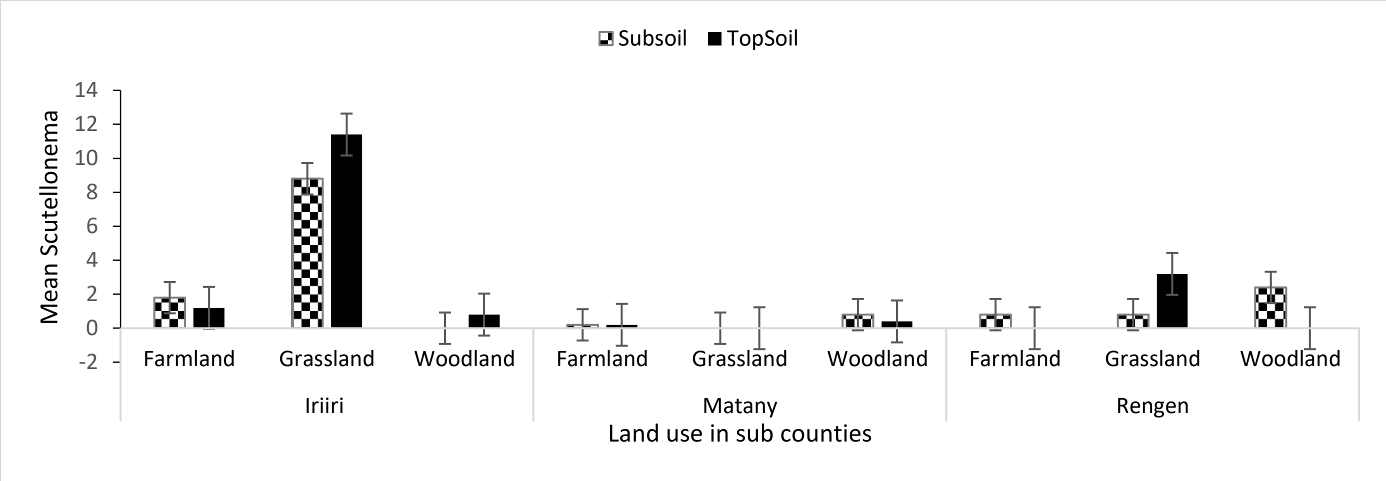


Figure 31: Effect of different Land use change on the Scutellonema spp of nematodes availability and diversity in the study Sub-county

Plate 5: Scutellonema nematodes spp found in the study area

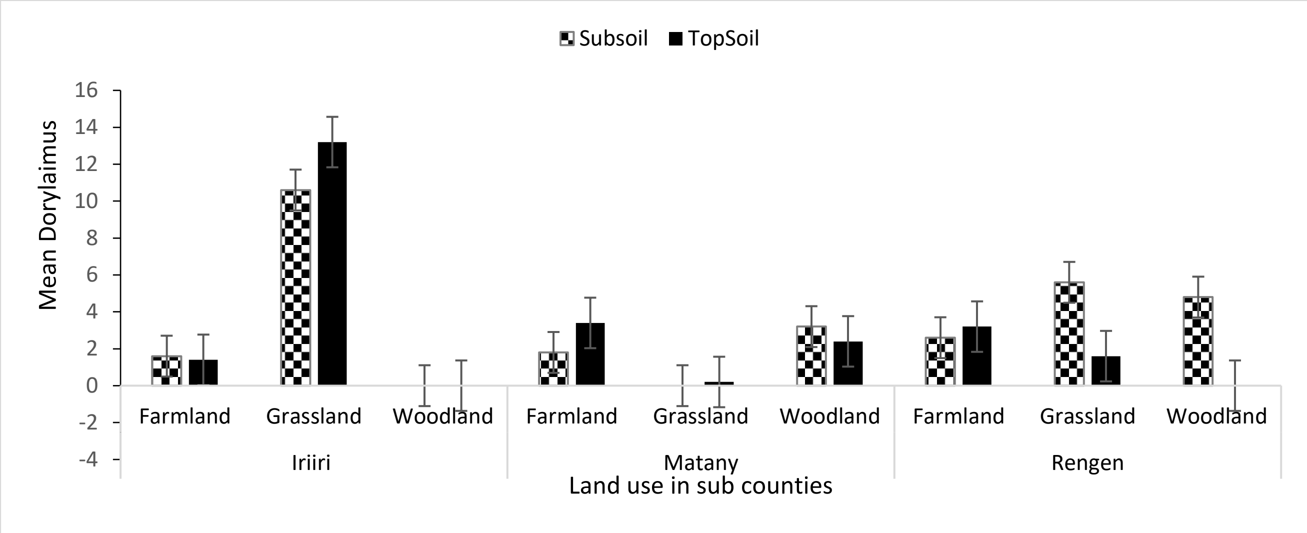


Figure 32: Effect of different Land use change on the Dorylaimus spp nematodes availability and diversity in the study Sub-county

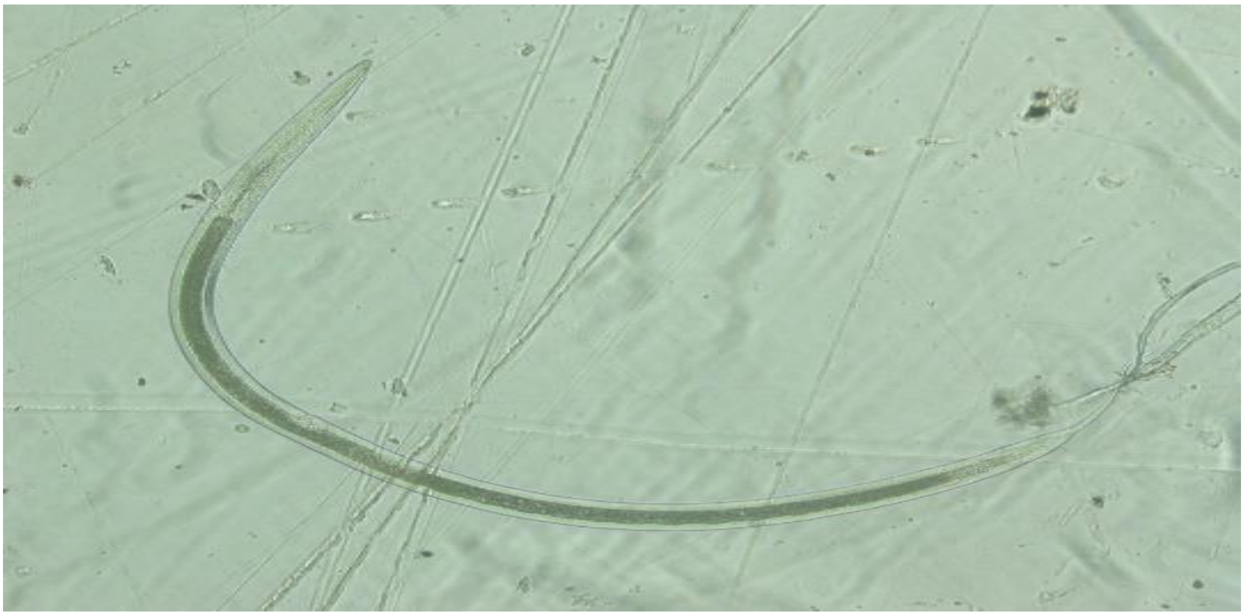

Plate 6: Dorylaimus nematodes spp found in the study area

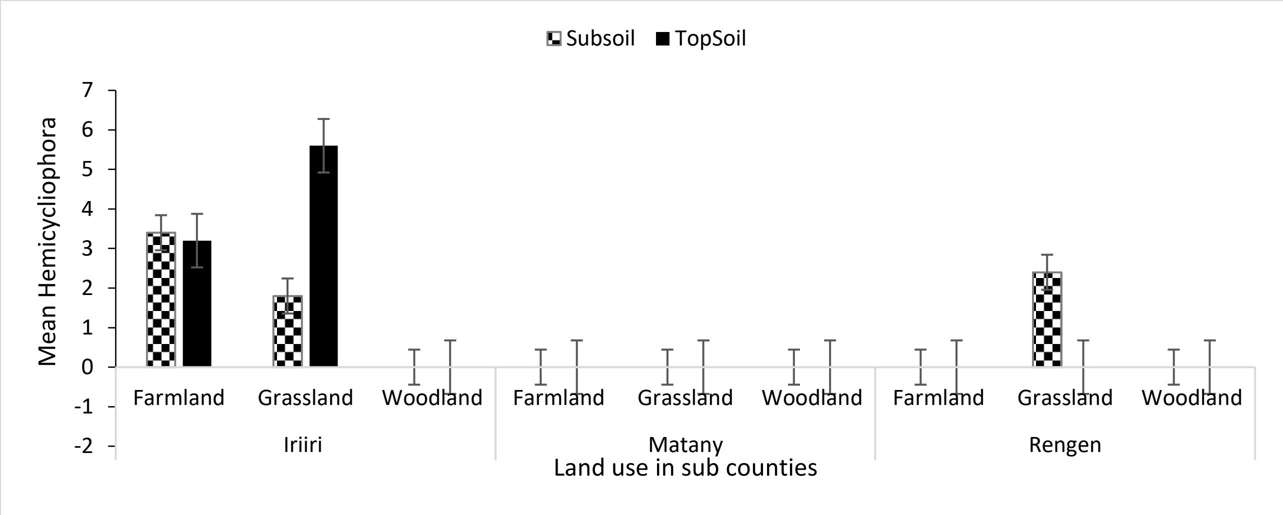


Figure 33: Effect of different Land use change on the Hemicycliophora nematodes spp availability and diversity in the study Sub-county

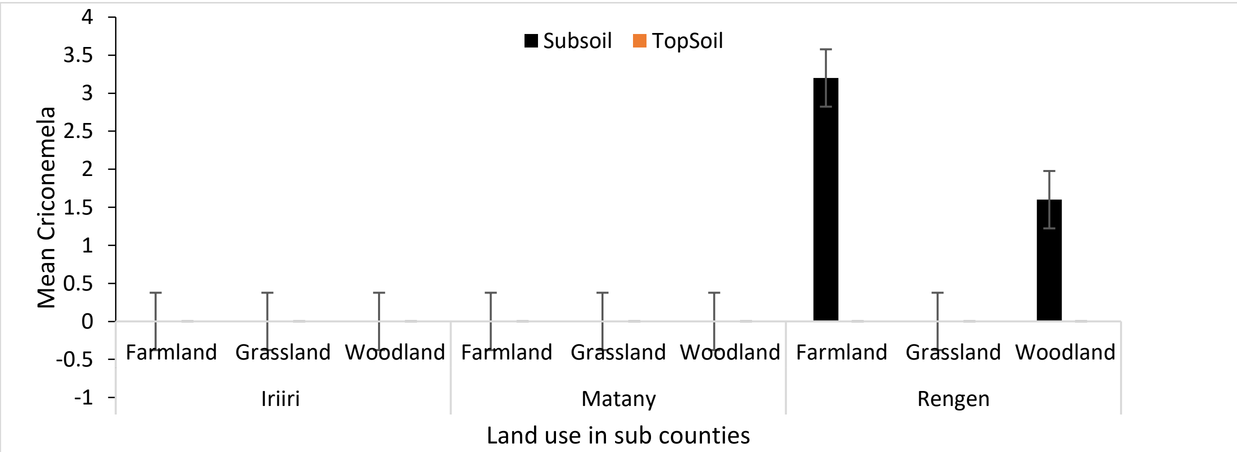


Figure 34: Effect of different Land use change on the Criconemela nematodes spp availability and diversity in the study Sub-county

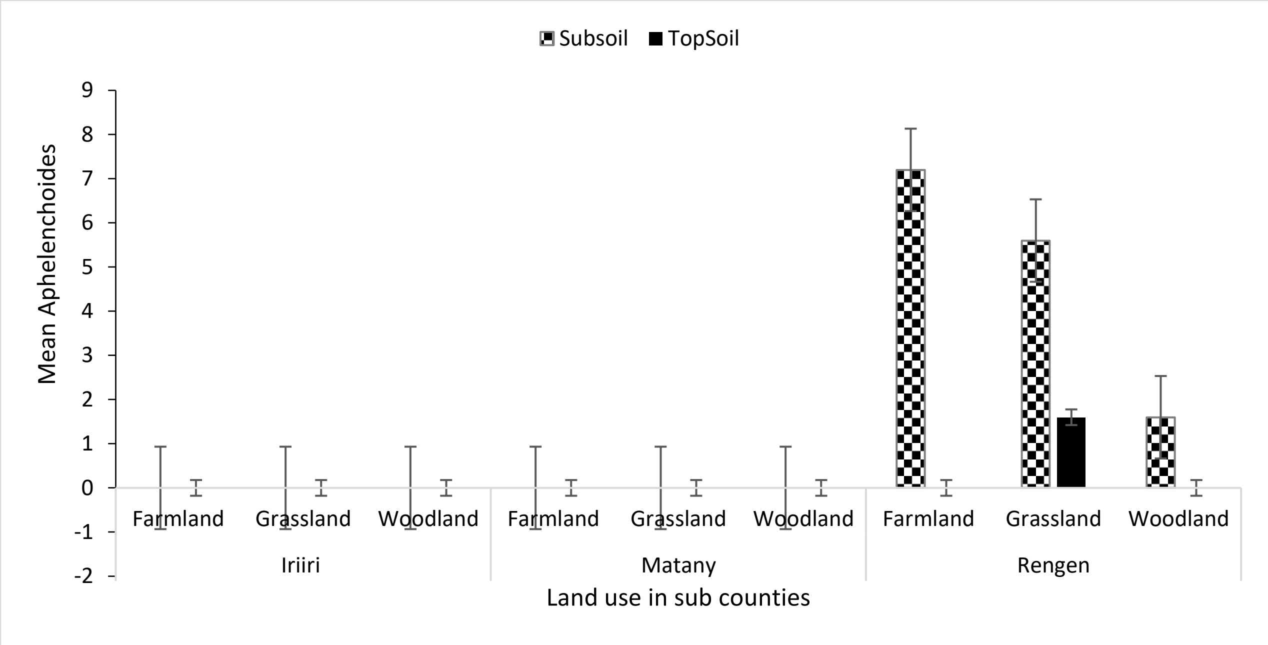


Figure 35: Effect of different Land use changeon the Aphelenchoides nematodes spp availability and diversity in the study Sub-county

Plate 7: Aphelenchoides nematode species found in the study area

The populations of *Aphelenchoides species*, were not significantly different ($p > 0.05$) in Iriiri and Matany across all study land uses. In Rengen farmland had the highest significantly different ($p < 0.05$) population in the sub -soil compared with grassland and woodland (Figure 35).

**<u>Aphelechoides</u>** = these nematodes feed on fungi, they are also plant parasitic. *Aphelenchoides besseyi* and *Aphelenchoides fragariae* that are plant pathogenic nematodes of rice and strawberry.

**Source: <u>Rhabdites</u>** Plate 8 are free living nematodes, non-parasitic, modified mouth parts that feed on bacteria, beneficial nematodes in the soil, their numbers are high in amended soils.

Plate 8: Rhabdites = Free living nematodes, non-parasitic nematode found in the study area

## 4.4. Discussion

### 4.4.1 Soil Chemical Properties

#### 4.4.1.1 Soil pH and soil organic matter

The pH in different land uses were not significantly different between land uses within each study Sub-County. The difference in pH values between different Sub-Counties land uses could be attributed to the inherent soil property such as mineral contents and their quantities in the parental material. Naturally, soil pH imitates the combination of the factors which form soil that is; topography, parental material, climate, living organisms and time (USDA-NRCS, 2019). According to the only available Chenery, 1960 classification, Matany soils were largely black and grey clay and clay loam often calcareous. This implied that the soil pH were often high due to the inherent calcium level. To the contrary, Iriiri Sub-County soils were mainly classified as Sebei series with patches of LIXIC FERRALSOLS, ACRIC FERRALSOLS, EUTRIC REGOSOLS and VERTICAL. Therefore, the differences in soil pH were attributed to differences in soil classes and textural class of Karamoja sub-region of Uganda (Chenery, 1960).

The low pH recorded in Rengen Sub-County might have been caused by the cultivation, which disturbed the soil structure allowing calcium to erode, or leach to lower layers; as such, the soil pH in the upper soil horizons of farmland reduced. It is known that Ca levels in the soil mainly contribute to the pH. The pH decreases as calcium decreased due to natural erosion and agricultural activities (de la PaixMupenzi et al., 2011). Grassland had the significantly lower pH values than other land use in Rengen Sub-County. The low pH values in grassland of Rengen Sub-County could be due to the trampling effect of livestock. Livestock trampling lead to compact soil which reduce water infiltration culminating into accelerated erosion with calcium loss in the top soil. Once $Ca^{++}$ is removed from the soil its pH reduces. It is widely documented that livestock destroy the top soil aggregate (Bari,1993; Zhou et al., 2010 and Kotzé et al., 2013) leading to reduced water infiltration accelerated soil erosion with calcium loss which eventually led to increase in the hydrogen ions as they replace calcium lost through rain fall wash off.

The high soil organic matter in Matany Sub-County was probably due to clayey soil with high pH. In addition, the clay soils retain more water making it poorly aerated, hence, reducing the aerobic microbial decomposition activities. These imply that the rate of OM decomposition was low due to the low biological activities in the compact soils smiral conclusions were made by Oades, 1988; Lopes-Mazzetto et al., 2018. Hence, OM remained undecomposed for a long time than in the light textured soils of Rengen. Inline with the above discusion, clay soils are known to have large porosity and carbon dioxide release as a measure of organic matter decomposing in soil decrease with increase in porosity and the reverse was true (Mtambanengwe et al., 2004).

The low OM levels in farmland of Rengen were likely be due to the fact that the soils were sandy loam. Sandy loam soils are well aerated which allow quick decomposition of OM, particularly when they are mechanically disturbed through tillage. The high OM in grassland Rengen and grassland and woodland top soil of Matany compared to farmland could related to accumulation animal manure which is spread during grass grazing and the plant litter fall, as opposed to cultivation where the litter is removed, burnt and exposed to higher oxidation enhanced by soil tillage. Cumulative residues from animals and plants provide carbon for microorganism's activities in soil. This creates a favourable condition for fixing carbon from the environment or atmosphere as such Wanga et al., 2005; Zhu et al., 2010 recorded progressively increase soil OM content. Another study in Shinyang River by Yang et al. (2011), reported a reduction in SOC by 2.5 folds when the woodland and grasslands were cleared and planted with crops. Their observations were attributed to plant in woodland and grassland generation more litter than the crop land. Other researchers have concluded that cultivation lead to more pronounced OM decrease in farmland than in other land uses understudy (Cattle et al., 1994; Yemefack et al., 2005).

The low values of OM in top soil of the woodland could be attributed to the biological activities; usually macro-fauna like termites destroy the surface litter and burrow it in the sub-soils. In addition, OM accumulation in the lower soil layers also might have attested to the fact that woodland was less disturbed for a long time, implying that the build-up of vegetation root and exudates for long time could have resulted into higher OM in sub than the top-soil. However, the low levels of OM in the farm land are attributable to the high or quick decomposition of OM due to increased aeration by tillage practices. This is in line with de Assis et al. (2010) study which revealed OM oxidation in the soil to be inversely proportional to the soil depth, as soil depth increase the OM accumulation in the soil increase.

Alternatively, the low levels of OM in farmland could be attributed to the rate of decomposition of organic matter. Farming activities enhances soil aeration; thus, SOM was exposed to quick decomposition by aerobic organisms both fungi and bacteria. As removal of natural vegetation and cultivation continued, the SOM stock (substrate for microorganisms) in the soil decreased this resulted into reduction in both fungi and bacteria population. This was in agreement with a study by, He et al., 2017 in Tibet, China, where conversion of forest into other land uses led to alteration in microbial population in the organic layer.

#### 4.4.1.2 Mean available P values of Iriiri, Matany and Rengen Sub-Counties land uses

The high nitrogen content in top soil of Rengen farmland can be attributed to the dry season grazing. During the dry season uncontrolled number of livestock are grazed on sorghum and other crops straw. Livestock manure is dropped in the fields particularly on top soil. The low levels of nitrogen in both Iriiri and Matany's clay soils as opposed to the light textured Rengen sandy loam soil is difficult to explain. On the other hand, the high level of OM in farmland top soil of Rengen can be related to dry season livestock grazing which lead to depositing of the dung. Perhaps this explains why farmland had more N in top soil and other land uses and level recorded non-significant levels.

The high level of P recorded in Iriiri sub-soil could be because the soils had no clear distinction between soil layers. The top soil and sub-soil appeared to be the same. However, the lower layer might have accumulated P from top through drainage and leakages from top soil. Further, Iriiri was mainly in the confluence of the seasonal wetland implying that there might have been P deposited from none point source in the area by water. Similarly, a study by Silva et al. (2009), reported high levels of P and N after rainfall runoff, from non-point sources in the tributary of Ocoí river Sub-basin of Itaipu's, Brazil. This implied that P can be eroded and then deposited in the lower areas with a possible accumulation in the soil lower layers.

The comparatively high P levels in the top soil of grassland could be attributed less disturbance and cattle grazing and cow dung deposited on the surface. Phosphorous being a less labile nutrient could have accumulated to the surface as was indicated in a study done by Domagalski and Saleh, 2015 in rive California and its neighbouring states. The high level of P in topsoil of the woodland of Rengen, could be attributed to the less disturbance to the land. This further may indicate that the soils are near its equilibrium or ecological balance.

The significantly lower P levels in Matany and Rengen could be an indicator of effect of farmland/ cultivation on soil P. As P is declining with cultivation also pH is reducing, perhaps this implied initial stages of soil quality decline in the study area (Okalebo et al., 2002). Overall, the P levels in the study area are below the critical range. This means that P could be one of the most important limiting indicators of soil quality decline in the study area.

#### 4.4.1.3 Soil Calcium and magnesium

The reported high levels of calcium and magnesium in Rengen study site sub-soil visas other land uses may be attributed to soil depth. Sub-soils are usually less disturbed by cultivation, hence, rendering the nutrient less redistributed or lost. Therefore, the low levels of both nutrients in top soil could be because of redistribution and losses through leaching to lower layers. To the contrary, in a fallow study which was conducted in the great Plains by Tarkalson et al. (2006) reported no significant differences between calcium, magnesium and potassium levels in the two top soil layers soil layers (0-5 and 5-10 cm). Perhaps, the differences between their study and this study were due to the soil depth, sampled. In this study, top soil ranged from 0-15 cm and sub-soil 15-30 cm. The higher levels of Ca and Mg in both Iriiri and Matany may be related to the inherent soil properties from the parental material. The soils of the two sub-counties had high calcium levels due to the $CaCo_3$ content found in the parental rocks (Chenery, 1960). Further, the same explanation holds for the generally low levels of both Ca and Mg in Rengen sandy loam soils.

#### 4.4.1.4 Soil Pottassium

The high levels of $K^+$ in top soil of both grass and woodland could be attributed to the pump back effect of vegetation. Grasses are known to have luxurious $K^+$ consumption which is dropped on the soil surface a residue. Nutrients are recycled from underground to the surface by plants through the transpiration pull and eventual dropping of the above ground biomass, thus, increasing the amount of $K^+$ in top soil. This was in agreement with a study which was carried out by Aghasi et al. (2011) where high level of Potassium was recorded in pasture plants in Iran than in other land use. Woodland having more $K^+$ than other land uses confirmed the fact that, it was less disturbed than other land uses. The vegetation in undisturbed natural setting drop their leaves to the soil surface together with the nutrients. Upon decomposition the K+ and other nutrients are released into soil through a process known as nutrients recycling. When natural vegetation is less disturbed the soil underneath tend to be near its ecological balance, hence, the high $K^+$ recorded in this study. The low values of $K^+$ in top soils of the farmlands in Iriiri and Rengen study areas could be that the nutrient recycling was disrupted by cultivation. Cultivation tend to destroy the soil structure of the top layer, which when coupled with the dry season livestock grazing enhance soil pulverization, therefore, reducing the porosity. This in turn led to potassium loss with runoff water. In addition, cultivation expose soil surface (bare soil) to rainfall drops, which compact the top layer, and enhances the nutrient loss in runoff. Further, some of the nutrients are lost through harvesting without replenishing resulting into declining soil quality. Tropical regions receive torrential rainfall, which may lead to $K^+$ loss in less protected soil. This was in line with Acharya et al. (2007), study significant losses of up to 0.08 kg $K^+$ per hectare per year in run off was recorded in mid-hill, Napal.

### 4.4.2 Soil physical properties

#### 4.4.2.1 Mean % sand composition of Iriiri, Matany and Rengen Sub-Counties land uses

The high clay percentage in the soils of Iriiri and Matany were tested and revealed a clay textural class while Rengen had a sandy loam texture. Silt content of the soil was significantly higher in Iriiri and Matany than in Rengen. The findings are in agreement with the Chenery, 1960 that put Iriiri and Matany soil to be mainly clay. It is important to note that there is no clear update of the soil Figures in Karamoja.

**4.4.2.2 Mean available water, field capacity and permanent wilting point under different land uses**

The different levels of the available water, field capacity, wilting point which were recoded in the current study could be attributed to the inherent soil factors**.** Rengen soil were sandy while the Iriiri and Matany clay. It is known that available soil water capacity increases its texture. Sandy soils are known to have a lower field capacity than the fine textured clay (Yimer, et al., 2008). This was due to that fact that clay have fine pore which hold water against drainage. However, sandy loam soils with enough SOM can have more available water than the clay soils with high permanent wilting point as indicated in the woodland of Rengen Sub-County. Soil organic matter has the ability to improve the soil water stable aggregates which enhance both the pore size and the water holding ability (Spaccini and Piccolo (2013). The lower water levels indicated in farming can be attributed to the tillage effect on soil aggregate stability which resulted into soil compaction. Compaction resulted into reduction in the available water capacity by adversely affecting the field capacity plus the permanent wilting point. When soil was compacted through cultivation its pore volume reduced ending into reduced soil water storage.

**4.4.2.3 Mean drainage rates, soil bulk density (BD) and water stable aggregates under different land use chang in the study area**

The low drainage rates recorded in both Iriiri and Matany land use could be related to the clay soil texture in the Sub-Counties. Such soil has low porosity and high-water retention properties. Water ponding was common in such soils making it unsuitable for crops production. Clay soil are known to have a low representative water infiltration rate ranging between 0.0254 and 0.254 and oppose to sandy loam with 1.016 to1.524 cm per hour (Kopec, 1995). The close packed soil particle cannot allow root penetration.  The decrease in the water drainage rate in Rengen farmland could also be attributed to the soil aggregate disturbance due to cultivation. Cultivation destroyed the heterogeneity of soil properties. The soil structure was destruction, which impaired the water infiltration rate leading to increased runoff during the rain seasons and the reverse is true. Alteration of soil aggregates due to tillage and livestock trampling together with low SOM have been reported to cause decline in the infiltration capacity and the field capacity (Yimer, et al., 2008).

The finding is in accordance with Jin He et al. (2009); Zhang et al. (2018), who recorded a high sum of macro-aggregates and high-water infiltration in no tillage than in conventional tillage in China. Mixing of soil through farming activities or cultivation modifies water balance and homogenizes soil. When the macro aggregates disintegrated, the soils become more compact and did not allow easy water infiltration.

The high bulky density recorded in the grassland could be a result of the frequent livestock trampling of the top soil, which led to compaction of the top layer leading to reduction of soil macro pores. Taking woodland (which was near to ecological balance) as a reference were animal activities were limited, the diversion from it implies that there were significant soil quality disruptions through compaction. Uncontrolled number of livestock grazing on a piece of land are known to not only compact and reduce water infiltration, but also reduce biodiversity (Byrne et al., 2018). Thus, enhance soil loss through erosion, which may led to loss of top soil, reduce water infiltration and negatively impact soil biological properties and processes (FAO, 2016). Similarly, the increased in bulky density in the Rengen farmland indicated deteriorating soil quality due to cultivation. High soil bulk density is known to retard crops growth through hindering, root penetration into the soil, chemical, physical and biological activities, which results into reduced water and nutrients availability. Similar results have also been reported by Mwonga (1986), who found out an increased bulky density of the cultivated as compare with uncultivated field in Andosol in forest soil of Kenya.

The difference in water availability could be because soils textural class of Iriiri and Matany sub-counties was clay. Such soils retain water for a long time than the sandy loam. Clay soils have greater porosity and less permeability than the light textured soils; hence, it could keep more water (Cleveland and Solie, 1991). To the contrary, Rengen Sub-County soils were sandy loam, such soils have a high-water drainage rate, low water retention and higher wilting point than the clay soils of Iriiri and Matany. This was attributed to the textural characteristics, but in addition, the rate at which the water to be lost form the soil, could be enhanced by cultivation and livestock trampling of the top soil which tend to destruct the soil macro aggregates and pores; thus, accelerating surface water runoff. This was in agreement with a study, which was conducted by Bezabih et al. (2016) in Ethiopia. Therefore, cultivation of Rengen soils requires soil quality maintenance.

Soil water properties were generally influence by the soil texture. Therefore, the lack of significant differences in the soil water saturation point in Iriiri and Matany were related to soil clay textural class. Clay had high porosity and was able to retain more water than Rengen soils, which are sandy loam. This explains in part the lower field capacity of Rengen soils as compared with the recorded the former two sub-counties. The soil physical properties are known to be disrupted upon removal of ground cover. In this regard, removal of woodland for cultivation affected the water availability in Rengen. The slightly low decrease in available water in the farmland and grassland as compared to the woodland in Rengen could be an early warming of the soil quality decline. In the grassland, livestock trampling led to soil compaction, which reduced not only the water holding capacity of the soil but facilitates runoff. Consequently, leading to top soil loss. The same explanation holds for inappropriately managed cultivation, which led loss of SOM, pulverization of top soil, aggregate disruption and exposure of the top soil to rain drops impact (Yimer et al., 2008). The lowest permanent wilting point observed in Rengen woodland as opposed to other land uses was difficult to explain.

### 4.4.3 Soil biological properties

#### 4.4.3.1 Soil fungi

The high levels of both fungi and bacteria population in Rengen can be attributed to the soil conditions. Rengen had sandy loam soil which is known to be more favarable for aerobic microbial growth. Whereas the clay soil of Matany and Iriiri are less favourable to the aerobic soil mcroorganisms. Hence the population of the anaerobic alone is lower than that of both organism in a favourable Rengen soil. To the contry, Najmadeen et al., 2010 in Egypt found a higher population of microbes in fine than in coarse textured soils and the results were related to the chemical composition of the soil.

#### 4.4.3.2 Soil Number of Bacteria, fungi and actinomycetes (cfu)

The high number of fungal cfus in Rengen Sub-County could be explained in part, in terms of pH. Because Rengen had low levels of calcium than Iriiri and Matany, and pH is calcium dependent, was likely that the survival of fungi in low pH was enhanced. Slightly low pH increases the fungal population and activities (Rousk et al., 2009). In addition, fungi are known to tolerate a wide range of pH (Kawahara et al. 2016); implying that they can survive in a wide range of soil pH. Nonetheless, this could mean under high pH, their populations were compromised for resilience and changes for survival. On the other hand, bacterial cfus were higher in Iriiri and Matany than in Rengen. This can be attributed to high pH, which is known to be more favourable for bacteria than lower pH as per Lauber et al. (2009) and Rousk et al. (2009) reports. Therefore, the combination of calcium, pH and microbial population presents an edge as determinants of SQ in the agro-pastoral Karamoja.

The low level of the fungal colony forming units in Iriiri and Matany sub-counties could be attributed to the soil pH. The soils of the two sub-counties were high in pH. Most of the fungi species were acidophiles, known to thrive well in low in acidic conditions (Rousk et al., 2009). It is therefore probable that the species that could not survive in alkaline soils were naturally eliminated, hence the low population. On the other hand, the soils of Rengen were sandy loam with a relatively neutral pH, which might have supported the fungal population proliferation. Sandy loam soils were more aerated further creating a condition, which was favourable for OM decomposition. In contrast, the bacteria population was high in the alkaline soils of Matany. Most bacterial are alkalophiles known to have their favourable growth in alkaline conditions. It has been observed widely that bacterial population decrease with decrease in pH (Fernández-Calviño, and Bååth, 2010; Rousk et al., 2009). Hence, the higher number of bacterial in iriiri and Matany. However, the high population of bacteria in Rengen woodland and grassland could be attributed to organic matter decomposition in well-aerated sandy loam soils which holds more bacterial than the clay which is found Iriiri and Mata y. When soil is well aerated the soil microbial activities increase enhancing the rate of decomposition of OM. However, upon prolonged SOM decomposition the stalk and quality of OM will reduce which resulting low. Such condition is common in tilled light textured soil. Chau et al. (2011) reported a high number of bacterial richness were in sandy soils. Microorganisms were reportedly high in decomposing organic matter. This is related to the reduced OM in the well-aerated sandy loam of Rengen as opposed to the Iriiri and Matany sub-counties.

The actinomycetes population was not different in all land uses probably due to the soil pH of the study area which was within favourable range for Actinimycetes. It has been reported that Actionomycetes survive well between pH range of 6.5 to 9 (Smith and Collins, 2007). The lack of significant difference in grass and woodland impact on soil microbial was likely due to temporal time. Soils may still be in its early degradation stages, which are difficult to determine by the methods, which were used in this study.

Farmland lower population of both bacteria and fungi than in other land uses was likely due to the destruction of the soil structure, enhanced runoff by exposing the soil to eroding factor and increased OM decomposition. When soil structure was destroyed some fungi, which acted as binders, were destroyed, OM was exposed to quick decomposition reducing the organism's substrate and eventually led to population decrease. In addition, the soil become vulnerable to losses through wind and water erosion, which resulted in some organisms' loss. The exposure of the organism to the ultra-rays of the sun also caused detrimental effect on some microorganisms, hence reducing their population. Farming or cultivation reduced the number of plants species per unit area, which end up in limited microorganism's substrate source in terms of quantity and quality. It was probable that the C: N ratio of the crops, mainly grown in the study area (sorghum and maize), took longer to decompose. Thus, rendering the strovers unavailable for microbial consumption for a long time. In line with that, sorghum and maize root exudates may influence the population and diversity of bacteria in the rhizosphere. Some root exudates are attractive to specific organism implying that their population proliferate around the root zone resulting into elimination of the less favoured organisms. This might have reduced the microbial population availability, abundance and diversity. Different plants reported to exhibit great influence on the community of bacteria in the rhizosphere (Söderberg et al., 2002; Zhou, 2012; Tkacz et al., 2015). Cultivation can reduce the diversity and population of both fungi and bacterial Miah et al. (2010). Similar, reason could explain why the top soil in farmland had lower levels of cfu than the sub-soil since the latter was less disturbed. For grazing land, the fungi cfu values were not far from those of forest, implying that the soil was less disturbed. Therefore, fungi cfus is an indicator of soil quality degradation in farming.

#### 4.4.3.3 Soil Respiration

The high carbon dioxide release, which was recorded in grassland in both Rengen and Matany, could be an indicator of enhanced soil organic matter decomposition. The livestock dung, deposited in grassland (grazing land) after livestock grazing, had a low C: N ratio and a greater surface area for microbial attack and demineralize than the leaf litter in woodland. In addition, Land use change had a strong influence on pool carbon: nitrogen ratio. This was in agreement with a study, which was curried, by Wang et al., 2013, where annual respiration was related to C: N ratio after conversion of grassland to woodland. Soil respiration in woodland of both Matany and Rengen could be related to the ecological balanced carbon dioxide release in the study site. The low levels of respiration in grassland and woodland of Matany and Iriiri respectively, could be due to the possible reduction in the, availability, abundance and diversity of aerobic microorganisms due to waterlogging in the clay soils. The two study areas soil textural class was clay with poor drainage. Very low respiration usually caused by high soil bulk density is an indicator of poor-quality soil with limited release of nutrients for plants growth (Wang et al., 13). Possible release of toxic gases like sulphur dioxide to the environment, hence contributing to the green gas effect to the environment. This may require addition of SOM to curb the soil quality decline.

#### 4.4.3.4 Mycorrhizae

The study established higher population of *Glomus spp, G. mosseae, G. intrrraradices, Scutelospora verrucosa, Scutellospora spp, Acaulospora spp and the Gigaspora* in woodland was an indicator of soil, which were not degraded. The high population of AMF in the woodland of the entire study area was due to the heterogeneity, which favour the AMF diversity. The woodland had favourable microclimate and well-balanced ecosystem due to less disturbance from human activities. On the other hand, AMF population reduction in grassland and farmland was a sign of soil quality decline due to farming practices. Farming practice have been reported to decrease the availability, abundance and diversity of AMF (Hijri et al., 2006; Verbruggen et al., 2012; Xiang et al., 2014). The presence of AMF was the environmental indicator of quality soil. The mycorrhizas are beneficial organisms, which help in recycling and delivering nutrients particulary P from deep and distance soils to the crops in exchange for carbon. They also help plant to tolerate stress like prolonged dry spells (Gianinazzi et al., 2010; Doubková, 2011). As such, their presence in the soil was an indicator of good ecological or fairly balanced soil quality. Therefore, under this condition, AMF was one of the best indicators of soil quality.

#### 4.4.3.5 Soil Nematodes

The availability and diversity of nematodes spp the Scutellonema, Dorylaimus spp, Aphelenchoides, Rhabdites nematodes *spp*, Hemicyliophora, Criconemela nematodes spp in different land uses can be an indicator of changes in soil quality. The study revealed high population of Scrutellonema, Dorylaimus and Hemicycliophora species in grassland and in woodland of Iriiri and Rengen study areas. The presence and absence of nematodes species in some study area can be attributed to, in part, the presence of vegetation with low C: N ratio, which favours some species proliferation compromising others, availability. Bacteriovore are likely to increase in numbers under low C: N vegetation cover which favour high bacteria population prevalence (Makulec et al., 2014). The presence of Rhibdites predicts amended or good soils; for the genera is known to be opportunistic, free living commonly found in agricultural soils with short instars and large substrates resources requirements (Bongers, 1999; García etal., 2011).

The relatively high nematode population in grassland can be related to the quantity and quality of OM due to the plant spp composition. Organic matter is the source of food for plant and bacterial feeder nematodes. The increase in the amount and quality of nematodes substrates, that is, the amount of organic residue and root exudate plus the prolification of bacterial substrate, likely enhances the nematode population. Wachira et al., 2010, in a study which was conducted in Kenya, found a high population of saporofitic and free-living nematodes in forested areas than in farmed land which recoded a high population of parasitic nematodes. In respect of that, grassland had both a wider range pasture plants species composition and the livestock dung, which both lead to high quality substrate favoured by nematodes more benefi. Simiral finding were related to soil structural modification by the grass species, and the quality of OM Viketoft et al. (2009). This was also in agreement with studies by Wasilewska, (1979). Therefore, it was plausible that the population of nematode was highest in grassland than in other land uses. According to their diversity and their involvement in numerous functions at different soil food web levels, nematodes can be used as indicators of SQ. As such a number of scientists have suggested nematodes counting in different families or trophic groups to be the most suitable SQI (Blair et al., 1996). In support of the above suggestion and in contrast to bacteria, the nematodes diversity and population stability under different soil moisture regimes and temperature can be useful indicators of the soil quality alterations, as their response to Land use change are pridicatable. Changes in their population imitate changes in soil micro-environments.

### 4.5 Conclusion and Recommendation

1. The results of this study revealed that land use change from the natural forest to cultivation impacted soil biological, chemical and physical properties negatively. Generally farming led to the soil chemical and physical properties deterioration.

2. This research has shown that soil inherent properties like texture, the mineral content in addition to SOM are important buffers of soil quality when subjected to land use alterations.

In order to curtail the impact of the land use change on the soil measurable properties climatic smart agriculture practices for sustainable soil management must be promoted.

# CHAPTER FIVE: USE OF PRINCIPAL COMPONENT ANALYSIS TO EVALUATE THE SOIL QUALITY INDICATORS RELATIONSHIP TO SELECTED LAND USE CHANGE IN THE SEMI-ARID AGRO-PASTORAL REGION OF KARAMOJA, UGANDA.

**Abstract**

Soil quality indicators (SQI) are one of the synthetic tools for the valuation and comparing the sustainability of Land use change. Soil quality indicators for different land uses were developed using minimum data set (MDS) from samples which were collected and analysed for physical, chemical plus biological attributes. In order to assess the influence of different land uses on soil measurable parameters, analysis of variance (ANOVA) was accomplished using SPSS (version 24). To separate the mean value significance and determine the strength of relationships among soil attributes, Duncan's multiple range test and Pearson's correlation coefficients, respectively were performed. The soil quality index was determined by selecting the most suitable minimum indicators data set of the soil function. Then the indicators in the MDS were scored and incorporated in the soil quality index (SQI). Various land uses resulted into different SQI with farmland having the lowest SQI. This suggest that farming negatively influenced soil quality. However, due to differences in soil forming parental rocks in the study area, it was difficult to come up with one universal soil quality index for the entire area. The combined analysis of soil quality attributes (SQI) showed declining trends in Karamoja farmland due to nutrient imbalance; soil texture and its effect on soil water availability for crop yield were the most critical indicators of SQ in relation to crops production in Karamaoja.

*Key words: minimum data set, principal component analysis, soil quality index*

## 5.1 Background

Soil quality (SQ) is an important factor responsible for the sustainable environment, maintenance of biological productivity, promote plants, human and animal health (Doran and Parkin, 1994; Benedetti and Mocali, 2011; Ciccarese and Silli, 2016). However, globally it has been over disturbed by man for different purposes (land use) like farming and other activities which are vital in meeting the requirements for the ever-growing human population. The soil disturbances have been reported by several researcher to lead to mainly negative soil quality and environmental consequences (Moges, et al., 2013; Liao, et al., 2015; Pham, et al., 2018).

Nonetheless, the concerns are caused by many different Land use change which impact soils in different ecological systems differently. Soil differ from zone to zone this is mainly due to the parental material, weathering processes, mediated by living organisms, relief and time. Further, the aforementioned factors dictate the dominant physical, chemical and biological soil properties which determine its suitability for a desired purpose. In this regard, it is imperative, to determine SQ in small zones than global or region scales.

Soil quality indexing is a new method used in spatial plus temporal assessment of land management practices which influences on soils functional capacity (Erkossa et al., 2007; Bünemann, et al., 2018). Indexing SQ is a simple and logical way of determining the soil quality state. It is determined using the soil chemical physical and biological attributes. It identifies the sensitive soil quality indicators (SQI) in each land use and integrate them to generate the SQ status (Granatstein and Bezdicek, 1992; Erkossa et al., 2007; Masto et al 2009; Bünemann, et al., 2018). The knowledge of soil status is useful for land users, policy makers and other stakeholders.

Andrews et al., 2002; Nabiollahi, 2017 suggested three steps in determining the soil quality index. The first is to choose suitable indicators, followed by indicator transformation into scores and combining the scores to get the soil index. There are several indicators selection opinions suggested by different authors. These include, selecting soil quality indicators can be done statistically by using the principal components analysis, expert opinion or factor analysis (Doran and Parkin: 1994 Andrews et al. 2001; Brejda et al. 2000; Ghaemi et al., 2014; Safaei et al., 2019). Scoring can be done by linear and none-linear and multiplicative, weighted additive, simple additive methods (Singh et al., 1992; Karlen et al. 1998; Andrews and Carroll 2001; Andrews et al., 2002; Erkossa 2007; Nabiollahi, 2017).

Despite the vast studies done concerning soil quality as influenced by Land use change in different regions of the world, there is no such study in the agro-pastoral Karamoja sub-region of Uganda. Karamoja is a semi-arid area with soil and environment which is unsuitable for cultivation/ farming, the area has been overgrazed by livestock and other extractive land use systems. However, the Government of Uganda have been promoting sedentary cultivation to the pastoral community for decades (Nakalenbe et al., 2017).

The impact of the different land use on the soil quality in this sub region is unknown. The crop yields are sub-optimal which is linked to Land use change associated with declining fertility

SQ. Hence, it is imperative to study the soil quality index for different land uses. The objective of this study was to assess the effect of selected land use on soil quality in the agro-pastoral Karamoja.

## 5.2 Materials and methods

### 5.2.1 Study location

For the location and description of the study site, study approach are as ascribed in Chapter Three-Materials and Methods.

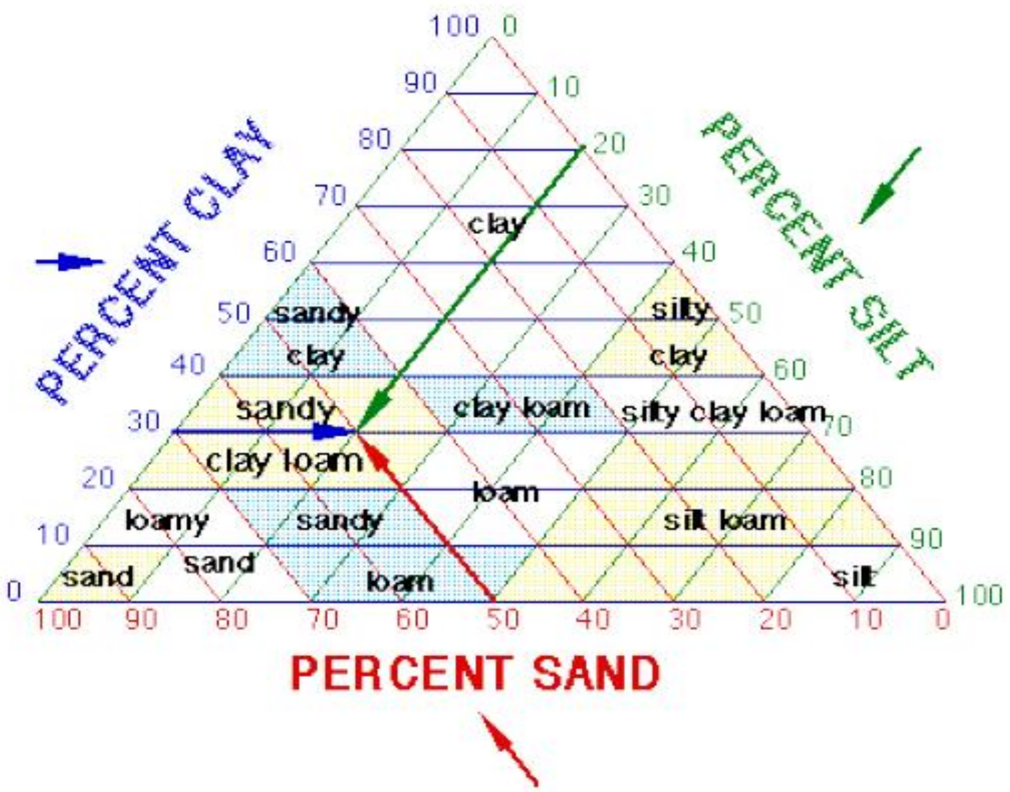


Figure 36: Soil textural triangle adapted from Brady et al., 2007 and used in determining the soil physical critical ranges

Different soil measurable attributes, statistical average values, were obtained from the laboratory analyses and used in ranking each soil parameter. Ranking was done by comparing the mean value of each attribute, with its critical range in crops production as per recorded ranges by Okalebo et al. (2002); Harrach et al. (1999) Appendices 11,12,13 and 14. The critical range for sand, clay and silt were obtained by getting the mid-point of the range for respective soil texture components from the textural triangle (Figure 36). The measured average values for each soil texture were compared with its range values in the loam soil and then ranked as in the preceding explanation for other variables alluded to before. Loam soil is known to be the best soil for most agricultural crops production (Brady et al., 2007**).** Loam soils are made up of sand, clay and silt in proportions indicated in the soil textural triangle (. Increasing each texture (sand, clay and silt) above or below its limits in loam soil has a detrimental effect on its quality.

### 5.2.2 Selection of minimum data set (MDS) for soil quality indexing

The soil quality index is mainly calculated form the minimum data set (MDS) equation or a formula by (Doran & Parkin, 1994: Andrews *et al.,* 2004). Where; SQI = *f* (scored MDS)

$$SQ = f\ (K_1SQ_{E1})(K_2SQ_{E2})(K_3SQ_{E3})(K_4SQ_{E4})(K_5SQ_{E5})(K_6SQ_{E6})\ (K7SQ_{E7})\ (K8SQ_{E8})(K9SQ_{E9})$$

Where**:** $SQ_{E1=}$ soil structure; $SQ_{E2=}$ aggregate stability; $SQ_{E3=}$ Bulky density; $SQ_{E4=}$ Available water capacity; $SQ_{E5=}$ water filled pores; $SQ_{E6=}$ pH; $SQ_{E7=}$ OM/TOC; $SQ_{E8=}$Active carbon $SQ_{E9=}$Microbial biomass; $SQ_{10=}$ extractable nutrients (NPK); K $_=$ Weighting coefficients

The soil physical, chemical and biological data from farmland, grassland and woodland of Iriiri, Matany and Rengen sub-counties were tested for normality distribution. In order to assess the influence of different land uses on soil measurable parameters, analysis of variance (ANOVA) was accomplished using SPSS (version 24). To separate the mean value significance and determine the strength of relationships among soil attributes, Duncan's multiple range test and Pearson's correlation coefficients, respectively were performed.

The soil quality index was determined by selecting the most suitable minimum indicators data set of the soil function using methods described by Andrews et al. (2002). Then the indicators in the MDS were scored and incorporated in the soil quality index (SQI).

Principal component analysis (PCA) is a technique used to find underlying correlations that exist in a (potentially very large) set of variables (Bloomer et al., 2014).

Principal components (PC) are sets of variables which are linearly uncorrelated. The PC of dataset are known as linear combinations of variables that explain the maximum variance within the whole set of data. The system attributes representative variables which were used in this study were those with high eigenvalues from the PCA and high factor loading. Hence, the principal components which had >1 eigenvalues plus those that explain a minimum of 5% were considered for varimax rotation as per Brejda et al. (2000) and Sharma et al. (2005) studies.

The varimax rotation was done to maximize the correlation between principal components plus the attributes which were measured (Shukla et al., 2006). The attributes, which had the highest positive and negative loadings, were considered for scoring. The considered indicators were scored by transforming them using linear scoring method as detailed by Andrews et al. (2002). Further, the indicators were grouped based on available scientific knowledge, which either put its higher or lower values as good or bad in terms of soil quality. In cases where the higher is better, the highest recorded value of a parameter scored 1 whiles the rest less than 1. Similarly, in cases where the lower is better, the lowest recorded value of a parameter scored 1 and the rest <1. This was done by dividing either the better higher or lower parameter value by its self hence, resulting into 1 and the rest into <1. In cases where the scientific better was in a range, for instance pH 5.5-7.2, parameters were either scored as more is better up to the threshold value or the less is better above that threshold as per Liebig et al. (2001) study. The observed values were transformed into score, then weighted by using the results from the PCA. The individual principal component articulated a percentage of all formally selected variations PCs and was given a weighted factor (W)

Each principal component explained a certain percentage of the variation in the total data set. This percentage, divided by the total percentage of variation explained by all the previously selected PCs, gave the weighted factor (W) for attributes selected under a given PC (Appendices 1- 10). Weighted variables' scores for each observation were summed up using the equation

$$SQI = \sum_{i-1}^{n} w_i \, s_i$$

Where $S_i$ is the score for the soil measurable variable and $W_i$ is the weighting factor derived from the PCA. Higher scores of SQI signify better soil quality and vice versa. Different land use soils prameters of each study Sub-County were grouped into different categories based on the ratings of their soil quality indices

### 5.2.3 Limitation range determination

The limitation ranges of each listed key soil parameter, in the principal components (PC), for general crops growing were obtained from available literature/theories. The minimum data set (MDS) were scored on a scale of 1-10. This was done depending on the scoring function, developed for individual attribute from literature (Gugino et al., 2017). A score of ≤ 3 was considered as very - low, 4-8 were regarded as moderate and any value with score greater than 8 was regarded as suitable. In this regard, a parameter in its detrimentally high levels for crops growth was ranked as low as the one in the very low state. This was done to maintain the soil quality for crops production. Parasitic nematodes, were ranked low in the moderate ranking while the beneficial were ranked slightly higher. This was done due to the fact that, parasitic nematodes are known to interrupt crops growth and reduce their yields (Gillet et al., 2017). However, they are parasitic, they may be beneficial in the ecological system balance, which was not in the scope of this study, hence were not ranked in the critical levels. All mycorrhiza species (AMF) being beneficial to plants and the ecological system, were ranked high.

The cumulative scores, for each Land use change was used to compare the soil quality and the comparative and superlative degrees awarded after the discussion of the limitations of each individual MDS as per Gugino et al., 2007. The ranking of the land use for quick grasping was presented as bar graphs. The ranking for soil attributes was also done at range level for many crops, other than critical levels that mainly target individual crops.

## 5.3. Results and Discussion

### 5.3.1 Minimum data set (MDS) of different land use for soil quality indexing

The principal component analysis resulted into significantly altered measurable attributes across the three land uses (woodland, grassland and farmland) in the entire study area. Appendix Table 1, indicates the actual extracted factors. The section categorized as “Rotation Sums of Squared Loadings (RSSL),” shows factors that met the cut-off criterion (extraction method). Five factors had eigenvalues > 1. The percentage of variance column indicates how much of the total variability (all the variables together) can be accounted for by each of the factors or summary scales. Factor 1 accounts for 51.4%, while 2, 3, 4 and 5 accounts for 14.4, 13.8, 9.6 and 5.4 % respectively, of the variability in all 32 variables. Cumulatively, the five variable accounts for 94.6% (Appendix Table 1).

In order to facilitate quick understanding of the influence of land use on soil quality (SQ), 32 soil qualities were correlated. The correlation matrix indicated a high correlation among 85 out of 90 soil qualities ($P < 0.01$ & $P < 0.05$). This indicated that soil physical, chemical and biological properties respond to Land use change in clusters. Hence, in order to determine principal components of the 32 parameters, their analysis was done. This led to 7, 6 and 17, PCs with <1 eigenvalue for Iriiri grassland, farmland and woodland respectively. Overall, explaining 91.605%, 96.063% and 96.073% respectively (Appendix Tables 2, 3 and 4). To determine the PC for other sub-counties similar procedures alluded to above were followed. The results for Matany Sub-County were; for grassland 8, farmland 9 and woodland 29 PC. The PC explained 95.334%, 95.830% and 93.921% for grassland, farmland and woodland for all attributes respectively (Apendix table 5.5, 5.6 and 5.7). For Rengen, for grassland 10, farmland 11 and woodland 10 PC contributing to 97.382%, 98.176% and 98.143% of the entire attributes respectively (Appendix Table 8, 9 and 10).

Finally, all land use attributes combined resulted into grassland 6, farmland 13, and woodland 7 PC with each contributing to 83.095%, 82.974% and 82.376% of the entire data respectively. The contribution of soil attributes to SQI in deferent land use for each study Sub-County varied significantly. Since there were many attributes for each land use and Sub-County, the attribute with the highest rotated factor loading per each PC column was considered for discussion. Therefore, in Iriiri grassland, field capacity (FC) contributed the highest in PC-1 with a rotated factor loading of 0.985. Then the PCs, which were considered in PC 2, 3, 4, 5 and 6, are, OM (0.905), available water (0.957), fungi cfus (0.943), Gigaspora (0.993) and calcium (0.962). In the farmland, PC-1 to PC 6 were; stable aggregates (0.890), available water for plants (0.878), *Aphelenchoides* sp (0.872), *Scruttellonema* nematode sp (0.912) and calcium (0.962). The woodland had SP (0.984) for PC-1, magnesium (0.988), aphelencoides nematode sp (0.821), available water (0.960) and OM (0.946).

The soil quality index (SQI) for Matany Sub-County, grassland PCs were represented by, SP with rotated factor loading of 0.975, Bd (0.915), available water (0.916), bacteria cfu (945), *Scuttelospora* (0.927), calcium (0.824) and pH (0.813) from PC-1 to PC-6. In case of farmland, SP (0.979), OM (0.84), soil respiration (0.9231), *Drylaimus* nematode (0.856), *Actinomycetes* (0.955) and soil bulky density (0.823). The considered PC for woodland were; SP (0.989), Bd (0.938), calcium (0.790), Stable aggregate (0.872), Drainage rate (0.839) and Gigaspora (0.771).
Rengen SQI for grassland, farmland and woodland were represented by their PCs with the highest values in each column as presented. Grassland had Scuttelospora (0.964) as the highest in PC-1 was Mg (0.985), available water for plants (0.954), permanent wilting point (0.954), OM (0.909) and stable aggregates. For farmland K (0.968), SP (0.977), available water (0.903), actionmycetes cfu (0.988), permanent wilting point (0.882) and Gigaspora (0.780). While

woodland scored OM (.972), available water (0.972), pH (0.858), bacteria cfu (0.861), Tylenchus nematode sp (0.833), K (775), soil respiration (0.906) and stable aggregates (0.920) Appendix Tables 1-10.

The soil quality indices were categorized on a scale range of 1-5 are presented in Appendix. The scales were adopted from (Harrach et al., 1999; Okalebo et al., 2003).

Table 11: Major Principal Components for each study site and land use

| Study site | | | Land use | | |
|---|---|---|---|---|---|
| Iriiri | Textural class | | Grassland | Farmland | Woodland |
| | | PC-1 | Clay | OM | Clay |
| | Clay | PC-2 | P | Sand | Mg |
| | | PC-3 | Ca | AW | *Aphelencoides* (Nematode $_b$) |
| | | PC-4 | *Rhibdites* (Nematodes $_b$) | *Aphelenchoides* (Menatode $_b$) | AW |
| | | PC-5 | *Gigaspora* (Mycorrhiza) | *Scrutellonema* (Nematode $_P$) | OM |
| | | PC-6 | *Aphelencoides* (Nematode $_P$) | Ca | SA |
| Matany | | | | | |
| | | PC-1 | Clay | Clay | Clay |
| | Clay | PC-2 | BD ( ℓϐ ) | OM | BD ( ℓϐ ) |
| | | PC-3 | AW | CO2 emission | Ca |
| | | PC-4 | Bacteria cfu | *Drylaimus* (Nematode $_b$) | SA |
| | | PC- | *Scuttelospora* (Mycorrhiza) | Actomycetes (cfu) | Silt |
| | | PC-6 | Ca | BD ( ℓϐ ) | *Gigaspora* (Mycorrhiza) |
| | | PC-7 | pH | Ca | |
| Rengen | | | | | |
| | | PC-1 | *Scuttelospora* (Mycorrhiza) | BD (ℓϐ ) | Clay |
| | Sandy loam | PC-2 | Mg | Clay | Silt |
| | | PC-3 | Clay | AW | pH |
| | | PC-4 | PWP | Actomycetes (cfu) | Bacteria (cfu) |
| | | PC-5 | OM | pH | Nematodes $_P$) |
| | | PC-6 | SA | *Gigaspora* (Mycorrhiza) | P |
| | | PC-7 | - | - | CO2 emission |
| | | PC-8 | - | - | Stable Aggregate |

[1] Where PC = principal component; BD = bulk density; SA = stable aggregates; AW = available water and cfu = colony forming units, Nematode $_b$ = beneficial nematodes; Nematode $_P$ = parasitic nematodes.

### 5.3.2 Categories of soil quality of different land uses in each study Sub-County

Soils of Iriiri and Rengen ranged from low to high, while Matany soil were generally of low quality for cultivation (Table 11). Categorically, Rengen soil were more suitable for cultivation.

Table 12: Categories of Soil quality in different Sub-Counties according to land use

| Sub-County | Land uses | SQI | Soil quality rank |
|---|---|---|---|
| Iriiri | Farmland | 0.398 | Low (0 < 0.5) |
| | Grassland | 0.471 | Medium (0.45-0.5 ) |
| | Woodland | 0.6 | High (> 0.5-1) |
| Matany | Farmland | 0.32 | Low |
| | Grassland | 0.43 | Low |
| | Woodland | 0.502 | Medium |
| Rengen | Farmland | 0.193 | Low |
| | Grassland | 0.475 | Medium |
| | Woodland | 0.613 | High |

Adopted and modified from Lima et al., 2013

### 5.3.3 Farmland SQ ranking in Iriiri, Matany and Rengen Sub-Counties

The farmland SQ equations indicated low quality. This was attributed to soil degradation due to inappropriate farming practices (Tables 11 and 12). The lowest ranking of the SQI in farmland in all sub-counties was linked to soil aggregate mechanical destruction by cultivation. Soils are known to lose its stable aggregates and other physical attributes when it is subjected to the mechanical tillage forces which affect the microbial community (Helgason et al., 2010). The particles are destroyed making both smaller soil aggregated and individual particle. The loosening of soil further lead to top soil pulverization which does not allow water infiltration. This culminates into reduced soil pores, enhanced soil loss through erosion, thus low soil quality for crops production (Mantel and Van Engelen, 1997; Gao, et al., 2017). In line with the above, cultivation increase soil aeration, respiration and the rate of soil OM decomposition. The organic matter loss lead to disintegration of soil particle hence, low percentage aggregates. The SOM reduction resulted in increased soil bulk density as the soil mineral particles lost their organic binders. Zhang et al. (2016) in north China reported a strong negative correlation amid soil organic matter and soil bulk density. Further, the capacity of the soil to hold more water reduced when the aggregates disintegrated. In Iriiri and Matany waterlogging led to the reduction of its SQI. Saturated soils are known to have poor aeration which reduces roots respiration and crops growth (Khtar and Nazir, 2013). In Rengen, soil texture played an important role of the water properties. Water easily drain from light soils because of its low water holding capacity, high drainage rate due to low porosity. Likewise, nutrients like K and other quickly leaked to soil lower layer in light soils. Mainly, the soils were sandy loam, which require minimum tillage and high OM input to maintenance of nutrients holding capacity

(CEC). Zero tillage can conserve up to 2% OM than conversion tillage (Rasmussen and Collins, 1991). It is therefore imperative to add OM in the farmland to enhance and maintain the soil quality.

### 5.3.4 Grassland SQ rank in Iriiri, Matany and Rengen sub-counties

The grassland indicated medium soil quality this can be attributed to slow degradation of soil in the grassland area. Grassland or rangeland are known to have high vegetation diversity and as such OM of different quality. Different vegetation is known to have different C: N ratio. Grasses can recover from any sock much quickly than other vegetation this renders them added advantage of maintaining the SQ through vegetation recycling. However, the observed relatively lower SQ than in grassland can be attributed to the uncontrolled livestock grazing and the resultant soil trampling which are known to reduce carbon dioxide sequestration (Unger et al., 1991; Moscatelli et al., 2015). Soil is compacted by livestock which reduce water infiltration leading to enhanced soil erosion, reduced nutrients availability and less aerated soil. On the other hand, woodland had a high soil quality index. The high SQ index of woodland can be attributed to the relatively more stable ecological setting with lower bulky density. Woodland were less disturbed by human activities, moreover, some forests were considered sacred by the indigenous people. Less disturbance of an ecological setting enabled it to accumulate OM and nutrient in the soil plus maintaining good soil physical properties. This rendered soil to have negligible SQ alteration. Sharrow, (2007) reported a higher soil bulk density in silvopastures 17% greater than that of the adjacent forest.

Iriiri grassland was ranked medium implying that the soil is less degraded than the farmland. Soil porosity is one of the key indicators of soil quality in this study area. Soil with high porosity is known to retain more water which reduce soil aeration, root respiration, nutrients availability to crops and alteration of soil pH (Shallow, 2007) As such the soil quality for crops growth deteriorated. Iriiri and Matany soil are mainly clayey with low permeability and high porosity resulted into waterlogging. Further the cracking nature of clay soils in the dry spells lead to crops roots damage. In addition, soil nutrients were removed through grazing and depositing the dung in other areas (Da Silva et al., 2014). Livestock grazing can be used to determine the low, medium and heavy grazing. This can be represented by the patches of pastures which can be observed in the grazed grass land Schulz, (2016). Further, grazing depreciated the carbon stocks of Caatinga forest eco-systems of Brazil. The available water in the grassland soils was lessened by animal trampling with led to increased soil organic matter stock deterioration, runoff, reduced soil aggregate stability, lessened soil porosity hence, reduced water holding properties (Schulz et al., 2016).

### 5.3.5 Woodland SQ ranking in Iriiri, Matany and Rengen sub-counties

In the woodland, the high SOM can be attributed to the accumulation organic matter associated with ecological balance in the less disturbed woodland as oppose to grazing and cultivation. (Yimer, 20017). The soil pH in both Iriiri and Matany was high which reduce the availability of some nutrients like P through fixation elimination. Rinsing pH increase P availability while the reverse is true (Carrino-Kyker et al., 2016). However, in woodland the nutrients availability is maintained through the vegetation or trees pump back effect which may support beneficial organisms like mycorrhza (Carrino-Kyker et al., 2016). Trees are known to recycle the nutrients by dropping their leaves on the soil surface. The vegetation in the forests take in nutrients from the soil underground to the soil surface where some of the nutrients are dropped as leaf litter. Upon decomposition nutrients are released into the soil. Some of the SOM and its various particles help in binding the soil particles forming water stable aggregates which are important in retaining not only nutrients but water for a well balance SQ. This results into ecologically balance nutrient in the soil under their canopies. Since the soils under woodland are well balanced with relatively high OM, and it is substrate for the beneficial organisms like mycorrriza (Gigaspora spp) availability was higher than in other land uses. In the current study one of the physical indicators is stable aggregates. In this regard, microorganisms like mycorrhiza and OM sources bind soil particles to form stable soil aggregates (Rillig and Mummey 2006; Spaccini and Piccolo, A. (2013).

Table 13: Major Principal Components for each study site, land use and soil attribute averages

| **Study site** | | | | | | |
|---|---|---|---|---|---|---|
| **Iriiri** | **Indicator** | **Grassland units** | **Indicator units** | **Farmland** | **Indicator** | **Woodland** |
| | Clay | 59.6 | OM | 3.14 | Clay | 60.123 |
| | P | 5.572 | Sand | 39.641 | Mg | 1521.25 |
| | Ca | 9379.77 | AW | 0.119686 | Nematode b | 2.8 |
| | Nematode b | 2 | Nematode P | 3.4 | AW | 0.11935 |
| | Mycorrhiza | 2.2 | Ca | 9379.77 | OM | 4.01 |
| | Nematode P | 30.8 | | | SA | 53.976 |
| Matany | Indicator | Grassland | Indicator | Farmland | Indicator | Woodland |
| | Clay | 53.77 | Clay | 53.39 | Clay | 52.47 |
| | BD ( ℓϬ ) | 1.5 | OM | 3.2 | BD ( ℓϬ ) | 1.448 |
| | AW | 0.12664 | CO2 | 0.23052 | Ca | 13137.08 |
| | Bacteria cfu | 4848000 | Actinomycetes cfu | 569900 | SA | 60.948 |
| | Mycorrhiza | 7.7 | BD ( ℓϬ ) | 1.359 | Silt | 17.575 |
| | Ca | 16815.48 | Ca | 12147.89 | Mycorrhiza | 5.5 |
| | pH | 8.43 | | | | |
| Rengen | Indicator | Grassland | Indicator | Farmland | Indicator | Woodland |
| | Mycorrhiza | 10.2 | BD | 1.67 | Clay | 16.47 |
| | Mg | 488.44 | Clay | 15.15 | Silt | 17.72 |
| | Clay | 17.12 | AW | 0.087725 | pH | 6.07 |
| | PWP | 0.158 | Actinomycetes | 580000 | Bacteria cfu | 4756000 |
| | OM | 2.315 | pH | 6.34 | Nematode P | 0.8 |
| | SA | 25.354 | Mycorrhiza | 0.9 | P | 13.872 |
| | | | | | CO2 | 0.3024 |

Source: GL = Grassland; FL = Farmland and WL = Woodland

### 5.3.6 The soil quality indices for Iriiri Matany and Rengen grass, farm and woodland

The soil quality indices for Iriiri grassland were low mostly due to the low levels of P, very high levels of both clay and calcium (Figure 37). For the farmland, the most limiting attributes were sand, available water and calcium. The woodland most limiting attributes were clay, Mg and available water. For Matany, the most limiting soil attributes were pH, clay and calcium. In farmland the most limiting attributes were soil texture, available water and calcium. While for woodland clay texture, Mg and available water were the most limiting soil attributes (Figure 38). Rengen grassland, Mg and the permanent wilting point were the most limiting attributes while, farmland the available water was the most limiting attribute. Finally, the woodland of Rengen had all of its attributed within the medium to high SQ levels. Thus, giving it the status of best soil quality in the study area (Figure 39).

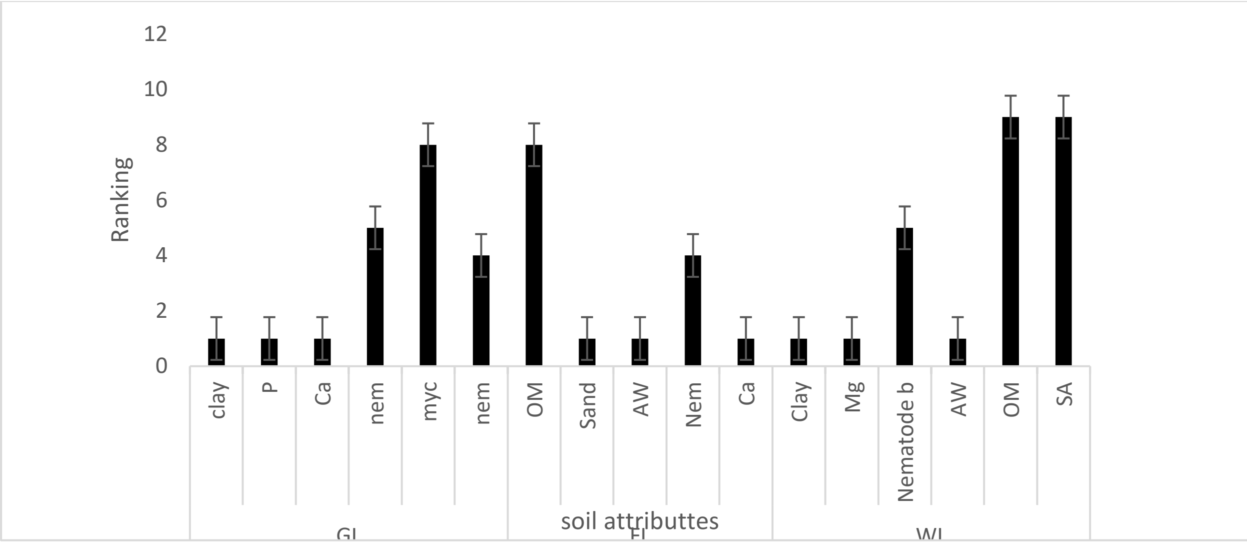


Figure 37: Soil quality rating for Iriiri land uses

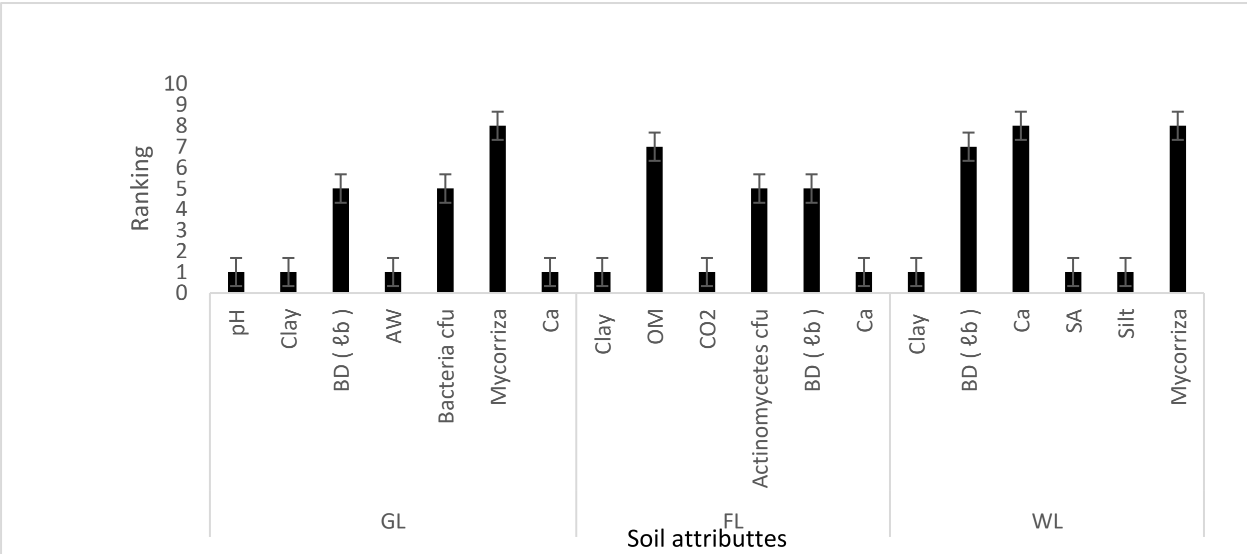


Figure 38: Soil quality rating for Matany land uses

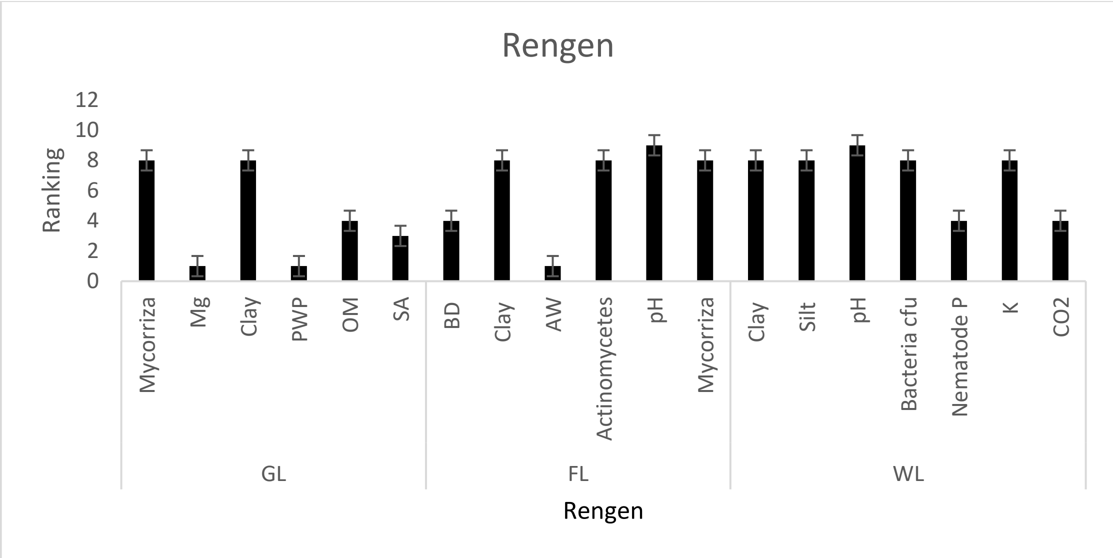


**Figure 39: Soil quality rating for Rengen land uses**

## 5.4 Conclusion and recommendations

1. The results of this study, revealed that soil quality indicators are depends on the type of Land use change in the agro-pastoral Karamoja.

2. Woodland soils were generally of good quality (SQ) closely followed by the grassland and lastly farmland. The reason for these differences is because woodlands are less disturbed by human activities. Soil quality indicators in the woodland reflect a maintained soil ecological balance.

3. Although, soil texture and soil calcium were the most outstanding soil quality indicator across all land uses and Sub-County, there were no universal soil quality indicator for all land use in the study area.

4. Further, in this research, there were fewer soil indicators (physical, chemical and biological) which holds the Liebig's law of the most limiting parameter or nutrients for soils.

6. The alteration of the fungal, nematodes, plus other organisms' community structure and functions in the soil, indicate soil quality changes. Hence, can be used to evaluates the soil quality index

7. The soil quality indicators which are important in determining SQ of Iriiri, Matany and Rengen land use were for grassland soil texture, P, mycorrhiza, nematode and Ca; texture bulk density, Bacteria cfu, pH, AW and Ca; texture permanent wilting point, OM, SA and magnesium respectively.

8. In order to determine soil quality for farmland the following indicators must be considered; texture, OM, Available water, Nematodes and Ca; Texture OM, bulk density, Ca and soil respiration; texture, bulk density, actinomycete cfu, pH, and mycorrhiza fungi for Iriiri, Matany and Rengen respectively.

9. The indicators for woodland which must be tested were texture, available water nematodes and OM; texture bulk density, Ca, water stable aggregates and Mycorrhiza, texture, pH bacteria cfu, nematodes and P for Iriiri, Matany and Rengen respectively.

Therefore, taking into consideration of the most limiting parameter listed (for each study area) can reduce the cost in terms of money and time used in soil sample analyses. Finaly, it is imperative to analyse the soil quality indices, as it helps in monitoring the soil quality to better inform end users.

Hence, there is need for well-planned soil management for sustainable farming in Karamoja. To maintain sedentary agriculture in Karamoja, it is crucial, to practice conservation farming. Thus, there is need to apply SOM, planting green mulch legumes for example *Mucuna spp* Carnavalia and lablab, control soil erosion, maintain optimum livestock carrying capacity to minimize the effects of over grazing and set objective land use policies.

## CHAPTER SIX: SEDENTARY AGRICULTURE AND ITS IMPLICATIONS ON SOIL QUALITY IN AGRO-PASTORAL SEMI-ARID KARAMOJA, UGANDA


### Abstract

Uganda Government embarked on promoting sedentary agriculture in Karamoja agro-pastoral semi-arid livelihood zone, which experienced rapid environmental and high soil quality (SQ) decline. However, studies on sedentary agriculture's impact on soil quality using farmer's knowledge are limited. Consequently, a survey was carried out in Karamoja (Iriiri, Matany and Rengen sub-counties of Kotido, and Napak districts) to determine the soil quality indicator parameters based on the farmers knowledge in order to build a local soil knowledge database to better inform land users. Using a semi-structured questionnaire, forty indigenous farmers per Sub-County, were interviewed within August and September 2015. The study took into account the social demographic characteristics of the people, farming enterprises, methods of raising crops, crops yields trends, causes of the perceived yields trends, soil quality indicators. Prospects of developing Karamoja indigenous knowledge database depends on visible features that predict soil quality. Farmers use 36 parameters to determine SQ. The parameters were clustered into five that is; soil, crop, biological, environmental and management each category contributed 42, 19,14,8 and 17% of the total indicators, respectively. The relationship between age group and the perceived indicators of soil fertility was statistically significant (p-value=0.045) with the majority stating that they use either soil colour, soil depth or soil texture to tell the fertility of soil. The farmer's soil quality indicators assessed in this study is important in establishing indigenous-scientific hybrid knowledge database to enhance soil fertility maintenance and better inform policy makers and other stakeholders. Which age group used these methods most?


**Key words**: *agro-pastoral, Indigenous people, Karamoja, soil quality*


### 6.1. Introduction

Recently, the Government of Uganda decided to promote and extend sedentary agriculture to Karamoja pastoralists (MAAIF, 2010). This has resulted in conversion of expansive areas of the natural land cover into agriculture (Nakalembe et al., 2017). In the agro-pastoral zone, the common crops grown which contribute 50% of household food and income include sorghum (*Sorghum bicolar* L. Moench*)*, maize (*Zea mays* L), field peas (*Vigna unguiculata* L) beans

(*Phaselous vulgaris* L), bulrush millet (*Pennisetum glaucum* L), finger millet (Eleucine *caracana* L), pigeon peas (*Cajanus cajana* L) and sunflower (*Helianthus annuus*) (Jordaan, 2015). Unfortunately, in eastern Uganda crop yields are reportedly sub-optimal due to declining soil quality (Tenywa et al., 1999).

According to Ortega et al. (2016), sedentary agriculture are systems which started around year 12,000 BC, whereby groups of people and their animals started staying in one location permanently. Currently, such a system may include communal pastures where animals graze in proximity distances per day. The pastures are mainly natural rangelands and the cropping areas after harvesting or fallows. Sedentary agriculture is one of the coping strategies to enhance household food security. It can be something brought about by changing economic activities, alteration in technologies, education and government policies. However, sedentary agriculture has a great influence on soil quality.

Soil quality, which is the ability of a soil to sustainably permit plant and animal productivity, conserve or augment water and air quality, and maintain people and their livelihood (Karlen et al.,1997), is generally on the decline throughout Sub-Saharan Africa. In respect of the declining soil quality due to land use alteration, farmers, scientists, policy makers and other stakeholders have become more concerned and have designed different mechanisms for detecting the changes (Muluneh and Arnalds, 2011). Different stakeholders use different indicators to detect soil quality status at any point in time during farming (Buthelezi et al., 2013; Brandt and Geeson, 2015).

Among several soil quality indicators, which various studies have identified as fundamental for soil quality determination in sedentary agriculture, is indigenous knowledge (Brandt and Geeson, 2015). In line with it, farmers have designed copying strategies and/or mechanisms to ameliorate the deterioration. Although indigenous knowledge has no definite definition, it is important in solving local problems in poor communities. Investigating what the people know and have can enhance understanding of local conditions, thus providing productive context for strategies set to help the people (Werner, 2000).

Soil quality maintenance in Karamoja, like in most parts of Sub-Saharan Africa (SSA), is characterised by minimum addition of external inputs (Bekunda et al., 2002 and Bekunda et al., 2010). For example, soil fertility is maintained through dry season grazing of the crop straws (adding livestock dung and urine) and by shifting cultivation. Livestock harvest forages, which they deposit in different parts of the farm as dung containing soil nutrients (Wells and Dougherty, 1997).

In Uganda, a lot of research has been carried out in several locations on soil conservation practices as a part of soil quality maintenance (Bekunda et al., 2010). However, little or no research on either modern or indigenous soil conservation techniques in Karamoja.has been done. This implies that, farmers have managed to keep the soil productive through inherited indigenous knowledge. Nonetheless, the farmers' knowledge of soil quality in Karamoja has been generally disregarded or undocumented by researchers (Mettrick, 1993). There is limited focus on indigenous' people and their complete wealth of knowledge on soil in the agro-pastoral zoneof Karamoja. Elsewhere, Langill (1999) alerted researchers that the strength of indigenous knowledge lies in its ability to place local technologies in their socio-ecological settings. Simiraly, Hart and Mouton (2005) indicated clearly that the indigenous farmers have cocktails of knowledge to perceive differences in farming enterprise. It is upon this back ground that Karamoja indigenous knowledge must be studies, documented before it disappears with the introduced modern soil maintenance technologies

In order to maintain soil quality in its high productive state for a long time, it is imperative to integrate scientific knowledge of soil properties with other stakeholders' knowledge, for example, indigenous people's knowledge, that has sustainably allowed local communities to use and survive on the land (Shukla et al., 2006). The fact that farmers' indigenous knowledge, skills and experience on management of soil quality are not well documented in Karamoja formed the basis of the current study. Perhaps, indigenous knowledge about soil quality alterations due to Land use change can be used to build a local soil knowledge database to better inform land users.

Tapping, documenting and utilizing indigenous knowledge of Karamoja people before it is lost is crucial for practical design of soil quality conservation in the agro-pastoral Karamoja.

## 6.2. Materials and methods

### 6.2.1 Study location

For the location and description of the study site, study approach are as ascribed in Chapter Three - Materials and Methods

### 6.2.2 Data collection

A survey was carried out between August and September, 2015 in the agro-pastoral Karamoja in two districts of Kotido (Rengen Sub-County) and Napak (Iriiri and Matany sub-counties) using a semi structured questionnaire (Appendix 15). The study was purposively done to assess and determine soil quality indicators using sedentary indigenous farmers' knowledge.

To ensure quality of data collection, a team of enumerators from each study Sub-County was selected and recruited with the help of the agricultural extension workers and Sub-County chiefs. The teams were separately trained in all aspects concerning data collection. The training involved theoretical and practical aspects to ascertain that the enumerators were conversant with the questionnaire drawn to collect the desired data. The questionnaire was pretested in each study sub-counties to establish its clarity to both the enumerators and the respondents.

Survey sites and the respondents were selected purposively with the help of agricultural extension officers, political leaders and elders. Respondents were purposively selected targeting farm families, which had been involved in farming for longer than ten years. The main purpose was to get experienced interviewee who were fit to represent the entire population of the agro-pastoral livelihood zone. Using the pretested semi-structured questionnaire, three face-to-face surveys were conducted in the sub-counties by the local enumerators who were earlier trained by the researcher.

The questionnaire which was used to assess farmers' indigenous perceptions on soil quality had closed and open-ended questions. Data on indigenous knowledge on soil quality, information about socio-demographic characteristics, crops yield trends and soil quality indicators were collected by individually interviewing a household member present. Forty farmers were interviewed from each of the three study sub-counties giving a sample size of one hundred and twenty (120) for the entire study area. In addition, separate informal interaction between the researchers, extension workers and elders in the community were carried out and recorded to identify and document other indicators of soil quality. This enabled the researcher to include more information such as the use of plants species as an indicator of soil quality.

### 6.2.3 Statistical Data analysis

Data collected, was cleaned, coded and entered in the Statistical Package for Social Scientists (SPSS 24 version). Data analysis was done, where descriptive statistics were generated for each Sub-County. The data collected from informal discussion with elders was analysed and presented as general indigenous knowledge for the entire study area.

## 6.3. Results and Discussion

### 6.3.1 Socio-demographic characteristics of respondents

Most of the respondent were in their middle age throughout the study sub-counties followed by the old aged and a small number of youth (Table 14). As far as gender is concerned, more male in Iriiri and Rengen answered the questionnaire as opposed to the large number of females in Matany Sub-County. Most of the interviewees were married in the study area. Divorced respondents and few singles were in Rengen and Iriiri with Matany registering neither. However, Matany had more widowed respondents followed by Rengen with Iriiri having none. Majority of the respondent were coming from families with 6-10 people. Respondent families varied from 1 to > 16 and 1-10 people in Iriiri and Rengen sub-counties respectively. Majority of the respondents had received no formal education in both Iriiri and Rengen Sub-County. All sub-counties had interviewees who had attended primary seven (P.7) formal education. Whereas no Rengen Sub-County respondents had gone beyond P.7, Iriiri had all levels of education while Matany had more highly educated respondents than the rest of the study sub-counties.

Table 14: Socio-demographic characteristics of the respondents

| Demographics | | Sub county % respondents Iriiri | Rengen | Matany |
|---|---|---|---|---|
| Age group | Youth (18-35) | 3.0 | 11.4 | 14.7 |
| | Middle age(36-55) | 72.7 | 65.9 | 35.3 |
| | Old (55+) | 24.2 | 22.7 | 50.0 |
| | **N[1]** | **33** | **44** | **34** |
| Gender | Male | 57.6 | 56.8 | 14.7 |
| | Female | 42.4 | 43.2 | 85.3 |
| | **N** | **33** | **44** | **34** |
| Marital status | Married | 93.9 | 77.3 | 75.0 |
| | Single | 3.0 | 11.4 | 0.0 |
| | Divorced | 3.0 | 2.3 | 0.0 |
| | Widowed | 0.0 | 9.1 | 25.0 |
| | **N** | **33** | **44** | **32** |
| Family size | 1-5 | 17.4 | 41.5 | 20.0 |
| | 6-10 | 39.1 | 43.9 | 80.0 |
| | 11-15 | 30.4 | 14.6 | 0.0 |
| | 16+ | 13.0 | 0.0 | 0.0 |
| | **N** | **23** | **41** | **5** |
| Highest level of education | None | 69.7 | 0.0 | 94.1 |
| | PLE (Primary Living examinations) P1-P7 | 12.1 | 47.2 | 5.9 |
| | UCE (Secondary ordinary level) S1-S4 | 9.1 | 16.7 | 0.0 |
| | UACE (Advanced level) S5-S6 | 3.0 | 2.8 | 0.0 |
| | Tertiary education | 3.0 | 33.3 | 0.0 |
| | Below PLE (Primary) | 3.0 | 0.0 | 0.0 |
| | **N** | **33** | **36** | **34** |

Where N (in all Tables) is the number of respondents who answered the questions posed

The socio-economic and demographic characteristics in Iriiri Rengen and Matany sub-counties indicated that middle aged were more involved in sedentary farming than the old aged people and the young. This can be attributed to age difference; middle-aged people tend to work a lot using both mental and physical capability to meet their increasing home demands. Old people tend to spend a lot of time on hobbies and leisure like drinking than the middle aged. Young people tend to spend a lot of time having fun with friends. In a study which was conducted by Verbrugge et al. (1996) in the Longitudinal Studies Branch, Gerontology Research Centre, National Institute on Aging, Baltimor, it was found out that different age groups allocate time for activities differently.

Mainly married people were involved in farming. This is expected in a population where children as young as 10 years of age get married. According to UBOS, 2017, 73.2 5% of the people above 18 years in the study area are married and 50.5% are married at only 10 years of age.

It further illustrated that farming is more dominated by men as opposed to the other gender. The male dominance in farming in the study area is because they are the household head in majority of the farm families [69 and 76 % in Napak and Kotido district respectively (UBOS, 2017)].

The study showed a low level of education in the community. Majority of the farmers were middle and old age with very low level of education 81.9% as opposed to the reported 80% for Napaka district or Bokora County. This is the basic level of education in Karamoja. Most of farmers in Karamojang (93%) are involved in keeping cattle. Therefore, cattle numbers are symbol of wealth and the noblest work (UBOS, 2017). As such, they preferred herding to attending schools.

The mean farmers' household size for the study area (5-10) was in agreement with the reported 5.1 for Matany 5.4 for Iriiri and 7.0 for Rengen sub-counties (UBOS, 2017).

### 6.3.2. Crops commonly grown in the study area

Crops were grown throughout the study sub-counties. However, Rengen farmers were growing more crops than the rest, followed by Matany and lastly Iriiri. According to respondent perception, sorghum was the most widely grown crop throughout the study area, followed by maize, beans, sunflower, simsim and finger millet. A litany of other crops were reportedly grown (Tables 15).

More beans, maize and sunflower were grown in Iriiri, than in Matany and Rengen sub-counties. Out of the three sub-counties, Matany was by far the highest producer of cowpeas. Rengen Sub-County exceeded the others in growing simsim, millet and groundnut (Table 15).

Table 15: Crops grown in each Sub-County

| | Sub county | | |
|---|---|---|---|
| **Crop grown (%)** | **Iriiri** | **Rengen** | **Matany** |
| Sorghum | 24.20 | 24.60 | 26.30 |
| Beans | 21.90 | 10.20 | 12.30 |
| Maize | 22.70 | 10.80 | 13.20 |
| Cowpeas | 2.30 | 3.60 | 13.20 |
| Simsim | 2.30 | 15.00 | 7.90 |
| Millets | 1.60 | 16.80 | 5.30 |
| Cucumber | 0.00 | 1.80 | 1.80 |
| Green grams | 3.10 | 0.00 | 2.60 |
| Pumpkins | 0.00 | 0.00 | 0.90 |
| Sunflower | 17.20 | 2.40 | 8.80 |
| Groundnut | 3.90 | 11.40 | 7.00 |
| Watermelon | 0.00 | 2.40 | 0.90 |
| Cabbages | 0.00 | 0.60 | 0.00 |
| Tomatoes | 0.00 | 0.60 | 0.00 |
| Pineapple | 0.80 | 0.00 | 0.00 |
| **N** | **128** | **167** | **114** |

The reason for farmers' choice of growing sorghum and maize than other crops could primarily be due to the fact that they are drought tolerant, versatile and meets farmers' need for both food and cash. This is in line with a study carried out by Kudadjie et al. (2004); Murungweni, (2016) which revealed sorghum and maize as climate smart crops. . The second reason could be that the sorghum crop can store well under local conditions. Therefore, most farmers prefer growing it. Thirdly, sorghum fetches high market price USD $11-12 and $16-23 compared to its supplementary maize crop, for which price ranges between $9-11 and $14-22 for a 100 kg bag during bumper harvest and bad seasons respectively (Ezaga, 2010). The growing of a variety of other crops in the study area was not a surprise. It is a common practice by most local farmers in various parts of Uganda, which helps to circumvent possible crop failure. This is in agreement with a study, which was conducted in Zimbabwe by Makate et al. (2016), where farmers used crop diversification as a smart agricultural practice to enhance crop productivity and increase resilience in rural smallholders' systems. Crop diversification can lead to reduced incidences of pests, diseases, and weed infestation (Larkin et al., 2010).

### 6.3.3. Farming practices and tools with implications on soil quality

The biggest number in the entire study area used hand hoes and /or slashers while farming, followed by those who used organic residues to amend their soil quality. Only a small number used chemicals. Interestingly, some famers practiced irrigation (Table 16). All respondents in

Matany agreed that they entirely use hand hoes/slashers for growing crops. Iriiri respondents mentioned that they used chemical fertilizers and irrigation for crop production. It was only in Rengen where it was mentioned that they used both farm and inorganic residues.

Table 16: Practices and tools used in raising crops on farm

| Sub-county | Mode of raising crops (%) | | | | | N |
|---|---|---|---|---|---|---|
| | Using hoes/slashers | Chemicals (pesticides) | Irrigating | Organic residues | House and inorganic fert | |
| Iriiri | 76.90 | 5.10 | 17.90 | 0.00 | 0.00 | 39 |
| Rengen | 61.40 | 0.00 | 0.00 | 21.10 | 17.50 | 57 |
| Matany | 100.00 | 0.00 | 0.00 | 0.00 | 0.00 | 25 |

The use of Hand tools in the study area were expected in a community of poor farmers who cannot afford the use of powered implements and can only buy rudimentary farm tools. The tools delay farmland preparation and other activities leading to late planting and plant growth, which expose soil to erosion agent. This was in agreement with Levine (2010) whose report established and documented a cocktail of problems of farming in Karamoja. These included, but was not limited to, environmental degradation, deforestation, poor soils and use of rudimentary farm tools in cultivation. The use of chemical inputs (pesticides) and irrigation in Iriiri could be attributed to the fact that the Sub-County shares its boundary with the relatively more advanced Teso Farming System where various pesticides and some irrigation are used in farming. Therefore, Iriiri farmers could have learnt modern farming practices by observation. In addition. Iriiri Sub-County has a boarder trading centre market where some of these inputs are sold.

### 6.3.4. Crop yield trends and their causes

According to farmers, the level of farm yield in the Karamoja region generally had been decreasing. Only 18.10% of the respondents mentioned that the yields were increasing. A small number of respondents were not aware of the trend of crop yield and did not respond to the locally known causes of yields decline (7.50%). The decreasing crop yields trend could be attributed to soil exhaustion, changing weather and pests and disease.

### 6.3.5. Causes of crop yield decline

The respondents who stated that farm yields were decreasing highlighted unfavourable climate, low quality of seeds, soil exhaustion, soil erosion, diseases and pests as major causes (Table 17). Other reasons included lack of labour, inappropriate farming practices and illiteracy.

Table 17: Respondents assessment of causes of decreasing crop yields

| | **Sub-County** | | |
|---|---|---|---|
| **Reasons for crop yield decrease (%)** | **Iriiri** | **Rengen** | **Matany** |
| Unfavourable climate/ Unreliable rainfall | 8.20 | 21.43 | 46.97 |
| Lack of quality seeds for planting | 22.95 | 15.87 | 12.12 |
| Soil exhaustion | 18.03 | 17.46 | 9.09 |
| Soil erosion | 19.67 | 8.73 | 13.64 |
| Diseases (Crops infested with unknown diseases) and pests | 9.84 | 17.46 | 6.06 |
| Lack of labour to weed | 8.20 | 6.35 | 4.55 |
| Lack of fertilizer application both organic and inorganic | 13.11 | 0.79 | 0.00 |
| Poor farming methods | 0.00 | 3.17 | 3.03 |
| Poor tools | 0.00 | 2.38 | 3.03 |
| Livestock grazing in crops | 0.00 | 3.97 | 0.00 |
| Illiteracy | 0.00 | 0.79 | 1.52 |
| Lack of pesticides | 0.00 | 1.59 | 0.00 |
| N | 61 | 126 | 66 |

The farmer's response to crop performance was not a surprise, most interviewed had experienced many crop failures due to unreliable rainfall and prolonged dry spells. The dry spell further has both direct and the indirect effects. The direct is when crops dry due to insufficient moisture. The indirect can affect the quality of the yield. For instance, when crops received less than enough rainfall, they produce incompletely filled seeds, leading to wrinkle, and diseased seeds. In the subsequent season, farmers may plant these seeds and the resulting yield is likely to be lower than expected. In the study area, soil nutrient mining by crops (exhaustion) and erosion were perceived as the main causes of soil quality decline. These conclusions are similar to the ones recorded by Pimentel and Burgess (2013) and Hatfield et al. (2017) who cited high global soil loss through erosion ending up in declining crops yields worldwide. In addition, the reason for the crop yield decline could be that the soil fertility of Karamoja was low, so the first crops planted were likely to yield higher than the subsequent due to declining soil nutrient status without addition of external inputs. This is in line with a study by Tenywa et al. (1999) which was conducted on finger millet in eastern Uganda, which revealed declining millet yields due to continuous cropping without additional external input.

The litany of other causes of decreasing crops yields perceived by indigenous people were expected and can be explained in part by farmers' having a good understanding of the causes of the crops yield decline. Firstly, this was in line with the GOU (2016) which warned that there was an increase in threat from the pests and diseases invasion. In particular, the Fall Army Worm (FAW) led to a 15 % loss of crop yield countrywide (GOU, 2016 on line). Secondly, the crop yield decline is mainly attributed to unreliable rain season, dry spells and invasion by pests in particular the FAW (GOU, 2016). Thirdly, climatic change is reportedly influencing crop yields by increasing not only pest and diseases prevalence, but enhancing crop losses due unpredictable weather patterns (Larkin et al., 2010 and Makate et al., 2016). These directly reduce the planted crop population and yield per unit area. In a survey carried out by Nakalembe et al. (2017) in Moroto district, the farmers highlighted several causes of declining crop yield similar to the one mentioned by farmers in this study.

### 6.3.6 Farmers' general perception on soil quality trends

Majority of the respondents from the entire study area (80.2%) concurred that they understood the term soil quality through soil fertility. Nonetheless, a minority of interviewees (19.8%) were not aware of soil quality. On the other hand, 73.60% of the respondents confessed that the soil quality was declining and 26.4% were not aware of the changes.

Majority of the farmers understanding of the term soil quality and their awareness of its decline in quality was not a surprise since most farmers consider the soil fertility in relationship to the crop they wish to grow. This decision starts, when the farmers clear the natural vegetation for farming. Farmers first judge whether the soil will produce a good crop or not. This is always done using observable features (Corbeels, et al., 2000 and. Michel et al., 2015. The middle age and old age groups are usually the most knowledgeable age group in farming. They move a lot; compare their soil capability with others in their vicinity. They also discuss with fellow farmers, which makes it easy for them to know the soil quality or productivity status. They always use the experience they have gained over years of growing crops, to compare and contrast the soil productivity during the farm establishment and the existing status.

### 6.3.7 Farmer's soil quality indicators

Respondent farmers were able to tell of the decline in soil quality in Iriiri, Rengen and Matany using a combination of indicators (Tables 18). The interviewee farmers indicated that they mainly use visual soil appraisal approach to identify their farm soil quality and determine its productivity. High and quality crop yields was perceived by the interviewees to be indicators of high-quality soils for crop production and low crop yields for poor soils in all study sub-counties (Table 18).

Most farmers related loam soil to high quality as opposed to sand and clay. Respondents perceived soil with black and brown colours throughout the study area as more productive. Deep soils were perceived as soil more suitable for crop production.

A high-quality soil was related to producing crops with strong stems (vigorous growing crops) whilst weak stems was related to low quality soils. Farmers further attributed low quality soils to the growth of certain weeds and other pests. Well-drained soils were only mentioned in Rengen Sub-County as indicator of high-quality soils.

Soil with high humus content with the presence of earthworm was considered as high-quality soil. Further Matany respondent attributed high soil quality to moisture retention for a long time (without ponding) than the one, which loses it. These responses from the interviewees could mean that they have experience that enables them to know the soil quality status.

Table 18: Farmers' knowledge of good soil quality indicators

| | Sub county | | |
|---|---|---|---|
| **Farmers' indicators of high soil quality (%)** | **Iriiri** | **Rengen** | **Matany** |
| High and quality crop yields | 41.03 | 14.48 | 20.00 |
| Soil texture and morphology (sandy, loam and clay) | 15.38 | 11.76 | 12.00 |
| Soil Colour (black, brown) | 7.69 | 12.67 | 12.00 |
| Soil depth (deep and shallow) | 7.69 | 8.60 | 14.00 |
| Crop firmness (strong and weak stems) | 8.97 | 6.33 | 22.00 |
| Presence of certain weeds and other pests | 5.13 | 8.60 | 10.00 |
| Natural vegetation (like tall grass) | 6.41 | 10.41 | 0.00 |
| Soil pH | 0.00 | 7.69 | 0.00 |
| Well drainage soil | 0.00 | 6.78 | 0.00 |
| Soil friability (easy to cultivate) | 6.41 | 0.45 | 10.00 |
| Soil structure | 0.00 | 2.71 | 0.00 |
| Soil degradation (visible erosion futures) | 0.00 | 3.61 | 0.00 |
| Humus content and macro-fauna presence | 1.28 | 4.06 | 0.00 |
| Good soil moisture retention | 0.00 | 1.81 | 0.00 |
| **N** | **78** | **221** | **50** |

Perception of crops yields quality as indicator of soil quality by the farmers revealed that they related output to the crops growing conditions. Normally, whatever reduces the yield quality decreases the palatability, saleability and profitability of crops. This knowledge can be attributed to the high agricultural activities done in the entire Rengen Sub-County as oppose to other study sub-counties. Through repeated cultivation, farmers might have acquired experience. It probable that farmers have used different soils for growing crops and through experience, they have gained can clearly tell the suitable soil physical conditions for crops growth. The indigenous knowledge recorded from the farmers, pointed out that their management systems are motivated by the yields prediction. Therefore, it is important to carry out small-scale crops yields experiments with them to enhance their management skills. Highly eroded soil was only perceived as of low quality for crop cultivation in Matany. This is not surprising as most highly eroded soils loose the quality for farming through erosion (Pimentel and Burgess (2013*)*.

### 6.3.8. Farmer's Indicators of declining soil quality

Respondent farmers using a cocktail of indicators (Table 19) assessed soil quality decline. In all study sub-counties, the major indicators of declining soil quality were low crop yields with deformed seeds, low harvest from the farm compared with previous harvests and crops growing poorly and maturing unevenly. Respondents in Iriiri and Rengen majorly assessed soil quality decline by the existence of certain weed species like witch weed (*Striga* species). Change of crop colour for instance from green to yellow was considered as an indicator in soil quality deterioration.in Rengen and Matany. When a soil which has been supporting a good crop previously, demonstrates poor seed germination and eventual stunted crop growth farmers attributed this to reducing soil quality.

Table 19: Assessed declining soil quality indicators

| **Soil quality decline indicators as perceived by the farmers** | **Sub county** | | |
|---|---|---|---|
| | **Iriiri** | **Rengen** | **Matany** |
| Low quality yields (deformed and small seeds) | 41.94 | 17.57 | 61.76 |
| Low harvests from the farm compared with the previous | 16.13 | 22.97 | 0.00 |
| Crops growing poorly and maturing unevenly | 9.68 | 16.22 | 11.76 |
| Existence of certain spp. of weeds (Lojokosimat, Kojosimat, Lokothima Bu, Akodet and striga) | 12.90 | 14.86 | 0.00 |
| Highly eroded Soil | 6.45 | 8.11 | 8.82 |
| Change in the colour of the crops (yellow) | 0.00 | 1.35 | 8.82 |
| Previously Good demonstrate poor or no seed germination | 3.23 | 4.05 | 0.00 |
| Stunted crops growth | 3.23 | 2.70 | 0.00 |
| Crops wilt quickly soon after a rain season | 3.23 | 1.35 | 2.94 |
| Crops with weak stems | 3.23 | 1.35 | 0.00 |
| Development of hard pans (soil becomes difficult to work) | 0.00 | 2.70 | 0.00 |
| Bare soil (becoming whitish with erosion features) | 0.00 | 2.70 | 0.00 |
| Cracking soil | 0.00 | 1.35 | 2.94 |
| Poor water infiltration through the soil (water ponding) | 0.00 | 1.35 | 2.94 |
| Quick water drainage | 0.00 | 1.35 | 0.00 |
| **N** | **31** | **74** | **34** |

The indigenous knowledge of the Karamoja farmers was in agreement with the research finding recorded from Nicaragua dry forests. In the study, soil macro-fauna were the keys indicators of soil quality used by indigenous people (Pauli et al., 2016).

Soil moisture retention is important for plant growth. Soils, which drain quickly leads to wilting of crops. On the other hand, soils with ponding water are not suitable for crop production. Water ponding prevents soil aeration.so this is a soil physical property which is important as a measurable indicator of soil quality. The results were in agreement with the findings by Barrios, et al. (1994); Fujisaka et al. (2000); Desbiez et al. (2003) Fleskens, and Jorritsma, (2010), where farmers' indicators of soil quality were based on plant and or crop growth, colour, water holding capacity and texture. However, Karamoja farmers added crop yield quality. It is well documented that nutrient deficiency in crops include necrosis, plants tissues death, loss of crops vigour, wilting. Reducing soil nutrient deficiencies reduces crop yields and plant yield quality. Similar responses were reported in a study, which was conducted by Dawoe et al. (2012) in Ashanti region, Ghana. Scientifically, soil quality indicators are not only limited to its chemical, physical, biological properties but observations, socio-economic indicators together with the procedures used to measure these quantitative indices in agriculture in a broad sense (Mueller et al., 2010). Fleskens did a study and Jorritsma (2010) in Maroon in Suriname where farmer's indicator of soil quality were crop growth, dark colour, water holding capacity and texture.

### 6.3.9 Farmers' use of soil texture as an indicator of soil quality

Soil texture as perceived by farmers (using feel method) Iriiri and Matany were mostly soft and fine, while that in Rengen were rough and less sticky. The different soil textures were perceived as soft and fine, rough, sandy or gritty, sticky and stony (Table 20).
Soft and fine soils were perceived as good soil for crop cultivation, while rough textured soil was termed low to good quality soils for farming. Sandy soils were perceived as poor for crop growth. Sticky related to stagnant water and was of low value to crop cultivation. The shallow and stony soils were assessed as low-quality soils for farming.

Table 20: Farmers' soil texture perception

| Sub county | Farmers Soil texture perception (%) | | | | | | N |
|---|---|---|---|---|---|---|---|
| | Soft and fine | Rough | Sandy soil | Sticky | Shallow | Stony | |
| Iriiri | 22.2 | 27.8 | 1.9 | 40.7 | 0 | 7.4 | 54 |
| Rengen | 43.6 | 30.9 | 7.3 | 14.5 | 3.6 | 0 | 55 |
| Matany | 36.2 | 11.3 | 26.8 | 16.9 | 2.8 | 7 | 71 |

Soil textural classes did not compare well with the analytical results from the National Agricultural Research Laboratories (NARL) Kawanda, which revealed that soil textural classes were; clay for Iriiri and Matany while Rengen soils were mainly sandy loam. In this regard, the soil texture determination by the farmers is not clear. This discrepancy between the scientific and the perceived soil texture can be attributed to the fact that farmer used verysmall areas to determine the texture, or that the samples they used were not representative enough. Therefore, there is need for further investigation.

### 6.3.10 Farmers' soil suitability for crop production

Using indigenous knowledge, farmers classify soil quality for its suitability for agricultural use. The classification of soil and its suitability for use depended on the available plant species (Table 21). Farmers listed a number of plant species used as soil fertility indicators. They indicated the level of soil fertility and the main purpose for which the land under such indicators can be put to use (Table 21).

Table 21: Some common plant species used by Karamoja farmers as soil fertility indicators

| **Soil status for crop production** | **Indicator plant/weeds in Ng'Karamojong language** | **Economic importance of the weeds mentioned by the farmers** |
|---|---|---|
| Fertile soil | Ekwang (*Abutilon hirtum*) | Weeds pasture grass/legumes |
| | Emuria (*Cynodon..dactylon*) | |
| | Eliaro (*I kituiencis*) | |
| | Alilat | |
| Poor soil (infertile soils) low productivity) | Lokile (*Euphobia prostrate*) | Good for grazing |
| | Lomerekin (*Biden pilosa*) | Not good for grazing |
| | Namareta/lochiktae | Retards crops growth |
| | Emekui (*Crossandra subacautis*) | Retards crop growth, bad for grazing and injures farmers |
| | Emoto (S*triga hermontheca*) | |
| Fairly good soils (intermediate between fertile and infertile soils) | • Grasses | |
| | Coach grass (*Digitalia abbyssinica*) | Good grazing land |
| | Star grass (*Cynodon dictyolon*) | |
| | Ereleng.(*Hyperrhania rufa*) | |
| | Nyemomya (*Sorghum arundinacerum*) | |
| | • Legumes | |
| | Lomanang | |
| | Edupanal (*Hibiscus micrantha*) | |
| | Ekamongo | |

Naturally, plants prefer growing in places depending on the soil condition like pH and nutrients available concentration and combinations. A soil with lack of specific suitable soil nutrient and environment may not support some plant species growth. Therefore, plant propagation materials may be dispersed to a location but due to unfavourable conditions, they fail to grow or are suppressed and live only those, which can survive. This in part result into plants as acting as observable indicators of soil quality. The recorded knowledge dates back in 1927, when

Meinzer explained the existence plant species (xerophytes) in deserts that either they use available water sparingly or deep root to trap water from lower water table for their survival.

### 6.3.11 Chi-square differences in demographic characteristics against perceived indicators of soil quality

The relationship between age group, family size and the perceived indicators of soil quality was statistically significant (p-value=0.045); (p-value=0.036), with the majority stating that they use either soil colour, soil depth or soil texture to tell the fertility of soil.
Specific factors indicated that quality of soil, influenced by age group, While the youth (18-34 years) used soil colour and soil depth as indicators of soil quality, the middle aged (35-55 years) used soil colour and crop yield, and the old farmers used a wider variety of factors including: soil colour, soil texture, soil depth, Crop firmness and crop yield.

Information generated in the chi-squares test provide a realistic trend of indigenous knowledge in the study area. Different age groups use different indicators to determine soil quality (Chi-square not presented). Old people have vast experience and wisdom to extend to the new generation both the inherited knowledge and those that they logically learnt from environmental situation. However, Herzog and Rodger, (1988) have reported a result contrary to this that old people have poor knowledge.

### 6.3.12 Summary of farmer's indicators of soil quality

The indigenous farmers' knowledge about soil quality indicators is summarised in Table 22. The knowledge was categorised into five based on the source of the indicators listed by the farmers. Most of the indicators were soil based (42%), followed by those related to crop management (17%), and biologically based (14%).

Table 22: Summary of farmer's' indicators of soil quality

| Categories of farmers' indicators of soil quality | | | | |
|---|---|---|---|---|
| **Soil based (42%)** | **Crop performance based (19%)** | **Biologically based (14%)** | **Environment based (8%)** | **Management (17%)** |
| **Soil colour** | High crop yield | Natural vegetation vigour (vegetation which is removed before cultivation) | Presence of moisture (rain fall) | Inappropriate farming methods |
| **Soil depth** | Crops colour (very green) | Absence of pests and diseases | Location of the land for instance valley, hill side or top (hill sides better soils) | Deforestation |
| **Soil texture** | Crop growth vigorously | Vigorous growth of weeds before cultivation | Wilting of vegetation and crops soon after rain season | Labour shortage |
| **Good Drainage** | Low crop yields (deformed and small seeds) | Presence or absence of marco-fauna like earth worms. | | Occasional grazing livestock on crops |
| **Friability /good work ability** | Crops maturing unevenly | | | Mono cropping |
| **Soil structure Presence of soil OM (particular plant roots)** | Poor crops germination | Existence of certain weed species like witch weed (*Striga hermonthica*) | | Lack of modern farming knowledge |
| **Soil not exhausted** | Change in colour of crops e.g. yellowing | | | |
| **Soil erosion** | | | | |
| **Bare soil becoming whitish or brown** | | | | |
| **Cracking soils** | | | | |
| **Quick water drainage** | | | | |
| **Soil exhaustion** | | | | |
| **Soil texture** | | | | |
| **Local name of soil and. some areas** | | | | |

The indigenous knowledge categories clarify the importance of each source of information. The clusters are related to those, which were mentioned by Desdiez et al., 2004.This indicates that farmer's knowledge largely is related to the measurable parameter. However, the main difference is that farmers use mostly qualitative judgement to determine soil quality, whilst the scientific data makes use of empirical data easy to quantify and compare. Farmer's use of the five categories parameter is of importance and efforts must be given to see how they can be integrated as a measurable indicator of soil quality.

Generally, the study revealed that farmers in Karamoja use qualitative indices for soil quality as opposed to the quantitative indicators. The studies carried out by Desbiez et al. (2004) and

Dawoe. (2012) in Mid-hills of Nepal and Ashanti, Ghana respectively, found out that farmers were using indicators similar to the one in this study. Similarly, Habarurema and Steiner (1997) found out a corresponding relationship between farmers of southern Rwanda soil classification to scientific soil suitability.

### 6.4 Conclusion and recommendtions

1. The findings of this study indicated that according to farmers soil quality was declining in the last 30 years. The decline was linked to the sedentary farming advocated for by the Government of Uganda.
2. According to farmers perception, the SQ decline can be assessed by farmers through five categories namely; soil, crops, biologically, environmentally and management-based indicators.
3. Farmers' perception uses a cocktail of soil quality indicators. The major farmers' indicators of soil quality include; soil colour, soil morphology, soil depth, crop yields, plants growth vigour and colour, presence of certain weeds like *Striga hermonthica* (witch weed), presence or absence of macro-fauna like earthworms, rainfall, crops wilting during the offset of rain, inappropriate farming methods, labour shortage among others.
4. Farmers a vast knowledge of crops yields in relation to soil quality (SQ) terminologies, which agree with scientific parameters.
5. Further, the study findings revealed that there was a need for the people of Karamoja to acquire both formal and informal education and the on farm or field training. Therefore, participatory small-scale crops yield experiment with the farmers and other stakeholders to enhance not only their management skills, but conserve soil quality is imperative.

# CHAPTER SEVEN: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

## 7.1 General Discussion

The land use and cover changes in Iriiri, Matany and Rengen sub-counties are reflected in mainly six land uses categories namely, grassland, farmland, settlement, bare land, woodland, and wetlands. Understanding the extent of Land use change in the agro-pastoral ecological zone of Karamaja, Uganda, is a cornerstone for maintenance of quality soil by developing sustainable productivity strategies. Mainly, the study hinged on the status of soil quality form the scientific point of view, amalgamated with the indigenous knowledge for hybridized information, which enable quick grasping of soil quality maintenance innovations.

The observed increase in farmland size throughout the entire study area (sub-counties of Matany and Rengen), could be attributed to the reducing overdependence on livestock in the entire agro-pastoral livelihood zone of Karamoja. Other studies revealed that the main drivers of the Land use change were farming/cultivation increase, enhanced sedentary settlement, over-harvesting of wood for construction of Manyatas and the enclosures, charcoal production, bricks baking and firewood for both domestic plus household income generation. There were significant land use change due to human agricultural and settlement practices in the entire study area. The study further established that in each of the sub-counties (Iriiri, Matany and Rengen) farmland was the major expanding land use, followed by the settlement. Hence, studies on LULCC practices and their effect on measurable soil quality at sub-counties level are crucial in guiding land use planner, policy makers and other stakeholders for sustainable management practices in the area.

The difference soil chemical and physical properties between different sub-counties land uses could be attributed to the inherent property of the soil. Grassland had significantly lowest pH values than other land use in Rengen Sub-County. The high soil organic matter in Matany Sub-County was mainly due to clayey soil with high pH. In addition, clay soils are known to have large porosity and low carbon dioxide release due to organic matter decomposition. The SOM decomposition in soil decrease with increase in porosity and the reverse was true (Mtambanengwe et al., 2004). The low OM levels in farmland of Rengen, were likely be due to the fact that the soils were sandy loam.

The low values of OM in top soil of the woodland could be attributed to the biological activities; usually macro-fauna like termites destroy the surface litter and burrow it in the sub soils. In addition, OM accumulation in the lower soil layers also might have attested to the fact that woodland was less disturbed for a long time implying that the build-up of vegetation root and exudates for long time could have resulted into higher OM in sub than the top-soil.

The high level of P recorded in Iriiri sub-soil could be because the soils had no clear distinction between soil layers. The comparatively high P levels in the top soil of grassland could be attributed less disturbance and cattle grazing and cow dung deposited on the surface. The significantly lower P levels in Matany and Rengen could be an indicator of effect of farmland/ cultivation on soil P. As P is declining with cultivation also pH is reducing, perhaps this implied initial stage of soil quality decline in the study area (Okalebo et al., 2002).

The reported high levels of calcium and magnesium in Rengen study site sub-soil visas other land uses may be attributed to soil depth. Further, the same explanation holds for the generally low levels of both Ca and Mg in Rengen sandy loam soils. The low values of $K^+$ in top soils of the farmlands in Iriiri and Rengen study areas, could be that the nutrient recycling was disrupted by cultivation. Cultivation tend to destroy the soil structure of the top layer which when coupled with the dry season livestock grazing enhance soil pulverization, hence reducing the porosity. In addition, cultivation is known to expose soil surface (bare soil) to rainfall drops, which compact the top layer, and enhances the nutrient loss in runoff. However, for clay both Iriiri and Matany had a significantly higher amount of clay than in Rengen where soils were mainly sandy loam. This was because the soils of Iriiri and Matany were tested and revealed a clay textural class while Rengen had a sandy loam texture.

The difference in water availability could be because soils textural class of Iriiri and Matany sub-counties was clay. Clay soils have greater porosity and less permeability than the light textured soils; to the contrary, Rengen Sub-County soils were sandy loam, such soils have a high-water drainage rate, low water retention and higher wilting point than the clay soils of Iriiri and Matany.

This was attributed to the textural characteristics, but in addition, the rate at which the water is lost form the soil, could be enhanced by cultivation and livestock trampling of the top soil. The two activities tend to destruct the soil macro aggregates and pores. Therefore, cultivation of

Rengen soils requires soil quality maintenance precautions. Clay soil are known to have a low representative water infiltration rate ranging between 0.0254 and 0.254 and oppose to sandy loam with 1.016 to1.524 cm per hour (Kopec, 1995). The decrease in the water drainage rate in Rengen farmland could also be attributed to the soil aggregate disturbance due to cultivation, which may pulverize the top soil.

The slightly low decrease in available water in the farmland and grassland as compared to the woodland in Rengen could be an early warming of the soil quality decline. In the grassland livestock trampling led to soil compaction which reduced not only the water holding capacity of the soil but facilitated runoff. The same explanation holds for inappropriately managed cultivation, which led loss of SOM, pulverization of top soil, aggregate disruption and exposure of the top soil to raindrops impact.

The high bulk density recorded in the grassland was likely to be due to the frequent livestock trampling of the top soil, which led to compaction of the top layer leading to reduction of soil macro pores. Uncontrolled number of livestock grazing on a piece of land is known to not only compact and reduce water infiltration into soil, but also reduce biodiversity. Thus, enhance soil loss through erosion, which may led to loss of top soil, reduce water infiltration and negatively impact soil biological properties and processes (FAO, 2016). Similarly, the increased in bulk density in the Rengen farmland indicated deteriorating soil quality due to cultivation. The low level of the fungal colony forming units (cfus) in Iriiri and Matany sub-counties could be attributed to the soil pH. On the other hand, the soils of Rengen were sandy loam with a relatively neutral pH, which might have supported the fungal population proliferation. However, the high population of bacteria in Rengen woodland and grassland could be attributed to organic matter decomposers in well-aerated sandy loam soils which holds more bacterial. Farmland lower population of both bacteria and fungi than in other land uses was likely due to the destruction of the soil structure, enhanced runoff by exposing the soil to eroding factor and increased OM decomposition. It was likely that, when soil structure was destroyed some fungi, which acted as binders, were destroyed; OM was exposed to quick decomposition, thus reducing the microorganism’s substrate and eventual population decrease. In line with the above scenario, the soil become vulnerable to losses through wind and water erosion, which resulted in some organisms’ loss. The high carbon dioxide release, which was recorded in grassland in both Rengen and Matany, could be an indicator of enhanced soil organic matter decomposition. Soil respiration in woodland of both Matany and Rengen could be related to the ecological balanced carbon dioxide release in the study site. The low levels of respiration in grassland and woodland of Matany and Iriiri respectively, could be due to the possible reduction in the, availability, abundance and diversity of aerobic microorganisms due to waterlogging in the clay soils. Very low respiration usually caused by high soil bulk density is known to be an indicator of poor-quality soil with limited release of nutrients for plants growth. The AMF population reduction in grassland and farmland was a sign of soil quality decline due to poor farming practices. As such, their presence in the soil was an indicator of good ecologically or fairly balanced soil quality. Therefore, it was plausible that the population of nematode was highest in grassland than in other land Nematodes may be useful indicators of soil quality because of their tremendous diversity and their participation in many functions at different levels of the soil food web. Several researchers have proposed approaches to assessing the status of soil quality by counting the number of nematodes in different families or trophic groups (Blair et al., 1996).

The farmland soil quality equations indicated low quality. Cultivation is also known to increase the rate of soil respiration by enhanced soil aeration, which increase the rate of SOM decomposition. The SOM reduction in the soil resulted in increased soil bulky density as the soil mineral particles lost their organic aggregates binders. Potassium and other nutrients are known to leach to soil lower layer in light soils. Hence, addition of OM in the farmland to enhance and maintain the soil quality is imperative. The grassland indicated medium soil quality this can be attributed to slow degradation of soil in the grassland area. On the other hand, woodland had a high soil quality index. Soil porosity is a key indicator of soil quality. Therefore, the SQ of both Iriiri and Matany is affected by soil texture, which determine the soil bulk density. On the other hand, the reduction in soil quality of Rengen is majorly due to soil nutrients availability. The available water in the grassland soils can be lessened by animal trampling with led to increased soil organic matter stock, runoff, reduced soil aggregate stability, lessened soil porosity.

This, reduce water holding properties (Schulz et al., 2016).

In the woodland, the high SOM can be attributed to the accumulation organic matter associated with ecological balance in the less disturbed woodland as oppose to grazing and cultivation. The soil pH in both Iriiri and Matany is high which reduce the availability of some nutrients like micronutrients through precipitation.

In the agro-pastoral Karamoja, woodland soil was mainly of good quality closely followed by the grassland and farmland with declining soil quality due to the reason allude to above.
Due to differences in soil forming parental rocks in the study area, it was difficult to come up with one universal soil quality index for the entire area. The analysis of the combined soil quality attributes (SQI) showed that soil quality decrease in Karamoja farmland due to nutrient imbalance, soil texture and its effect on soil water availability for crop yield are the critical in crops production in Karamaoja. Soil nutrients especially the P and N are the most limiting chemical attributes for crops production. In order to maintain the soil quality for crops production farmers and other stakeholders should consider addition of organic matter to soils. Further, farmers need to employ crop rotation and minimum tillage to minimize soil surface disturbance with led to accelerate soil water losses. It is a common practice by most local farmers in various parts of Uganda, which helps to circumvent possible crop failure. The tools delay farmland preparation and other activities leading to late planting and plant growth, which expose soil to erosion agent. The farmer's response to crop performance was not a surprise, most interviewed had experienced many crop failures due to unreliable rainfall and prolonged dry spells. In the study area, soil nutrient mining by crops (exhaustion) and erosion were perceived as the main causes of soil quality decline. In addition, the reason for the crop yield decline could be that the soil fertility of Karamoja was low, so the first crops planted were likely to yield higher than the subsequent due to declining soil nutrient status without addition of external inputs. This was in agreement with Tenywa et al. (1999) study which was conducted on finger millet in eastern Uganda which revealed declining millet yields due to continuous cropping without additional external input.

The litany of other causes of decreasing crops yields perceived by indigenous people were expected and can be explained in part by farmers' having a good understanding of the causes of the crops yield decline. Secondly, the crop yield decline is mainly attributed to unreliable rain season, dry spells and invasion by pests. Thirdly, climatic change is reportedly influencing crop yields by increasing not only pest and diseases prevalence, but also enhancing crop losses due unpredictable weather patterns (Makate et al., 2016). These directly reduce the planted crop population and yield per unit area.

Majority of the farmers understanding of the term soil quality and their awareness of its decline in quality was not a surprise since most farmers consider the soil fertility in relationship to the crop they wish to grow. Farmers first judge whether the soil will produce a good crop or not. They also discuss with fellow farmers, which makes it easy for them to know the soil quality or productivity status. They always use the experience they have gained over years of growing crops, to compare and contrast the soil productivity during the farm establishment and the existing status.

Perception of crops yields quality as indicator of soil quality by the farmers revealed that they related output to the crops growing conditions. Normally, whatever reduces the yield quality decreases the palatability, saleability and profitability of crops. It probable that farmers have used different soils for growing crops and through experience, they have gained can clearly tell the suitable soil physical conditions for crops growth. Highly eroded soil was only perceived as of low quality for crop cultivation in Matany. This is not surprising as most highly eroded soils lose the quality for farming through erosion (Pimentel and Burgess (2013). In the study, soil macro-fauna were the keys indicators of soil quality used by indigenous people (Pauli et al., 2016). Soils, which drain quickly leads to wilting of crops. On the other hand, soils with ponding water are not suitable for crop production. Water ponding prevents soil aeration. As such, this is a soil physical property which is important as a measurable indicator of soil quality. This was similar to Fleskens, and Jorritsma, (2010) study in Maroon soil fertility management in Suriname where farmer's indicator of soil quality was crop growth, dark colour, water holding capacity and texture. However, Karamoja farmers added the term crop yield quality. It is well documented that nutrient deficiency in crops include necrosis, plants tissues death, loss of crops vigour, wilting. Reducing soil nutrient deficiencies reduces crop yields and plant yield quality.

Table 23: Hybridized soil database

| Scientific indicators | Indigenous Knowledge |
|---|---|
| Soil texture | Soil texture |
| Soil water holding capacity (AW, DR, SP, PWP) | Good drainage |
| Soil bulk density | Easy to plough soils |
| Soil biological properties like respiration | Observable soil organisms like earthworms |

When the soil measurable attributes were compared with farmers' knowledge, it was clear that some information which was got from farmers did match with the scientific knowledge (Table

23). Although indigenous people did not precisely indicate or quantify the parameter they use, most of the parameters they use, to some extent their ideas correspond directly with the scientific knowledge. For instance, the soil textural knowledge indicate differences in soil quality that was in agreement with the scientific knowledge where clay soils are known to have a higher water holding and compared with both sandy and loam. Farmer perception of a good soil as the one with good drainage also matched with the soil water properties listed in Table 23. For soil biological properties the perceived main difference was that, farmers could only identify macro-fauna like earthworms.

### 7.2 Conclusion

1. The study revealed that there are six dominant land uses. The results of the study has shown that substantial land use changes occurred between the years 1986 and 2015.
2. There was significant land use change due to human agricultural and settlement practices in the entire study area.
3. The study further established that in each of the sub-counties (Iriiri, Matany and Rengen) farmland had the greatest expansion rate, followed by settlement. The grassland, woodland and bare land were decreasing while wetland remained constant. Thus, human practices are the major causes of land use change in the agro-pastoral Karamoja.
4. The results suggested that Land use land cover change influenced soil chemical, physical and biological properties in the study Sub-Counties of the agro-pastoral semi-arid Karamoja. The alteration of natural woodland to grazing and farmland reduced the SOM, P and K.
5. The soil texture was more dependent on the soil inherent properties which are mainly determined by the soil forming factors.
6. The woodland changes to grassland reduced the water stable aggregates. Biologically, farming led to reduced soil respiration due to reduced SOM the microbial substrates.
7. The mycorrhiza population for AMF, *Gigaspora spp, Acaulospora spp*, and *Scutellospora spp* decreased in Rengen Sub-County. Farming also decreased the nematodes, *Scotellonema spp*, but increasesd the population and availability of *Aphelenchoides spp* which are plant parasitic nematodes.
8. The findings have shown that clearing of the woodland and the subsequent grazing and farming/cultivation have a negative influence on the measurable soil properties.

9. The study has shown a lower soil quality in farmland than woodland and grassland a hence superior soil quality under human managed than the natural vegetation/woodland
10. . The social survey which was carried out in the study area indicated that indigenous people were aware of the declining soil productivity which was in agreement with the declining soil properties in farmland as indicated with the measurable attributes.
11. . Whereas the farmers did not use empirical information, some attributes they use provide good hints of soil quality as the measurable parameters. For example, the presence of soil macro-organisms, the soil texture, and available soil water as indicators of soil quality. Therefore, farmer's indiginous knowledge can be used to determine soil quality.

## 7.3 Recommendations

1. Farming in the agro-pastoral Karamoja need soil conservation measures like organic amendments that include planting of legumes such as *Canavaria*, *Lab lab and Mucuna spp*, crop rotation and minimum tillage to minimize soil surface disturbance which lead to accelerated soil water losses.

2. There is a need to come up with the optimum livestock carrying capacity of the agro-pastoral Karamoja depending on the available natural vegetatative resources.
3. Further studies regarding the tracking and comparing famer's observations with scientific knowledge in order to determine the SQ and periodically furnish empirical recommendations as may be necessary.
4. It is critical to carry out more studies on soil quality to enable policy makers come up with rational land use policy for Karamoja agro-ecosystem constant soil quality monitoring.

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# APPENDICES

## Appendix 1: Scores for the soil variables

| Sub County | Iriiri | Iriiri | Iriiri | Matany | Matany | Matany | Rengen | Rengen | Rengen |
|---|---|---|---|---|---|---|---|---|---|
| **Land use** | **Farmland** | **Grassland** | **Woodland** | **Farmland** | **Grassland** | **Woodland** | **Farmland** | **Grassland** | **Woodland** |
| pH | 0.95 | 0.98 | 0.95 | 0.90 | 0.89 | 0.89 | 0.98 | 0.87 | 0.93 |
| OM | 0.70 | 0.82 | 0.89 | 0.71 | 0.97 | 1.00 | 0.22 | 0.51 | 0.60 |
| N | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 1.00 | 0.27 | 0.29 |
| Bd | 0.97 | 0.82 | 1.00 | 0.99 | 0.90 | 0.93 | 0.96 | 0.86 | 0.95 |
| P | 1.00 | 0.38 | 0.92 | 0.03 | 0.18 | 0.34 | 0.15 | 0.32 | 0.95 |
| Ca | 0.21 | 0.10 | 0.16 | 0.08 | 0.06 | 0.07 | 0.45 | 1.00 | 0.61 |
| Mg | 0.51 | 0.83 | 0.54 | 0.95 | 1.00 | 0.99 | 0.25 | 0.17 | 0.23 |
| K | 0.84 | 0.76 | 1.00 | 0.41 | 0.44 | 0.49 | 0.29 | 0.81 | 0.91 |
| Sand | 0.76 | 0.51 | 0.51 | 0.56 | 0.52 | 0.58 | 1.42 | 1.37 | 1.27 |
| Clay | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.68 | 0.66 | 0.00 |
| Silt | 0.46 | 0.55 | 0.53 | 0.69 | 0.78 | 0.70 | 0.44 | 0.47 | 0.71 |
| PWP | 0.49 | 0.39 | 0.39 | 0.43 | 0.50 | 0.44 | 1.00 | 0.83 | 2.02 |
| FC | 0.82 | 1.00 | 1.00 | 0.93 | 0.93 | 0.91 | 0.43 | 0.46 | 0.47 |
| SP | 0.82 | 0.79 | 0.79 | 0.80 | 0.80 | 0.81 | 1.00 | 0.99 | 0.98 |
| DR | 0.81 | 1.00 | 0.99 | 0.91 | 0.97 | 0.96 | 9.03 | 8.77 | 9.01 |
| AW | 0.86 | 0.95 | 0.94 | 0.97 | 1.00 | 0.96 | 0.69 | 0.72 | 0.78 |
| cfu (Fungi) | 0.13 | 0.13 | 0.16 | 0.12 | 0.08 | 0.12 | 0.64 | 0.93 | 1.00 |
| cfu(Bacteria) | 1.00 | 0.73 | 0.68 | 0.74 | 0.70 | 0.53 | 0.08 | 0.63 | 0.69 |
| cfu (Actinomycetes) | 0.58 | 0.58 | 0.71 | 0.69 | 0.63 | 0.51 | 0.70 | 1.00 | 0.59 |
| CO2 mg g-1 of soil | 0.66 | 0.67 | 1.00 | 0.67 | 0.84 | 0.52 | 0.60 | 0.37 | 0.51 |
| Glomus SPP. | 0.27 | 0.23 | 0.47 | 0.22 | 0.23 | 0.62 | 0.32 | 0.62 | 1.00 |
| Scutellospora SPP | 0.31 | 0.36 | 0.29 | 0.34 | 0.36 | 0.94 | 0.35 | 0.48 | 1.00 |
| Acaulospora SPP | 0.28 | 0.21 | 0.51 | 0.22 | 0.21 | 0.52 | 0.43 | 1.00 | 0.93 |
| Gigaspora SPP | 0.27 | 0.40 | 0.53 | 0.16 | 0.40 | 1.00 | 0.16 | 0.71 | 0.82 |
| Rhabdites | 0.14 | 0.08 | 0.29 | 0.27 | 0.19 | 0.13 | 1.00 | 0.58 | 0.58 |
| Aphelenchoides | 0.82 | 0.09 | 1.00 | 0.21 | 0.56 | 0.26 | 0.09 | 0.09 | 0.08 |
| Scutellonema | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Dorylaimus | 0.13 | 1.00 | 0.00 | 0.22 | 0.01 | 0.24 | 0.24 | 0.30 | 0.20 |
| Hemicycliophora | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Criconemela | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Tylenchus | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Stable aggregates | 0.89 | 0.73 | 1.00 | 0.95 | 0.91 | 1.00 | 0.54 | 0.42 | 0.71 |

[1]Where (in all Tables) Bd = bulk density; FC = field capacity; SP = cfu =colony forming units; AW = available water; Dr = drainage rate; PWP = permanent wilting point.

Appendix 2: The principal components (PC) with Eigenvalues and percentage proportion of variance described, with rotated factor loadings and communalities of measurable soil attributes of Grassland in Iriiri

| **Soil attributes** | **PC-1** | **PC-2** | **PC-3** | **PC-4** | **PC-5** | **PC-6** | **Communalities** |
|---|---|---|---|---|---|---|---|
| pH | 0.516 | 0.418 | 0.266 | -0.132 | 0.520 | 0.145 | 0.821 |
| OM | -0.048 | **0.905** | -0.189 | -0.164 | -0.214 | -0.156 | 0.954 |
| Bd | -0.175 | **0.858** | -0.060 | 0.207 | -0.117 | 0.006 | 0.827 |
| P | 0.260 | **0.989** | -0.077 | -0.218 | 0.058 | 0.086 | 0.920 |
| Ca | -0.487 | -0.025 | **0.703.** | -0.076 | -0.347 | -0.119 | 0.871 |
| Mg | 0.556 | 0.393 | 0.483 | 0.134 | 0.254 | 0.111 | 0.792 |
| K | 0.206 | **0.902** | -0.279 | -0.216 | 0.114 | 0.003 | 0.994 |
| Sand | **0.908** | -0.142 | 0.361 | -0.108 | 0.000 | 0.024 | 0.987 |
| Clay | **0.984** | 0.055 | 0.146 | 0.061 | -0.006 | -0.021 | 0.997 |
| Silt | -0.344 | 0.139 | **0.921** | 0.070 | 0.012 | -0.001 | 0.991 |
| PWP | **0.985** | 0.048 | 0.086 | 0.069 | -0.051 | -0.034 | 0.989 |
| FC | **0.985** | 0.104 | -0.041 | 0.086 | -0.017 | -0.034 | 0.991 |
| SP | **0.781** | 0.109 | -0.071 | 0.095 | -0.012 | -0.036 | 0.990 |
| DR | **0.962** | 0.133 | -0.106 | -0.053 | -0.058 | 0.032 | 0.962 |
| AW | 0.127 | 0.145 | **0.957** | 0.160 | 0.070 | -0.013 | 0.984 |
| cfu (Fungi) | 0.174 | -0.591 | 0.226 | 0.621 | -0.148 | -0.398 | 0.997 |
| cfu(Bacteria) | 0.056 | -0.139 | -0.205 | **0.825** | 0.074 | 0.449 | 0.952 |
| cfu (Actinomycetes) | 0.042 | 0.066 | 0.011 | **0.860** | -0.198 | -0.071 | 0.791 |
| CO2 mg g-1 of soil | 0.021 | -0.141 | -0.054 | 0.690 | -0.510 | -0.006 | 0.760 |
| Glomus spp. | 0.302 | 0.053 | -0.129 | -0.162 | **0.927** | 0.365 | 0.799 |
| Scutellospora spp | -0.118 | 0.250 | 0.040 | -0.187 | **0.920** | 0.073 | 0.964 |
| Acaulospora spp | -0.337 | -0.078 | -0.266 | -0.161 | **0.780** | 0.055 | 0.994 |
| Gigaspora spp | 0.061 | 0.317 | 0.135 | -0.111 | **0.993** | -0.303 | 0.856 |
| Rhabdites | 0.118 | -0.249 | -0.098 | **0.927** | -0.123 | -0.030 | 0.962 |
| Aphelenchoides | -0.036 | 0.214 | 0.193 | -0.003 | 0.050 | **0.896** | 0.889 |
| Stable aggregates | -0.169 | 0.420 | 0.649 | 0.122 | 0.113 | 0.320 | 0.756 |
| Scutellonema | -0.177 | 0.135 | 0.640 | -0.606 | 0.162 | 0.302 | 0.944 |
| Eigenvalues | 7.899 | 6.596 | 3.928 | 2.630 | 2.351 | 1.330 | |
| % of Variance | 29.256 | 24.428 | 14.549 | 9.741 | 8.706 | 4.925 | |
| Cumulative % | 29.256 | 53.684 | 68.233 | 77.974 | 86.680 | 91.605 | |
| Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. | | | | | | | |
| a. Land use = Grassland | | | | | | | |
| b. Rotation converged in 7 iterations. | | | | | | | |

Appendix 3: The principal components (PC) with Eigenvalues and percentage proportion of variance described, with rotated: factor loadings and communalities of measurable soil attributes of Farmland in Iriiri

| **Soil attributes** | **PC-1** | **PC-2** | **PC-3** | **PC-4** | **PC-5** | **PC-6** | **PC-7** | **Communalities** |
|---|---|---|---|---|---|---|---|---|
| pH | -0.230 | 0.129 | 0.153 | **0.737** | 0.260 | 0.381 | -0.058 | 0.852 |
| OM | **0.854** | -0.047 | -0.090 | 0.128 | 0.112 | 0.017 | -0.196 | 0.988 |
| Bd | **0.809** | 0.258 | -0.013 | 0.052 | -0.228 | 0.306 | 0.288 | 0.952 |
| P | **0.742** | 0.173 | 0.393 | 0.174 | 0.375 | 0.160 | -0.001 | 0.931 |
| Ca | -0.193 | 0.098 | -0.109 | -0.057 | -0.038 | -0.044 | **-0.962** | 0.990 |
| Mg | 0.430 | 0.311 | -0.485 | -0.578 | -0.235 | 0.294 | -0.040 | 0.995 |
| K | **0.754** | 0.146 | 0.170 | -0.074 | 0.376 | 0.454 | -0.159 | 0.998 |
| Sand | -0.136 | **-0.854** | -0.487 | -0.028 | -0.096 | -0.004 | -0.031 | 0.996 |
| Clay | 0.060 | **0.760** | -0.256 | 0.060 | 0.007 | -0.040 | 0.048 | 0.999 |
| Silt | 0.097 | -0.154 | **-0.772** | -0.043 | 0.116 | 0.058 | -0.023 | 0.997 |
| PWP | 0.097 | **0.782** | -0.143 | 0.054 | 0.016 | -0.041 | 0.030 | 1.000 |
| FC | 0.099 | **0.790** | 0.037 | 0.049 | 0.045 | -0.018 | 0.038 | 0.998 |
| SP | 0.097 | **0.791** | 0.004 | 0.031 | 0.048 | -0.044 | 0.042 | 0.998 |
| DR | 0.076 | -0.150 | **0.740** | 0.144 | 0.058 | 0.246 | -0.050 | 0.999 |
| AW | 0.141 | 0.432 | **0.878** | -0.007 | 0.127 | 0.030 | 0.011 | 0.995 |
| cfu (Fungi) | **-0.763** | -0.090 | 0.072 | 0.218 | -0.055 | 0.042 | -0.018 | 0.993 |
| cfu(Bacteria) | **0.796** | 0.001 | 0.045 | -0.002 | 0.103 | -0.037 | -0.069 | 0.998 |
| cfu (Actinomycetes) | **0.783** | 0.000 | 0.002 | -0.120 | -0.066 | 0.011 | -0.091 | 0.994 |
| CO2 mg g-1 of soil | 0.180 | 0.046 | -0.579 | 0.213 | -0.179 | 0.408 | 0.231 | 0.667 |
| Glomus spp. | -0.405 | -0.633 | 0.174 | 0.055 | -0.039 | 0.551 | -0.104 | 0.915 |
| Scutellospora spp | 0.394 | -0.462 | 0.372 | 0.180 | -0.031 | 0.639 | -0.112 | 0.961 |
| Acaulospora spp | -0.144 | -0.363 | **0.719** | 0.509 | -0.205 | -0.060 | -0.057 | 0.978 |
| Gigaspora spp | -0.511 | -0.245 | 0.456 | 0.217 | -0.601 | 0.105 | -0.143 | 0.970 |
| Rhabdites | -0.340 | 0.651 | -0.284 | -0.001 | -0.548 | 0.034 | -0.144 | 0.943 |
| Aphelenchoides | 0.156 | 0.181 | -0.071 | **0.872** | 0.014 | -0.028 | -0.023 | 0.905 |
| Stable aggregate | **0.890** | 0.232 | 0.114 | 0.077 | -0.126 | -0.471 | -0.025 | 0.944 |
| Scutellonema | -0.010 | 0.072 | 0.252 | 0.258 | **0.912** | 0.018 | -0.122 | 0.982 |
| Eigenvalues | 8.389 | 6.359 | 4.723 | 2.084 | 1.802 | 1.442 | 1.138 | |
| % of Variance | 31.072 | 23.552 | 17.491 | 7.717 | 6.675 | 5.340 | 4.216 | |
| Cumulative % | 31.072 | 54.624 | 72.115 | 79.832 | 86.507 | 91.847 | 96.063 | |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Land use = Farmland

b. Rotation converged in 6 iterations.

Appendix 4: The principal components (PC) with Eigenvalues and percentage proportion of variance described, with rotated factor loadings and communalities of measurable soil attributes of woodland in Iriiri

| **Soil attributes** | **PC-1** | **PC-2** | **PC-3** | **PC-4** | **PC-5** | **PC-6** | **PC-7** | **Communalities** |
|---|---|---|---|---|---|---|---|---|
| pH | 0.343 | -0.162 | -0.279 | 0.416 | 0.066 | -0.068 | 0.696 | 0.888 |
| OM | 0.203 | -0.028 | 0.199 | 0.042 | **0.946** | 0.046 | 0.044 | 0.982 |
| Bd | -0.434 | -0.313 | 0.064 | 0.077 | 0.372 | **0.921** | -0.150 | 0.977 |
| P | -0.175 | -0.192 | 0.073 | -0.188 | 0.054 | **0.925** | 0.098 | 0.976 |
| Ca | -0.144 | **0.951** | -0.179 | 0.105 | -0.100 | -0.035 | -0.080 | 0.987 |
| Mg | 0.017 | **0.988** | -0.064 | 0.122 | 0.009 | -0.016 | -0.041 | 0.997 |
| K | -0.042 | **0.707** | 0.557 | 0.206 | 0.313 | -0.079 | -0.140 | 0.978 |
| Sand | **0.955** | 0.081 | 0.087 | 0.247 | -0.002 | 0.024 | -0.002 | 0.987 |
| Clay | **0.941** | -0.025 | 0.001 | 0.300 | 0.124 | 0.009 | 0.015 | 0.993 |
| Silt | -0.349 | -0.070 | -0.126 | **0.896** | -0.223 | -0.051 | -0.024 | 0.998 |
| PWP | **0.966** | -0.021 | 0.005 | 0.211 | 0.102 | 0.035 | 0.003 | 0.989 |
| FC | **0.981** | -0.044 | -0.029 | 0.129 | 0.088 | -0.004 | 0.010 | 0.990 |
| SP | **0.984** | -0.044 | -0.040 | 0.103 | 0.081 | -0.009 | -0.001 | 0.989 |
| DR | **0.981** | -0.100 | 0.024 | -0.071 | 0.005 | 0.039 | 0.119 | 0.994 |
| AW | 0.040 | -0.073 | -0.147 | **0.960** | -0.136 | -0.078 | -0.049 | 0.978 |
| cfu (Fungi) | 0.143 | **0.752** | -0.226 | 0.506 | -0.175 | 0.236 | 0.125 | 0.996 |
| cfu(Bacteria) | 0.296 | **0.981** | 0.210 | 0.096 | -0.156 | 0.223 | 0.133 | 0.890 |
| cfu (Actinomycetes) | 0.056 | 0.041 | **0.710** | -0.023 | -0.041 | 0.347 | 0.414 | 0.803 |
| CO2 mg g-1 of soil | -0.581 | 0.655 | 0.126 | -0.348 | -0.157 | 0.095 | 0.210 | 0.981 |
| Glomus spp. | 0.036 | -0.213 | 0.018 | -0.523 | 0.415 | 0.664 | 0.186 | 0.969 |
| Scutellospora spp | 0.546 | -0.290 | 0.631 | 0.121 | 0.365 | 0.162 | 0.010 | 0.955 |
| Acaulospora spp | 0.555 | 0.315 | 0.124 | 0.006 | 0.272 | 0.132 | 0.621 | 0.901 |
| Gigaspora spp | 0.174 | 0.554 | -0.626 | 0.087 | 0.435 | 0.122 | -0.028 | 0.941 |
| Rhabdites | 0.201 | -0.338 | 0.679 | 0.412 | 0.222 | -0.042 | -0.331 | 0.946 |
| Aphelenchoides | -0.263 | -0.323 | **0.821** | 0.055 | -0.244 | 0.250 | -0.092 | 0.981 |
| Stable aggregates | 0.196 | 0.094 | 0.278 | 0.100 | 0.111 | 0.138 | **0.837** | 0.866 |
| Scutellonema | 0.111 | -0.097 | -0.286 | 0.328 | **0.874** | 0.140 | -0.062 | 0.999 |
| Eigenvalues | 8.352 | 6.150 | 3.425 | 2.858 | 2.106 | 1.731 | 1.308 | |
| % of Variance | 30.934 | 22.778 | 12.684 | 10.585 | 7.799 | 6.410 | 4.845 | |
| Cumulative % | 30.934 | 53.713 | 66.397 | 76.982 | 84.781 | 91.192 | 96.037 | |
| Extraction Method: Principal Component Analysis.<br>Rotation Method: Varimax with Kaiser Normalization. | | | | | | | | |
| a. Land use = Woodland | | | | | | | | |
| b. Rotation converged in 17 iterations. | | | | | | | | |

Appendix 5: The principal components (PC) with Eigenvalues and percentage proportion of variance described, with rotated factor loadings and communalities of measurable soil attributes of Grassland in Matany

| **Soil attributes** | **PC-1** | **PC-2** | **PC-3** | **PC-4** | **PC-5** | **PC-6** | **PC-7** | **Communalities** |
|---|---|---|---|---|---|---|---|---|
| pH | 0.509 | -0.119 | 0.015 | -0.012 | -0.096 | 0.110 | **0.813** | 0.957 |
| OM | 0.278 | 0.647 | 0.003 | -0.329 | 0.150 | 0.278 | -0.522 | 0.976 |
| Bd | -0.111 | **0.915** | 0.354 | 0.101 | 0.066 | 0.087 | 0.039 | 0.999 |
| P | -0.438 | **0.842** | -0.069 | 0.239 | 0.105 | -0.046 | -0.101 | 0.987 |
| Ca | -0.117 | -0.041 | 0.035 | 0.358 | -0.315 | **0.824** | -0.161 | 0.949 |
| Mg | **0.854** | -0.133 | 0.080 | -0.257 | 0.141 | -0.372 | -0.056 | 0.982 |
| K | -0.403 | **0.818** | 0.057 | 0.211 | -0.133 | 0.105 | -0.013 | 0.908 |
| Sand | **0.901** | 0.028 | -0.385 | 0.046 | 0.086 | -0.082 | -0.105 | 0.989 |
| Clay | **0.975** | -0.099 | -0.090 | 0.026 | -0.040 | 0.052 | 0.095 | 0.983 |
| Silt | -0.487 | 0.156 | **0.829** | -0.132 | -0.062 | 0.031 | -0.019 | 0.972 |
| PWP | 0.308 | -0.592 | 0.519 | -0.245 | -0.193 | 0.331 | 0.275 | 0.998 |
| FC | **0.979** | -0.080 | 0.058 | 0.005 | -0.053 | 0.065 | 0.099 | 0.986 |
| SP | **0.975** | -0.077 | 0.069 | -0.005 | -0.061 | 0.071 | 0.113 | 0.983 |
| DR | 0.362 | 0.068 | **0.826** | 0.013 | 0.011 | -0.033 | -0.142 | 0.839 |
| AW | 0.236 | 0.111 | **0.916** | -0.150 | -0.146 | 0.067 | 0.077 | 0.961 |
| cfu (Fungi) | -0.132 | 0.120 | -0.163 | **0.943** | 0.011 | 0.194 | -0.123 | 1.000 |
| cfu(Bacteria) | -0.023 | 0.192 | -0.187 | **0.929** | -0.004 | 0.243 | -0.047 | 0.997 |
| cfu (Actinomycetes) | 0.070 | 0.049 | -0.135 | **-0.916** | 0.050 | 0.016 | -0.181 | 0.901 |
| CO2 mg g-1 of soil | -0.319 | -0.085 | 0.208 | -0.478 | 0.575 | -0.218 | -0.138 | 0.778 |
| Glomus SPP. | 0.160 | 0.137 | 0.061 | 0.117 | **0.759** | -0.402 | 0.097 | 0.809 |
| Scutellospora SPP | -0.172 | 0.189 | -0.183 | -0.092 | **0.927** | -0.104 | -0.139 | 0.997 |
| Acaulospora SPP | 0.092 | -0.162 | -0.336 | -0.021 | **0.907** | 0.057 | -0.030 | 0.974 |
| Gigaspora SPP | -0.126 | 0.444 | -0.698 | -0.006 | 0.510 | -0.060 | -0.179 | 0.997 |
| Rhabdites | 0.448 | 0.650 | 0.414 | -0.096 | -0.270 | 0.224 | 0.202 | 0.968 |
| Aphelenchoides | 0.093 | **0.739** | -0.527 | -0.106 | 0.247 | -0.061 | -0.123 | 0.924 |
| Stable aggregates | -0.665 | 0.476 | -0.127 | 0.431 | -0.286 | 0.073 | 0.038 | 0.960 |
| Dorylaimus | 0.192 | 0.304 | 0.160 | 0.273 | -0.121 | **0.792** | 0.314 | 0.970 |
| Eigenvalues | 8.160 | 5.383 | 4.194 | 3.820 | 1.922 | 1.261 | 1.002 | |
| % of Variance | 30.220 | 19.936 | 15.532 | 14.147 | 7.118 | 4.671 | 3.711 | |
| Cumulative % | 30.220 | 50.157 | 65.688 | 79.835 | 86.953 | 91.624 | 95.334 | |
| Extraction Method: Principal Component Analysis.<br>Rotation Method: Varimax with Kaiser Normalization. | | | | | | | | |
| a. Land use = Grassland | | | | | | | | |
| b. Rotation converged in 8 iterations. | | | | | | | | |

Appendix 6: The principal components (PC) with Eigenvalues and percentage proportion of variance described, with rotated factor loadings and communalities of measurable soil attributes of Farmland in Matany

| **Soil attributes** | **PC-1** | **PC-2** | **PC-3** | **PC-4** | **PC-5** | **PC-6** | **PC-7** | **Communalities** |
|---|---|---|---|---|---|---|---|---|
| pH | -0.179 | 0.540 | -0.324 | 0.105 | 0.364 | -0.629 | 0.081 | 0.974 |
| OM | -0.322 | **-0.846** | 0.369 | -0.051 | -0.008 | 0.071 | -0.051 | 0.966 |
| Bd | -0.038 | 0.069 | -0.255 | 0.078 | 0.306 | 0.334 | **0.823** | 0.960 |
| P | -0.365 | **-0.718** | -0.157 | -0.055 | -0.027 | 0.264 | -0.179 | 0.779 |
| Ca | 0.225 | 0.109 | 0.236 | 0.250 | 0.022 | **0.865** | 0.185 | 0.963 |
| Mg | 0.457 | 0.075 | 0.029 | 0.147 | -0.069 | **0.839** | -0.129 | 0.961 |
| K | -0.169 | -0.425 | 0.600 | -0.158 | 0.045 | -0.123 | -0.546 | 0.909 |
| Sand | **-0.981** | -0.094 | 0.021 | -0.086 | 0.079 | -0.095 | 0.041 | 0.997 |
| Clay | **0.952** | 0.099 | 0.060 | 0.020 | 0.060 | 0.199 | 0.191 | 1.000 |
| Silt | **0.789** | 0.063 | -0.155 | 0.180 | -0.301 | -0.107 | -0.434 | 0.974 |
| PWP | **0.949** | 0.116 | 0.074 | 0.083 | 0.060 | 0.192 | 0.171 | 0.997 |
| FC | **0.977** | 0.100 | 0.025 | 0.052 | 0.000 | 0.155 | 0.093 | 1.000 |
| SP | **0.979** | 0.100 | 0.024 | 0.050 | -0.008 | 0.150 | 0.071 | 1.000 |
| DR | **0.961** | 0.079 | -0.118 | 0.167 | -0.120 | 0.014 | -0.050 | 0.989 |
| AW | **0.935** | 0.075 | -0.072 | 0.121 | -0.192 | 0.025 | -0.229 | 0.990 |
| cfu (Fungi) | 0.515 | 0.643 | -0.268 | 0.124 | 0.429 | -0.009 | -0.215 | 0.996 |
| cfu(Bacteria) | 0.285 | 0.483 | 0.043 | **0.701** | 0.356 | 0.105 | 0.023 | 0.945 |
| cfu (Actinomycetes) | -0.200 | 0.075 | 0.039 | -0.015 | **0.955** | -0.035 | -0.055 | 0.964 |
| CO2 mg g-1 of soil | 0.137 | 0.271 | **0.923** | 0.053 | -0.018 | -0.052 | 0.083 | 0.958 |
| Glomus SPP. | -0.022 | 0.634 | -0.403 | 0.074 | -0.570 | 0.159 | 0.262 | 0.989 |
| Scutellospora SPP | 0.090 | 0.307 | 0.472 | 0.105 | -0.689 | 0.129 | -0.390 | 0.980 |
| Acaulospora SPP | 0.104 | 0.039 | **0.940** | -0.021 | -0.067 | 0.259 | 0.076 | 0.973 |
| Gigaspora SPP | 0.034 | -0.007 | 0.087 | -0.007 | -0.187 | -0.197 | **0.865** | 0.830 |
| Rhabdites | -0.397 | -0.306 | -0.100 | **0.761** | 0.178 | 0.316 | 0.125 | 0.987 |
| Aphelenchoides | -0.107 | **0.851** | -0.007 | 0.084 | -0.171 | 0.341 | -0.105 | 0.898 |
| Stable aggregates | -0.366 | -0.069 | -0.036 | **-0.834** | 0.349 | 0.050 | 0.162 | 0.986 |
| Dorylaimus | -0.288 | -0.200 | 0.130 | **0.856** | 0.076 | -0.146 | -0.106 | 0.910 |
| Eigenvalues | 9.898 | 4.596 | 3.035 | 2.709 | 2.181 | 2.033 | 1.423 | |
| % of Variance | 36.660 | 17.021 | 11.242 | 10.032 | 8.076 | 7.528 | 5.271 | |
| Cumulative % | 36.660 | 53.681 | 64.923 | 74.955 | 83.031 | 90.559 | 95.830 | |
| Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. | | | | | | | | |
| a. Land use = Farmland | | | | | | | | |
| b. Rotation converged in 9 iterations. | | | | | | | | |

Appendix 7: The principal components (PC) with Eigenvalues and percentage proportion of variance described, with rotated factor loadings and communalities of measurable soil attributes of woodland in Matany

| **Soil attributes** | **PC-1** | **PC-2** | **PC-3** | **PC-4** | **PC-5** | **PC-6** | **Communalities** |
|---|---|---|---|---|---|---|---|
| pH | -.186 | .155 | **.712** | .532 | .336 | -.045 | .963 |
| OM | -.273 | **.894** | -.209 | .145 | -.162 | .160 | .991 |
| Bd | .075 | **.938** | .102 | -.003 | .064 | .276 | .976 |
| P | -.140 | **.769** | -.208 | .479 | .171 | -.056 | .916 |
| Ca | .037 | -.367 | **.790** | .158 | -.113 | .324 | .902 |
| Mg | .079 | -.099 | -.418 | -.801 | .260 | -.217 | .947 |
| K | -.047 | **.918** | -.010 | .010 | .056 | -.375 | .989 |
| Sand | **.964** | .043 | .098 | .080 | -.219 | .054 | .998 |
| Clay | **.984** | -.031 | -.109 | -.020 | -.084 | -.025 | .990 |
| Silt | -.348 | -.024 | .064 | -.163 | **.891** | -.076 | .951 |
| PWP | **.985** | -.018 | -.120 | -.020 | -.057 | -.027 | .990 |
| FC | **.988** | -.036 | -.106 | -.041 | .022 | -.033 | .992 |
| SP | **.989** | -.039 | -.104 | -.047 | .032 | -.040 | .995 |
| DR | .373 | .031 | -.071 | -.051 | **.893** | .031 | .946 |
| AW | **.741** | -.047 | -.068 | -.160 | .631 | -.094 | .988 |
| cfu (Fungi) | .172 | -.009 | -.019 | .588 | .100 | .679 | .846 |
| cfu(Bacteria) | .551 | .443 | -.253 | -.041 | -.230 | .463 | .832 |
| cfu (Actinomycetes) | -.232 | -.017 | -.319 | .386 | -.099 | **.734** | .853 |
| CO2 mg g-1 of soil | -.434 | .501 | .544 | .260 | -.166 | .075 | .836 |
| Glomus spp. | .326 | **.805** | .003 | .062 | .104 | .385 | .917 |
| Scutellospora spp | .471 | .553 | .028 | .582 | -.019 | .040 | .869 |
| Acaulospora spp | .352 | .505 | -.616 | .165 | .401 | .095 | .954 |
| Gigaspora spp | .354 | .370 | -.037 | .307 | .040 | **-.771** | .954 |
| Rhabdites | -.188 | -.052 | **.828** | .411 | .115 | -.275 | .980 |
| Aphelenchoides | -.285 | -.209 | **.845** | -.081 | -.054 | -.147 | .871 |
| Dorylaimus | .018 | -.021 | **.884** | -.400 | .005 | -.117 | .955 |
| Stable aggregates | -.275 | .238 | -.138 | **.872** | -.214 | .007 | .958 |
| Eigenvalues | 8.111 | 6.223 | 3.879 | 3.370 | 2.278 | 1.498 | |
| % of Variance | 30.041 | 23.048 | 14.365 | 12.483 | 8.436 | 5.549 | |
| Cumulative % | 30.041 | 53.089 | 67.454 | 79.936 | 88.372 | 93.921 | |

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Land use = Woodland

b. Rotation converged in 29 iterations.

Appendix 8: The principal components (PC) with Eigenvalues and percentage proportion of variance described, with rotated factor loadings and communalities of measurable soil attributes of Grassland in Rengen

| **Soil Attributes** | **PC-1** | **PC-2** | **PC-3** | **PC-4** | **PC-5** | **PC-6** | **PC-7** | **Communalities** |
|---|---|---|---|---|---|---|---|---|
| pH | 0.653 | -0.593 | 0.239 | -0.111 | 0.260 | -0.292 | 0.021 | 1.000 |
| OM | 0.270 | -0.060 | -0.292 | -0.037 | **0.909** | -0.093 | 0.020 | 0.998 |
| N | 0.169 | -0.181 | 0.435 | 0.001 | **0.821** | -0.026 | 0.256 | 0.991 |
| Bd | 0.648 | -0.300 | 0.285 | -0.090 | 0.563 | -0.215 | 0.171 | 0.992 |
| P | 0.509 | -0.373 | 0.622 | -0.238 | 0.153 | -0.294 | 0.132 | 0.969 |
| Ca | 0.300 | **0.802** | 0.235 | -0.214 | 0.085 | -0.352 | 0.026 | 0.968 |
| Mg | 0.014 | **0.985** | -0.065 | 0.020 | 0.119 | 0.044 | 0.057 | 0.995 |
| K | 0.647 | -0.295 | 0.151 | -0.233 | 0.342 | 0.019 | 0.534 | 0.982 |
| Sand | -0.035 | -0.314 | **0.922** | -0.114 | 0.047 | -0.088 | -0.144 | 0.994 |
| Clay | -0.212 | 0.942 | -0.225 | -0.011 | -0.124 | 0.016 | -0.024 | 0.999 |
| Silt | 0.151 | -0.261 | **0.931** | 0.105 | 0.030 | 0.068 | 0.139 | 0.993 |
| PWP | 0.055 | -0.144 | 0.221 | **0.937** | 0.090 | 0.094 | -0.132 | 0.984 |
| FC | -0.139 | **0.813** | 0.505 | 0.103 | -0.159 | 0.086 | 0.117 | 0.993 |
| SP | -0.212 | **0.953** | -0.051 | -0.096 | -0.154 | 0.042 | 0.049 | 0.993 |
| DR | 0.199 | **-0.774** | 0.425 | 0.353 | 0.177 | -0.007 | 0.021 | 0.976 |
| AW | 0.118 | -0.145 | **0.954** | 0.131 | -0.016 | 0.077 | 0.146 | 0.990 |
| cfu (Fungi) | -0.297 | 0.217 | 0.423 | -0.317 | -0.016 | -0.681 | 0.329 | 0.985 |
| cfu(Bacteria) | -0.337 | 0.195 | 0.282 | 0.123 | 0.188 | -0.150 | 0.792 | 0.929 |
| cfu (Actinomycetes) | -0.481 | -0.369 | -0.091 | 0.143 | 0.159 | 0.254 | -0.647 | 0.916 |
| CO2 mg g-1 of soil | 0.517 | -0.079 | -0.345 | 0.532 | -0.361 | -0.364 | 0.205 | 0.978 |
| GLOMUS SPP. | **0.912** | 0.033 | 0.340 | -0.104 | 0.046 | -0.077 | -0.148 | 0.988 |
| SCUTELLOSPORA SPP | **0.964** | -0.044 | -0.035 | 0.167 | 0.167 | 0.012 | -0.048 | 0.987 |
| ACAULOSPORA SPP | **0.915** | -0.073 | 0.250 | 0.144 | 0.207 | 0.033 | -0.091 | 0.979 |
| GIGASPORA SPP | **0.887** | -0.170 | -0.319 | 0.133 | 0.044 | -0.147 | -0.168 | 0.985 |
| RHABDITES | 0.042 | -0.025 | 0.081 | **0.901** | -0.085 | 0.343 | -0.202 | 0.989 |
| APHELENCHOIDES | -0.132 | -0.203 | 0.310 | 0.478 | -0.346 | 0.694 | 0.077 | 0.991 |
| Stable aggregates | 0.175 | 0.082 | -0.176 | 0.329 | -0.061 | -0.051 | **-0.797** | 0.992 |
| TYLENCHUS | -0.216 | 0.027 | 0.308 | -0.081 | -0.565 | 0.659 | 0.178 | 0.819 |
| DORYLAIMUS | -0.324 | 0.398 | 0.108 | 0.257 | 0.065 | 0.742 | -0.227 | 0.928 |
| Eigenvalues | 9.104 | 5.392 | 5.064 | 3.775 | 2.000 | 1.551 | 1.355 | 0.946 |
| % of Variance | 31.393 | 18.593 | 17.461 | 13.018 | 6.895 | 5.349 | 4.673 | |
| Cumulative % | 31.393 | 49.985 | 67.447 | 80.465 | 87.360 | 92.709 | 97.382 | |
| Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. | | | | | | | | |
| a. Land use = Grassland | | | | | | | | |
| b. Rotation converged in 10 iterations. | | | | | | | | |

Appendix 9: The principal components (PC) with Eigenvalues and percentage proportion of variance described, with rotated factor loadings and communalities of measurable soil attributes of Farmland in Rengen

| **Soil Attributes** | **PC-1** | **PC-2** | **PC-3** | **PC-4** | **PC-5** | **PC-6** | **PC-7** | **PC-8** | **Communalities** |
|---|---|---|---|---|---|---|---|---|---|
| pH | 0.124 | -0.022 | -0.024 | -0.042 | **0.979** | 0.481 | 0.190 | 0.258 | 0.955 |
| OM | 0.684 | -0.080 | -0.628 | 0.299 | 0.028 | -0.046 | 0.022 | -0.038 | 0.967 |
| N | **-0.915** | 0.014 | 0.316 | -0.090 | -0.170 | 0.012 | 0.097 | 0.110 | 0.996 |
| Bd | **-0.853** | 0.083 | 0.299 | 0.068 | -0.268 | 0.026 | 0.311 | -0.044 | 0.999 |
| P | -0.529 | 0.167 | 0.350 | -0.239 | 0.034 | 0.636 | 0.285 | -0.154 | 0.996 |
| Ca | **0.951** | -0.240 | -0.056 | 0.092 | -0.046 | -0.067 | 0.125 | 0.003 | 0.995 |
| Mg | **0.945** | -0.263 | -0.034 | 0.033 | 0.057 | 0.067 | 0.163 | 0.033 | 0.999 |
| K | **0.968** | -0.203 | 0.035 | -0.128 | 0.044 | 0.010 | 0.004 | -0.047 | 0.999 |
| Sand | 0.119 | -0.637 | **-0.700** | -0.128 | 0.228 | -0.008 | -0.145 | -0.026 | 1.000 |
| Clay | -0.176 | **0.974** | -0.062 | -0.116 | 0.037 | 0.010 | 0.002 | 0.024 | 0.999 |
| Silt | 0.009 | -0.076 | **0.896** | 0.255 | -0.307 | 0.001 | 0.173 | 0.011 | 0.998 |
| PWP | -0.107 | -0.206 | 0.018 | -0.327 | 0.123 | **-0.882** | 0.037 | 0.009 | 0.952 |
| FC | -0.174 | **0.955** | 0.218 | -0.022 | -0.061 | 0.025 | 0.060 | 0.033 | 0.999 |
| SP | -0.147 | **0.977** | 0.129 | -0.002 | -0.021 | 0.072 | 0.028 | -0.001 | 0.998 |
| DR | 0.107 | **0.964** | 0.028 | -0.095 | -0.035 | -0.200 | 0.017 | 0.031 | 0.991 |
| AW | -0.028 | 0.144 | **0.903** | 0.212 | -0.295 | 0.008 | 0.174 | 0.007 | 0.998 |
| cfu (Fungi) | 0.345 | -0.127 | 0.036 | **0.921** | -0.034 | 0.016 | 0.060 | 0.102 | 0.999 |
| cfu(Bacteria) | 0.365 | 0.153 | **-0.709** | 0.255 | -0.252 | -0.027 | 0.017 | 0.424 | 0.973 |
| cfu (Actinomycetes) | 0.269 | -0.006 | 0.044 | **0.988** | 0.119 | -0.103 | 0.067 | 0.308 | 0.984 |
| CO2 mg g-1 of soil | 0.206 | 0.147 | 0.519 | 0.645 | 0.099 | 0.376 | 0.088 | 0.222 | 0.939 |
| GLOMUS SPP. | -0.269 | 0.223 | 0.686 | -0.251 | -0.029 | 0.074 | -0.254 | 0.259 | 0.790 |
| Scutellospora spp | -0.681 | -0.049 | 0.042 | -0.245 | -0.200 | -0.071 | 0.044 | 0.651 | 0.999 |
| Acaulospora spp | -0.456 | -0.438 | 0.293 | 0.354 | 0.134 | 0.257 | 0.506 | 0.216 | 0.991 |
| Gigaspora spp | -0.246 | -0.063 | 0.345 | 0.004 | -0.263 | 0.350 | **0.780** | 0.033 | 0.983 |
| Rhabdites | 0.654 | 0.000 | 0.236 | 0.249 | 0.077 | -0.461 | -0.291 | 0.387 | 1.000 |
| Aphelenchoides | 0.272 | -0.080 | -0.259 | -0.068 | **0.841** | -0.352 | 0.004 | 0.004 | 0.995 |
| Stable aggregates | 0.008 | 0.057 | -0.214 | -0.036 | **0.885** | -0.096 | -0.208 | -0.277 | 0.980 |
| Tylenchus | 0.623 | 0.200 | 0.179 | 0.510 | -0.372 | -0.041 | -0.227 | 0.278 | 0.979 |
| Dorylaimus | -0.251 | -0.516 | 0.086 | 0.065 | -0.126 | 0.236 | **-0.758** | 0.056 | 0.988 |
| Eigenvalues | 9.351 | 5.170 | 4.449 | 2.624 | 2.447 | 1.842 | 1.387 | 1.200 | 0.995 |
| % of Variance | 32.244 | 17.827 | 15.342 | 9.048 | 8.438 | 6.353 | 4.784 | 4.140 | |
| Cumulative % | 32.244 | 50.071 | 65.413 | 74.461 | 82.899 | 89.253 | 94.036 | 98.176 | |
| Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. | | | | | | | | | |
| a. Land use = Farmland | | | | | | | | | |
| b. Rotation converged in 11 iterations. | | | | | | | | | |

Appendix 10: The principal components (PC) with Eigenvalues and percentage proportion of variance described, with rotated factor loadings and communalities of measurable soil attributes of woodland in Rengen

| **Soil attributes** | **PC-1** | **PC-2** | **PC-3** | **PC-4** | **PC-5** | **PC-6** | **PC-7** | **PC-8** | **Communalities** |
|---|---|---|---|---|---|---|---|---|---|
| pH | 0.187 | 0.013 | **0.858** | 0.082 | 0.320 | 0.063 | -0.043 | 0.333 | 0.997 |
| OM | **0.877** | -0.028 | -0.212 | 0.176 | 0.005 | -0.295 | -0.041 | 0.220 | 0.987 |
| N | -0.266 | 0.089 | -0.568 | -0.663 | -0.327 | -0.136 | -0.087 | 0.149 | 0.997 |
| Bd | 0.523 | -0.046 | -0.115 | 0.338 | **0.713** | -0.228 | 0.030 | 0.138 | 0.986 |
| P | -0.281 | 0.450 | 0.087 | -0.278 | 0.132 | **0.771** | -0.060 | -0.117 | 0.994 |
| Ca | -0.177 | -0.037 | 0.911 | -0.103 | -0.251 | 0.230 | 0.012 | -0.073 | 0.994 |
| Mg | 0.245 | -0.042 | 0.494 | 0.001 | -0.345 | 0.293 | 0.674 | 0.082 | 0.973 |
| K | -0.005 | 0.097 | 0.287 | -0.359 | -0.098 | **0.775** | 0.315 | 0.205 | 0.977 |
| Sand | -0.327 | **0.934** | 0.011 | -0.044 | 0.041 | -0.081 | -0.013 | -0.041 | 0.990 |
| Clay | **0.954** | -0.255 | 0.073 | 0.045 | 0.105 | -0.055 | -0.046 | 0.005 | 1.000 |
| Silt | -0.278 | **0.946** | -0.052 | 0.011 | -0.096 | 0.101 | 0.038 | 0.033 | 0.994 |
| PWP | -0.103 | 0.082 | **0.881** | -0.037 | -0.475 | 0.010 | -0.278 | -0.073 | 0.928 |
| FC | **0.879** | 0.444 | 0.061 | 0.040 | 0.028 | 0.077 | -0.114 | 0.050 | 0.999 |
| SP | **0.972** | 0.002 | 0.120 | -0.048 | 0.175 | -0.054 | 0.065 | -0.033 | 1.000 |
| DR | **0.808** | 0.331 | -0.210 | 0.214 | -0.288 | 0.102 | -0.153 | 0.102 | 0.980 |
| AW | -0.129 | **0.972** | -0.032 | 0.014 | -0.101 | 0.149 | -0.029 | 0.038 | 0.996 |
| cfu (Fungi) | -0.042 | -0.338 | 0.131 | 0.001 | -0.135 | -0.233 | **0.860** | 0.062 | 0.959 |
| cfu(Bacteria) | 0.165 | 0.355 | -0.003 | **0.861** | -0.033 | -0.104 | -0.059 | 0.165 | 0.933 |
| cfu (Actinomycetes) | 0.246 | 0.347 | 0.054 | **-0.812** | -0.136 | 0.315 | 0.106 | 0.157 | 0.998 |
| CO2 mg g-1 of soil | -0.186 | -0.289 | 0.147 | -0.028 | -0.115 | -0.093 | **0.906** | -0.126 | 1.000 |
| Glomus spp. | -0.641 | 0.065 | 0.121 | 0.372 | 0.051 | 0.612 | 0.131 | 0.194 | 1.000 |
| Scutellospora spp | -0.410 | 0.285 | 0.124 | 0.514 | -0.030 | 0.637 | 0.086 | -0.241 | 1.000 |
| Acaulospora spp | -0.501 | 0.653 | -0.102 | 0.338 | -0.362 | 0.204 | 0.000 | -0.073 | 0.981 |
| Gigaspora spp | -0.469 | 0.213 | -0.409 | 0.551 | -0.230 | 0.031 | 0.228 | -0.313 | 0.938 |
| Rhabdites | 0.513 | -0.438 | -0.450 | 0.090 | 0.247 | -0.220 | 0.016 | 0.385 | 0.928 |
| Aphelenchoides | 0.142 | -0.373 | -0.140 | 0.121 | 0.299 | -0.431 | -0.235 | -0.677 | 0.981 |
| Stable aggregates | 0.083 | -0.021 | 0.114 | -0.031 | 0.280 | -0.063 | -0.221 | **0.920** | 0.997 |
| Tylenchus | -0.013 | -0.144 | 0.230 | -0.275 | **0.889** | 0.012 | -0.154 | 0.050 | 1.000 |
| Dorylaimus | 0.345 | -0.182 | 0.063 | 0.337 | **0.833** | 0.124 | -0.015 | 0.116 | 0.959 |
| Eigenvalues | 8.772 | 4.954 | 4.162 | 3.518 | 2.653 | 1.742 | 1.627 | 1.034 | 0.993 |
| % of Variance | 30.250 | 17.082 | 14.353 | 12.130 | 9.147 | 6.006 | 5.611 | 3.564 | |
| Cumulative % | 30.250 | 47.332 | 61.685 | 73.815 | 82.962 | 88.968 | 94.579 | 98.143 | |
| Extraction Method: Principal Component Analysis.<br>Rotation Method: Varimax with Kaiser Normalization. | | | | | | | | | |
| a. Land use = Woodland | | | | | | | | | |
| b. Rotation converged in 10 iterations. | | | | | | | | | |

Appendix 11: Rating for Mehlich 3 extractable nutrients

**Classification of Mehlich 3 extractable nutrients**

| | **P** | **K** | **Ca** | **Mg** | **Code** |
|---|---|---|---|---|---|
| | -----------------------ppm---------------------- | | | | |
| ***Very low*** | 0 -12 | 0-20 | <330 | <17 | 1 |
| ***Low*** | 12.5 - 22.5 | 20.5-40.5 | 330-655 | 17-46 | 2 |
| ***medium*** | 23 - 35.5 | 41-72.5 | 655-1640 | 46-87 | 3 |
| ***High*** | 36 - 68.5 | 73 - 138.5 | 1640-3280 | 87-145 | 4 |
| ***Very high*** | > 69 | >139 | >3280 | >145 | 5 |

Appendix 12: Rating for pH, $CO_2$ and available water (AW)

| | **pH** | **CO2** | **AW** | | | Code |
|---|---|---|---|---|---|---|
| | | g/kg soil/week | Sand | Clay | Silt | |
| ***Very low*** | 5.5 -6.5 | <300 | <0.112 | <0.181 | <0.164 | 1 |
| ***Low*** | 7 | 300 -500 | 0.113-0.144 | 0.182-0.214 | 0.165-0.187 | 2 |
| ***medium*** | 7.1-7.5 | 500-1000 | 0.115- 0.176 | 0.215- 0.216 | 0.188-0.197 | 3 |
| ***High*** | 7.6 - 8.3 | 1000 - 2000 | 0.177- 0.178 | 0.216-0.217 | 0.198-0.23 | 4 |
| ***Very high*** | >8.4 | >2000 | >0.178 | >0.0217 | >0.23 | 5 |

Appendix 13: Rating for total N and OM

| | OM | N | Code |
|---|---|---|---|
| | '-----------%--------- | | |
| Very low | 0.7-1.0 | <0.05 | 1 |
| Low | 1.0-1.7 | 0.05-0.15 | 2 |
| Medium | 1.7-3.0 | 0.15-0.25 | 3 |
| High | 3.0-5.15 | 0.25-0.5 | 4 |
| Very high | >5.15 | >0.5 | 5 |

Appendix 14: Rating for bulk density and stable aggregates

| | **Soil compaction (BD)** | **% SA** | | | **Code** |
|---|---|---|---|---|---|
| | | Sand | Clay | Silt | |
| ***Very low*** | 1.4 | <15 | <30 | <20 | 1 |
| ***Low*** | 1.41-1.5 | 16-22 | 31-40 | 21-25 | 2 |
| ***medium*** | 1.51-1.6 | 23-30 | 41-50 | 26-30 | 3 |
| ***High*** | 1.61-1.75 | 31-38 | 51-60 | 31-40 | 4 |
| ***Very high*** | >1.75 | 39-45 | >60 | >40 | 5 |

## Appendix 15: Indigenous Farmers' Knowledge Questionnaire

Introducing Guide for the respondents

It has been observed that crop yields are generally low and it is continuously declining due to soil fertility decline. Research has been done on soil and water conservation and technologies has been developed. However their use has remained minimal. The overall objective of this questionnaire is to examine the indigenous people's knowledge about soils in Karamoja, north eastern Uganda.

The views given by the respondents shall be kept confidential and used to accomplish the objectives of this research and for future soil productivity enhancement.

District-----------------------------------------------------------------------------------------------------------

County-----------------------------------------------------------------------------------------------------------

Sub-County------------------------------------------------------------------------------------------------------

Parish-----------------------------------------------------------------------------------------------------------

Village----------------------------------------------------------------------------------------------------------

Date of interview---------------------------------------------------------------------------------------------

**Section A : Social Demographic Information**

(1) Name of respondent-----------------------------------------------------------------------------------

(2) Age group ---------------------------------------------------------------------------------------------

(i) Youth (18-25) ☐

(ii) Middle age (25-55) ☐

(iii) Old (55+) ☐

(d) Sex (i) Male ☐ (ii) Female ☐

(e) Marital status

(i) Married ☐ (ii) Single ☐

(iii) Divorced ☐ (iv) Widowed ☐

(f) Family size

(i) 1-5 ☐ (ii) 6-10 ☐ (iii) 11-15 ☐ (iv) 16+ ☐

(g) What is the highest Level of education attained?

(i) PLE ☐

(ii) UCE ☐

(iii) UACE ☐

(iv) Tertiary level ☐

Apart from your family members, do other people help you on your farm?

1 Yes 2 No

If yes

1. How many?

2. What are the terms?

i. Contract

ii. Permanent

iii. Others (specify)

3. What is the size of your Household?

| **Age years** | **Number** | **Sex** | |
|---|---|---|---|
| | | Female | Male |
| Children <12 | | | |
| Adolescence 13-17 | | | |
| Youth 18-35 | | | |
| Middle age 36-60 | | | |
| Old >60 | | | |

4. What is your main occupation?

(i) Farmers ☐

(ii) Business ☐

(iii) Teacher ☐

(iv) Trader ☐

(v) Casual labourer ☐

(vi) Others specify ☐

5. How much land does your family have?

a.< 2 acres ☐

b. 2-5 acres ☐

c. >5-10 acres ☐

d. > 10 acres ☐

6. A. What type of ownership? ☐

a. Customary ☐

b. Mailo ☐

c. Leasehold ☐

d. Freehold ☐

(B) How did you acquire them?

(i) Inheritance ☐

(ii) Bought ☐

(iii) Hire ☐

(iv) Inheritance and bought ☐

7. (a) How many acres of land do you cultivate?

<1 ☐ 1- 5 ☐ 5-10 ☐ 10+ ☐

**Section B: Existing Soil and Water Management Strategies/Practices**

1. (a). What are the main farming enterprises on you farmland?

i. Crops

ii. Animals

iii. Both crops and animals

iv. Crop, animals and agro-forestry

v. Crops, livestock, agro forestry and aquaculture

vi. Others specify

(b). What farming system do you use on your farm?

i. Mono cropping

ii. Intercropping

iii. Agro forestry

iv. Mixed farming

(c) Which crops do you grow on your farm?

List them in order of importance

Perennials e.g. Banana,

-----------------------------------------------------------------------------------------------------------------------
----

Annuals e.g. Beans, maize

-----------------------------------------------------------------------------------------------------------------------
-----

If you mixed them, how do you usually do it?

(d) What portion of your acres is located to perennial and /or annual crops cultivation?

1- 2 ☐ 2- 3 ☐ 3-4 ☐ 5+ ☐

2. How do you raise these crops?

(i) Using hoes/ slashers ☐

(ii) Chemicals ☐

(iii) Irrigating ☐

(iv) Organic residues ☐

(v) Hose and organic residues ☐

(6) Hose, organic residues and chemicals ☐

3. (a) Basing on your farm analysis, are the yields from these crops increasing/ decreasing?

(i) Increasing ☐

(ii) Decreasing ☐

(iii) Both ☐

(b) If decreasing what are the standing reasons?

(i) Soil erosion ☐

(ii) Lack of labour to weed ☐

(iii) Fertilizer application both organic & inorganic ☐

(iv) Poor quality seeds ☐

(v) Soil exhaustion ☐

(vi) Diseases ☐

Others (specify) ______________________________________________________________

4. a) Do you understand the term soil fertility?

Yes ☐ No ☐

(b) Have you observed any serious soil fertility decline on your farm particularly in portions under crop cultivation?

Yes ☐ No ☐

(c) If so, how do you tell that the soil fertility is declining (Probe).

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---- (d) How do you compare the crop yields now and 5- 10 year ago?

(e) What do you think are the main causes of your observation in (d) above---------------------------

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**Table 1. Local soil taxonomy used by farmers of (location e.g. village----------------------- Karamoja**

| Local | Texture | Colour | Location | Uses |
|---|---|---|---|---|
| | | | | |
| | | | | |

(f) How do tell that your soil is fertile? e. g. (tick the appropriate option/s)

(i). Colour (ii). Soil depth (iii). Soil texture (iv). Presence of weeds (v). Crop firmness (vi). Crop yields (vii) Natural vegetation (viii) abundance of Meso-fauna (ix) Friability others specify

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5. (a) List plant species used as soil quality indicators in your area (probe)-------------------------------

----

(b) What are the local names of different types of soil ?-----------------------------------------------

---------------------------------------------------------------------------------------------------------------------

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(c) What is the meaning of each soil name you have mentioned? ---------------------------------------

-----

6. (a) Is there a relationship between the soil name of the area and the crop/soil productivity?

Yes /No

If yes fill the table 2 below

**Table 2. Crop suitability according to farmers (name of interview location---------------**

| Local soil name | Fertility status | Principle crops grown | Yield/kg/ (bags) probe |
|---|---|---|---|
| | | | |
| | | | |

(b) How do you hope to ensure sustainable soil conservation on your land for higher productivity------
----------------------------------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------

(c) List the observable permanent soil properties in your area and rank them according to order of importance (e.g. colour, flatness, stony)

Then let the ranking be done by groups

List the modifiable soil properties (you can use another paper)

**Thank you!!!**

Appendix 16: Questionnaire for GPS positions
AREA ID: ________SITE ID:_________TRAINING SAMPLE#:_________ TODAY

DATE: __/____/____LOCAL TIME:________SURVEYOR'S ______________________

NAME:____________________STATUS/OWNER
NAME:_________________________

DIAGRAM OF GENERAL OBSERVATIONS: Show location of GPS points & site in relation to major features Aerial View (include land marks, north arrow and scale bar) GEOGRAPHIC

COORDINATES: UTM Northing (X):____________ [m] UTM Easting (Y): ______________

[m] UTM Zone: ______ Datum LOCATION OF PLOT TOPOGRAPHICALLY: Ridge ___

Slope ____ Flat ____ Steepness of Slope: ____° (0-90°) Azimuth (downhill direction of maximum slope in which water would naturally run) _____ (0-360°) LAND COVER TYPE (put a check mark next to land cover ___________________________________________________________________________

If existing vegetation is secondary, give original vegetation if known: _______________________________________ PRESENCE OF MANAGED SPECIES (agriculture, agro-forestry, grazing, and range land): Number of managed species (inc. planted):________ Sci. Name (Family/Genus/Species):__________________________

Common name: ________________________ Density: Absent_______ Few ________

Moderate _______ Abundant ________ Uses: Sci. Name _________________(Family/Genus/Species):__________________________ Common name: __________________________ Density: Absent_______ Few ________ Moderate _______ _____________________________________Abundant ________ Uses: Other Observations: ____________________________________________ LAND USE HISTORY (Fill out as far back in time as possible, recording dates of change to forest, pasture, crop, plantation, etc): Time period (mm/yr) Land Cover / Land Use ____/____ - present ___________________________________________________ ____/____ - ____/____ ___________________________________________________ ____/_____ - ____/___

GENERAL OBSERVATION: Elevation (Altimeter reading in meters above sea level): __________________ Seasonal change affects land use or land cover: No_____ Yes_____ If yes, explain:

___________________________________________________________________________