IMPACT OF LAND USE AND COVER CHANGE ON SOIL QUALITY AND PASTURE PRODUCTIVITY IN SEMI-ARID RANGELANDS: THE CASE OF NAKASONGOLA DISTRICT, UGANDA

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A Thesis submitted in Partial fulfillment of the requirements for award of a Doctor of Philosophy Degree in Dryland Resources Management of University of Nairobi

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Declaration

I hereby declare that the thesis entitled "Impact of land use and cover change on soil quality and pasture productivity in semi-arid rangelands: the case of Nakasongola District, Uganda" is the outcome of my own study undertaken with the guidance and supervision of Dr. Geoffrey Kironchi in University of Nairobi, Department of Land Resource Management and Agricultural Technology. The thesis has not been submitted previously to any university or other such institutions for the award of any degree, diploma or other similar titles.

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Approval of supervisors

This is to certify that this thesis is a bonafide research work carried out by Zziwa Emmanuel under our guidance and supervision and is being submitted to the University of Nairobi, for the award of degree of Doctor of Philosophy in Dryland Resource Management.

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Dedication

To my family, friends, supervisors and Nakasongola community for the overwhelming support during the period of research and thesis development

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Abstract

The impact of land use and cover change on soil quality and pasture production was investigated in the rangelands of Nakasongola District, Uganda. Landsat (TM) images of 1986 and 1990 and Landsat (ETM+) of 2000 and 2004 for Nakasongola District were used to determine the extent and patterns of land use and cover change using the Integrated Land and Water Information Systems (ILWIS) 3.6 software. A modified-Whittaker sampling design was used to collect soil and pasture samples in three land cover types (bare, herbaceous and woody) under three production systems (settled, semi-settled and non-settled). The soil samples were analyzed for selected chemical and physical properties while pasture samples were oven dried for biomass yield. Analysis of variance, discriminant analysis and principle component analysis were conducted using XL-Stat software to differentiate the sites and ascertain the effects of different land cover and use types on soil properties. Multivariate analysis for 18 properties of soil was conducted for physical (5), chemical (7), organic matter (3) and aggregate stability (3) for the upper 15 cm of soil which were combined into a single general indicator of soil quality (GISQ).

The area covered by grassland decreased by 13.1% from 90,020 ha in 1986 to 78,199 ha in 2004. Between 1986 and 1990, much of the grasslands were converted into bush land (38,608 ha), woodland (19,659 ha) and cropland (9,159 ha) while between 1990 and 2000, 21,838, 5,912 and 4,506 ha of grassland were converted to woodland, cropland and bush land respectively and between 2000 and 2004, 33,354, ha were converted to woodland, 12,029 ha to bush land and 6,114 to crop land. In general, bush and woody encroachment engulfed approximately 65%, 50%

and 54% of grasslands in the periods of 1986 – 1990, 1990 – 2000 and 2000 – 2004, respectively.

Soils from bare land under non-settled production systems had significantly high levels of clay ($p<0.0001$) and bulk density ($p<0.02$). Soil from herbaceous vegetation had significantly high levels of organic matter and total nitrogen ($p < 0.001$) compared to woody and bare soils, while soils from woody vegetation had significantly high levels of available Phosphorus ($p < 0.04$). The semi-settled production system had high levels of pH ($p < 0.04$), Ca ($p < 0.038$) and CEC ($p < 0.001$) compared to the settled and non-settled systems. Basing on chemical and physical properties, soils from herbaceous vegetation were very distinct from those of bare ground but were 72% similar to soils under woody cover.

When the equation for calculation of the General Indicator of Soil Quality (GISQ) was developed (GISQ = 0.015PHYSICAL + 0.02CHEMICAL + 0.017ORGANIC MATTER + 0.024AGGREGATE STABILITY) and applied to all sites, GISQ was significantly affected by production system ($p < 0.05$) and the interaction between production system and cover ($p < 0.001$). Herbaceous cover under semi-settled production systems had the highest GISQ of 0.64 that ranged from 0.41 – 1.00, while bare cover under non-settled systems had the lowest GISQ of 0.23 that ranged from 0.1 – 0.53. Most soils had lower levels of organic matter and soil nutrients and thus the generally low GISQ.

Pasture biomass yield was significantly different between cover types ($p < 0.0001$), with high biomass in herbaceous (2019 kg/ha) and least in bare. Production systems also had significantly different ($p < 0.013$) biomass yield, highest in settled (1266 kg/ha) and least in semi-settled (953 kg/ha). Biomass yield was more associated with high levels of OM ($r = 0.91$), Ca ($r = 0.91$), Mg (0.83), N ($r = 0.77$) and base saturation ($r = 0.88$) and were therefore identified as the most critical soil nutrients limiting pasture production.

The results indicated that the rate at which grassland cover is lost to other land use and cover types is greater than the rate of grassland expansion meaning that grasslands are at the verge of disappearing if no conservation measures are instituted to protect them. Grasslands have been degraded to levels below their recuperative capacity and therefore rehabilitation back to herbaceous cover would require more time and external investments. The soils in Nakasongola are generally very strongly acidic (average of pH = 4.5) and therefore improving soil pH and addition of organic matter are major soil management practices that should be undertaken to increase pasture biomass yield in the degraded rangeland ecosystems. From this study, semi-settled production systems and herbaceous vegetation cover have been identified as the most appropriate land use and cover types for the semi-arid rangelands of Nakasongola District in terms of sustainable soil quality conservation and pasture production.

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ABBREVIATIONS AND ACRONYMS

ADE_4	Data Analysis Function for Ecological and Environmental data in the framework of Euclidean Exploratory methods
ADF	African Development Fund
BD	Bulk Density
DA	Discriminant Analysis
ETM	Enhanced Thematic Mapper
GIS	Geographical Information System
GISQ	General Indicator of Soil Quality
ILWIS	Integrated Land and Water Information Systems
IPCC	Intergovernmental Panel on Climate Change
ISSCAS	Institute of Soil Science, Chinese Academy of Sciences
MAAIF	Ministry of Agriculture Animal Industry and Fisheries
MMPS	Meat Master Plan Study
NEMA	National Environment Management Authority
PCA	Principle Component Analysis
PES	Payment for Ecosystem Services
TM	Thematic Mapper
UBOS	Uganda Bureau Of Statistics
UNDP	United Nations Development Program
WGS	World Geodetic System

Chapter 1
Introduction

1.1 Historical background of rangeland resource management in Uganda

Historically, the rangelands of Uganda were managed under traditional systems where grazers had open access to resources (Kisamba-Mugerwa, 1995). In 1950's, the colonial government embarked on the process of commercializing livestock production through bringing in commercial ranchers from Southern Rhodesia (now Zimbabwe) to start commercial ranching. This move was however strongly resisted and failed by natives. After independence (1962), the government developed a strategy of bringing large expanses of tsetse infected areas into production through establishment of ranching schemes. Five ranching schemes (Ankole, Masaka, Singo, Buruli and Bunyoro) were established in the country comprising of 207 ranches, with Buruli Ranching Scheme in present day Nakasongola District comprising of 27 ranches. These ranches were well managed with sound and profitable milk and beef production (ADF, 2002). It is believed that well managed commercial ranches had high stocking rates without causing any degradation to the environment and there was plenty of palatable pasture species, notably "Mukabala" (*Hyperrhania filipendula*). These ranches, owned under lease tenure system of 49 years continued to get technical and financial support from government and foreign donors throughout the 1970's which included dams, valley tanks, boreholes, dip tanks, quarantine stations, well equipped livestock markets and subsidies to inputs in order to improve production. (ADF, 2002)

However, by the end of the 1970s to 1986, political instability and guerrilla wars led to the collapse of the ranching systems and a decline in livestock numbers by about 30% of the pre-1970 numbers (ADF, 2002). After the 1986 liberation war, livestock production resumed in the dilapidated ranches with free grazing by landless communities displaced into the area by wars. Because of the reduced livestock numbers and migration of herders during the wars, most of the grazing areas had started to develop thick thickets at the time of return. The few animals could not favourably graze all the land and thus bush encroachment started to become a menace in the area (Mzee Ssebwato – personal communication).

In 1994, the Uganda Government initiated a project of restructuring ranches that saw them being divided into smaller divisions (1 – 2 sq. miles) in order to provide land to pastoralists and squatters that had been displaced into Buruli (Nakasongola) during the times of political instability. Because pastoralists were basically more interested in having large herds of animals, the small pieces of land allocated to them were rapidly overstocked, overgrazed, soil was compacted and degraded. This is believed to have provided a turning point for the once treasured rangeland resource which saw immense bare patches of soil, intense erosion, and extensive termite damage between 1995 and 1996. The provision of land to squatters from different cultural backgrounds also led to the introduction of alien land use practices (crop cultivation and charcoal production) that greatly transformed land cover form and initiated complex ecosystem interactions.

In 2000, the Uganda Government embarked on a national restocking/redistribution programme to assist communities that were affected by destocking of livestock as a result of civil unrest and cattle rustling (ADF, 2002). However, this project was kick started at the time when degradation was getting strong roots in most rangeland communities. Because the project failed to prioritize environmental protection as a prerequisite to efficient economic development (UNDP, 1992), the distributed animals increased the livestock density in the dwindling grazing areas and contributed to increased overgrazing and environmental degradation.

To date, the rangelands of Nakasongola are severely degraded in form of visibly compacted soils, open gullies, bare patches of soil, termite damages and woody encroachment, which have greatly jeopardized livestock production and threatened the livelihoods of rangeland communities and food security in the country (Mugerwa *et al.*, 2008; Owoyesigire *et al.*, 2008; Zziwa *et al.*, 2008). The need to critically understand the factors that have driven superfluous changes in the rangeland ecosystem, particularly conversions of vegetation cover, reduction in pasture production and degradation should be urgently undertaken in order to provide informed decisions and appropriate strategies for rehabilitation and transformation of rangeland productivity (MMPS, 1997).

1.2 Problem statement

Rangelands, the largest land cover type on earth are both an ecosystem and a resource. As an ecosystem, rangelands integrate diverse fauna, flora and the physical environment (Belsky, 1990; Scholes and Walker, 1993). As a resource they have various economic, ecological and social values (Lamprey, 1983; Friedel *et al.*, 2000; Sankaran *et al.*, 2005). Rangelands cover approximately 50% of the earth's land surface and 77.4% in Africa (Ramankutty *et al.*, 2008).

The greatest threat to the existence and importance of rangeland ecosystems is their conversion to different land use and cover types. Typically, the conversion of grass dominated savanna ecosystems to woodland (shrub encroachment) and crop land is of global concern (Belsky, 1990; Burrows *et al.*, 1990a; Scholes and Walker, 1993; Scholes, 1997; Scholes and Archer, 1997; Ramankutty and Foley, 1999). Conversion of natural land cover types results into complex processes that not only affect the ecosystem to reduce its usefulness as a resource but also drives climatic changes at local, regional and global scales due to alterations in the earth's biochemical and biophysical characteristics (Houghton, 1995; IPCC, 2007). In addition to alteration of biogeochemical cycles (Viglizzo *et al.,* 1997; Singh and Sen, 2002), conversion of grassland ecosystems to woodlands and bare lands reduces pasture availability and the carrying capacity for livestock. This consequently threatens the livelihoods of communities that depend on rangelands for livestock grazing (Lamprey, 1983; Scholes, 1997).

Several theories have been developed to explain the conversion of grassland ecosystem to woody dominated systems (Walter, 1939; Higgins *et al*., 2000; Wiegand *et al*., 2006). Although grazing and fire suppression have being frequently indicted as major drivers of such changes (Roques *et al*., 2001; Briggs *et al*., 2002; Higgins *et al*., 2000), there is also increasing evidence that grassland conversions can occur in areas where neither grazing nor fire is misused (Moustakas *et al*., 2010; Ward, 2010). Generally, most explanations of savanna encroachment are based on simplifications that are not applicable in all regions (Lambin *et al*., 2001). As such, there is a need to conceptualize location specific drivers and interactions if appropriate ecosystem protection and conservation measures are to be generated.

In Uganda, the term rangeland is used in a broad sense to cover natural grassland, bush land and wood land (Kisamba-Mugerwa *et al.*, 2006). These lands form what is known as the "cattle corridor", which forms an unbroken stretch of land that divides the other two areas of the country where the main agricultural activity is crop production. The "cattle corridor" runs from South-west to the North-east direction, from the Rwanda border to the Sudan/Somalia/Kenya borders and covers an estimated area of 84,000 sq:km, or 43% of the country's total land area (NEMA, 2006/07). Land use and cover change through woody encroachment, increase in bare patches and cultivation is identified as an imperative problem undermining the conservation of rangelands in Uganda and expected to drive major ecological changes in the country (NEMA, 2006/07). However, relevant data regarding the extent, spatial patterns, critical causes and ecological implications are scarce, the existing knowledge is incomplete and interpretation is largely influenced by the general simplifications of land degradation. Furthermore, there exist many sweeping statements regarding land degradation in the rangelands of Uganda which may lead to formulation of inappropriate measures in a bid to revamp rangeland degradation. This thesis therefore provides a holistic approach that encompasses the extent, patterns and implications of land use and land cover change on soil quality and pasture production in the rangelands of Uganda, with a focus on Nakasongola District.

1.3 Research objectives

The overall objective of the study was to assess the impacts of land use and land cover change on soil quality and pasture productivity in the semi-arid rangelands.

The specific objectives of this study were to:

1. Determine the magnitude and pattern of land use and land cover change in Nakasongola District between 1986 and 2004
2. Assess the effect of land use and cover change on physical and chemical properties of soil
3. Develop and evaluate a multifunctional general indicator of soil quality in assessing the effect of land use and cover change on soil productivity
4. Determine the effect of land use and cover change on soil nutrient status and pasture productivity in semi-arid rangelands of Nakasongola District

1.4 Research Questions

The central question of this thesis is: what has happened to the semi-arid rangelands of Nakasongola in terms of composition and pasture production potential. The specific questions that were addressed are:

1. What is the magnitude and pattern of land cover change in Nakasongola District?
2. What are the major land use and cover types encroaching on the grassland component?
3. Do changes in land use and cover have a significant affect the soil properties?
4. Does soil lose its production potential as a result of change in land use and cover?
5. What is the best land use and cover system for sustainable ecosystem functioning and production in Nakasongola?
6. Are there significant differences in pasture production following changes in land use and cover systems?

1.5 Description of the study area

1.5.1 Location of Nakasongola District

Nakasongola District was selected as the study area because of its specific location in the center of the cattle corridor. Nakasongola rangelands were identified as a ‘hot spot’ with severe land degradation, pasture and water scarcity that were translating into high livestock mortality and poverty. The District has hence received a national attention to help solve the environmental problems and save dependent communities. Nakasongola District covers an area of 4,909 km^2 and is located between latitudes 0^0 57’ 44.89” and 1^0 40’ 42.76” North and between longitudes 31^0 58’ 03.77” and 32^0 48’ 00.29” East (Figure 1.1). In administrative terms, it is situated in the central region and comprises of five sub-counties; Kakoge, Town council, Wabinyonyi, Kalungi, Kalongo, Lwampanga, Rwabyata, Nabiswera and Nakitoma.

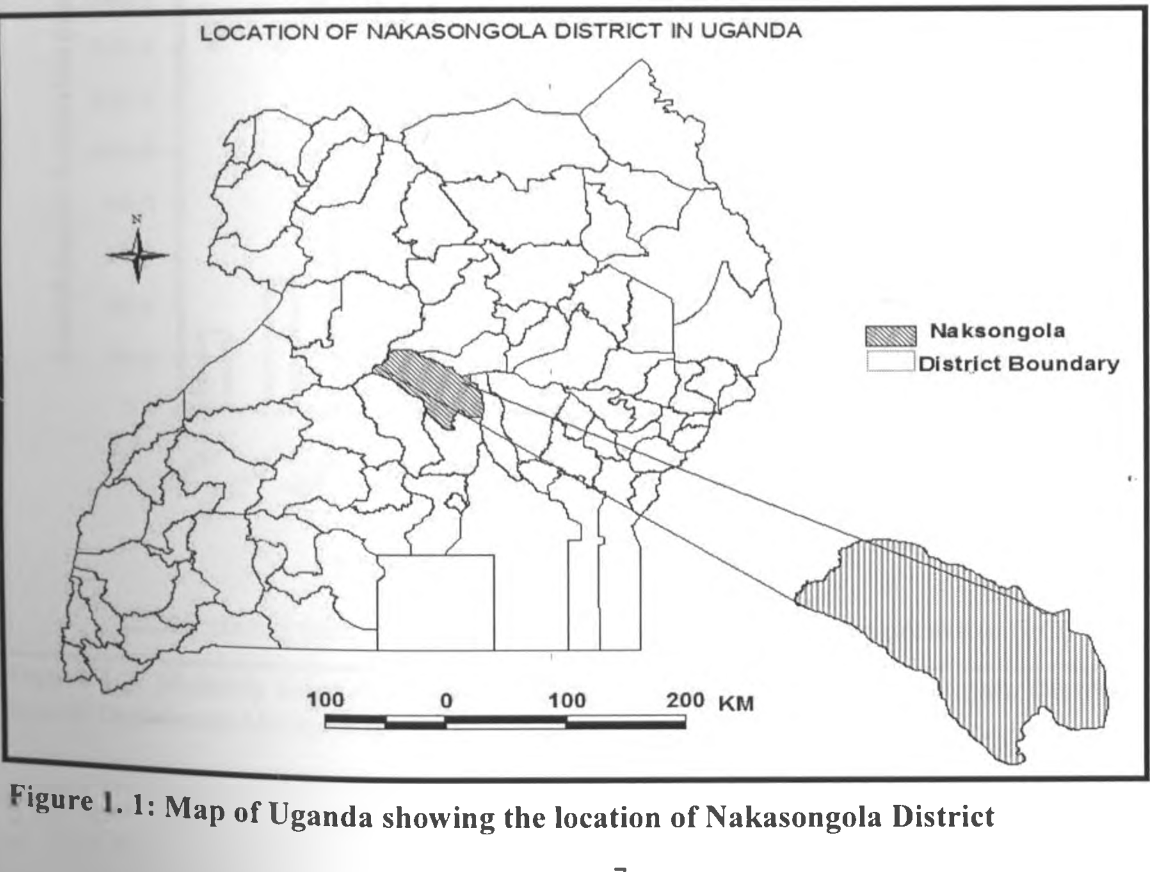

Figure 1. 1: Map of Uganda showing the location of Nakasongola District

1.5.2 Climate

The area receives a bi-modal rainfall regime with the first rainy season occurring in the months of March to May while the second season falls in August to November (Figure 1.2). The mean annual rainfall has ranged between 1,000 mm and 1,600 mm for the period 1960 to 2010 with seasonal variations and prolonged droughts at an interval of 8 – 12 years. The mean daily minimum temperature ranges between 15.0°C and 20.9°C while the mean daily maximum temperature ranges between 25.4°C and 33.7°C. The average humidity ranges from 80% in the morning to 56% in the afternoon. The potential evapotranspiration remains high throughout the year (~130 mm/month and ~1586 mm/year) and shows less variability unlike the rainfall

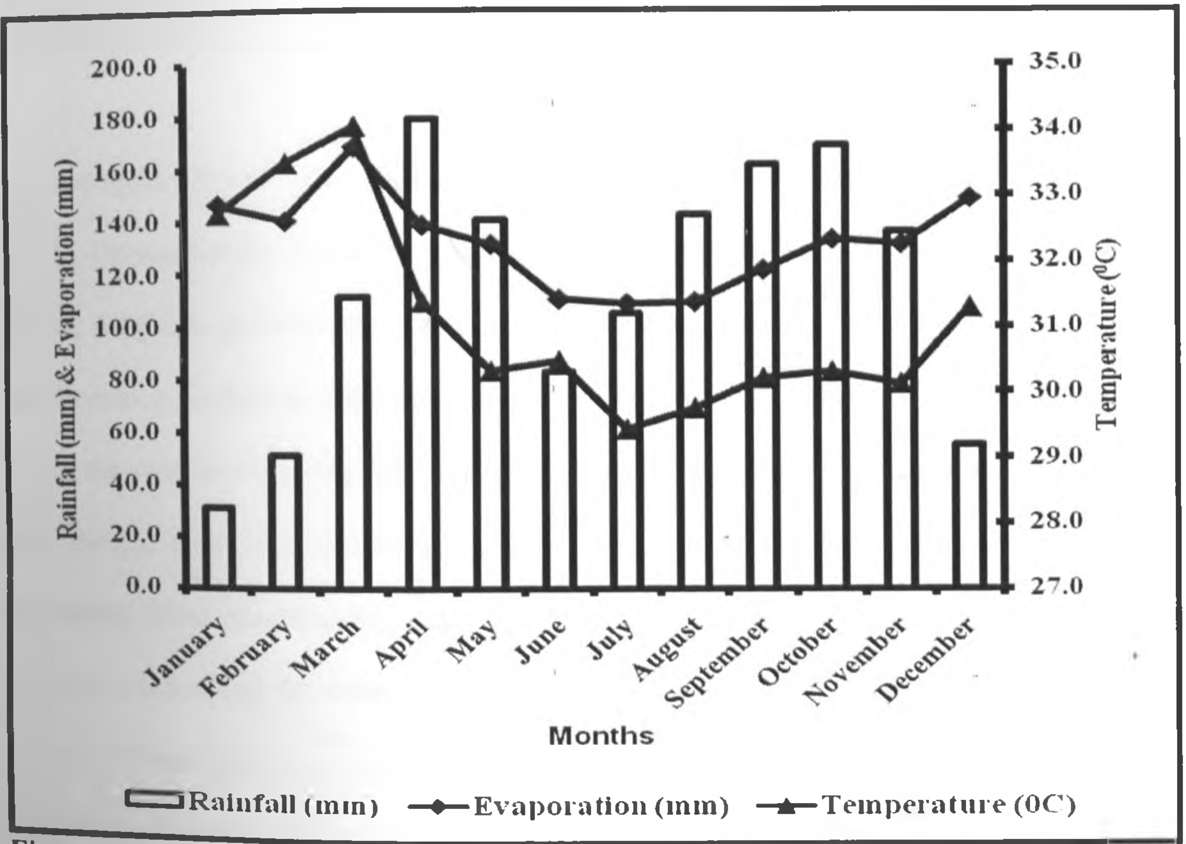

Figure 1.2: Monthly rainfall, evaporation and temperature of Nakasongola District
Source: Department Meteorology, Prime Ministers' Office, Uganda

1.5.3 Vegetation and land use

The dominant vegetation type in Nakasongola District in the early 1960's was dry savanna vegetation with *Hyparrhenia filipendula* and *Loudentia arundinacea* as the dominant grasses and scattered but numerous fire-tolerant species of trees and shrubs commonly dominated by *Combretum terminalis* and *Acacia brevispica* (Radwanski, 1960; Langdale-Brown *et al.*, 1964). The associated grass-shrub savanna is relatively sparse with a lot of bare ground. This together with termite activity is the main cause of low organic matter in the topsoil of the Buruli series. There was generally very little settled agriculture on Buruli soils which were used mainly for extensive grazing by relatively numerous herds of cattle.

Nakasongola District is classified under the banana-millet-cotton farming system (MAAIF, 1995). Because of the less stable rainfall, there is a great reliance on annual food crops basically millet, sorghum, groundnuts, cassava, pigeon peas and maize, with cotton as a major cash crop and livestock production dominating in the drier areas of the District (Kirumira, 2008). For many years, the rangelands of Uganda were predominantly used for livestock production (cattle, goats and sheep), under the communal grazing systems and this had little effect on the natural vegetation (Kisamba-Mugerwa, 2001). However, in recent decades, the rangelands have been severely encroached by cultivators from high potential areas who introduced major land use changes. Charcoal burning is also another "un-necessary" economic activity on which the livelihoods for a good number of people are supported in Nakasongola District.

1.5.4 Soils

Earlier studies on the soils and land use in Uganda classified the soils of Nakasongola under the Buruli catena (Radwanski, 1960). This catena represented the driest part of Buganda Province. The clay content in the upper layer was 12%, the nutrient status of this catena was very inferior in all respects with lower organic carbon (1%) in the upper horizon, pH of below 5 and deficient in available phosphorus and all the major exchangeable bases. The soil is structure less and has a tendency to form crusts on drying. The analysis of soil samples from Buruli catena in 1960 for selected physical and chemical properties between 5 – 20 cm depth showed the following ranges; Silt (2 – 6%), clay (12 – 20%), Ca (0.4 – 0.7), Mg (0.3 – 0.6), K (0.08 – 0.19), Na (0.0), Mn (0.05 – 0.22), Total exchangeable cations (0.24 – 1.52), CEC (3.7 – 4.7), pH (4.1 – 4.7), OC (0.56 – 0.96) and P_2O_5 (10 – 14) (Radwanski, 1960).

1.6 Thesis outline

The thesis is structured in seven chapters. The four main chapters are self-contained and structured in the format of journal articles (Chapter 3, 4, 5 and 6). Literature specific to each chapter is reviewed in the corresponding introduction sections.

Chapter 2 provides the general literature review regarding the definition of rangeland and savanna ecosystems, their dynamics in terms of tree grass co-existence and the factors driving the conversion of savanna ecosystems from one dominant land cover type to another.

Chapter 3 presents the determination of the magnitude and patterns of land use and cover changes in Nakasongola District from 1986 up to 2004. The use of the Integrated land and Water Information Systems (ILWIS) in analysis of satellite images and conducting land cover change detection are discussed.

Chapter 4 presents results on the impacts of land use and cover change on soil properties. Discriminant Analysis was conducted to test whether changes in soil properties as a result of change in land use and cover can be used to distinguish the resultant land forms

Chapter 5 describes the development and validation of a multifunctional general indicator of soil quality that can be used to assess the production potential and sustainability of different land use and cover types in the semi-arid rangelands of Nakasongola

Chapters 6 discusses the impact of land use and cover change on pasture productivity. A principle component analysis was conducted to identify the most critical nutrients limiting pasture production in the rangeland ecosystem of Nakasongola District.

Chapter 7 provides a comprehensive summary and recommendations drawn from the thesis. It discusses implications of land use and cover change on sustainability, livelihoods and the future development of the rangeland ecosystem in Uganda.

Chapter 2

Literature Review

2.1 Definition and composition of rangelands

For many years, the term rangeland has been used in reference to lands under different vegetation cover, management and environments and hence lacks a global objective definition (Lund, 2007). Rangelands may be defined based on cover (Heinzcenter, 2003), use (Wilcoks *et al.*, 2003), ecological potential (Lund, 2007) and administrative terms. Rangeland is often defined as a land cover or land use. Land cover is the vegetational and artificial constructions covering the land surface. It is the physical characteristic of earth's surface, captured in the distribution of vegetation, water, desert, ice, and other physical features of the land, including those created solely by anthropogenic activities. Land use, on the other hand, is the intent and management strategy placed on a land cover type. Shifts in intent and/or management constitute land-use changes while shifts in vegetation constitute land cover changes. In a broad sense, rangelands refer to land on which the historic climax plant community is predominantly grasses, grass-like plants, forbs, or shrubs. It includes lands revegetated naturally or artificially when routine management of that vegetation is accomplished mainly through manipulation of grazing. Rangelands include natural grasslands, savannas, shrublands, most deserts, tundra, alpine communities, coastal marshes, and wet meadows.

Globally, savannas are the most conspicuous among all rangeland types. They cover about a fifth of the global land surface and about half of the area of Africa, Australia and South America (Scholes and Archer, 1997, Sankaran *et al.*, 2004). Savannas comprise a mixture of woody species (trees and bushes), grasses and forbs with the existence of a continuous grass understorey and a discontinuous tree layer being the characteristic feature (Salzmann, 2000; Scanlon *et al.*, 2005). Tree-grass ratios vary widely in savannas, with higher precipitation usually leading to a more continuous tree layer (Sankaran *et al.*, 2005). However, tree canopies in mesic savannas are still discontinuous, with significant understorey grass biomass for the system to be characterized as a savanna and not forest. There are several different savanna ecoregions worldwide, each containing different subsets of species and displaying substantial variation in physical and structural attributes (Scholes and Archer, 1997, House *et al.*, 2003). The rangelands of Uganda, particularly those of Nakasongola District were classified as dry savanna vegetation by earlier studies on land use types of Uganda (Radwanski, 1960; Langdale-Brown *et al.*, 1964). Therefore, in Nakasongola District, the term rangeland and savannas can be used interchangeably and in this study, literature review was extensively based on savanna ecosystem especially on description of ecological and anthropogenic factors that drive land cover changes.

2.2 The dynamics of savanna ecosystems

Tree and grass components of savanna ecosystems have evolved for many years, and if not disrupted by climatic, biological and antropogenic factors can maintain their integrity over millions of years. There exists a number of models to account for the coexistence of the tree-grass components in savanna ecosystems (Moustakas *et al.*, 2010) namely; niche separation

(Walter, 1939), demographic bottlenecks (Higgins *et al*., 2000, Jeltsch *et al*., 2000), and patch dynamics (Gillson, 2004a; 2004b; Wiegand *et al*., 2006) as described in the following sections.

2.2.1 Competition-based models

There are four major variables recognized by ecologists as key determinants of savanna structure and function: water, nutrients, fire and herbivory (Frost *et al*., 1986). In competition-based models, water and nutrients are considered the primary determinants, with fire and grazing as modifiers (Stott, 1991). Trees and grasses coexist in savannas because of their differential ability to acquire and partition limiting resources. For the most part, models have focused on plant-available moisture, rather than plant-available nutrients as the main resource limiting plant growth in savannas (Walter, 1971; Walker *et al*., 1981; Walker and Noy-Meir, 1982; Fernandez-Illescas and Rodriguez-Iturbe, 2003). There exists four different, but potentially related, competition-based models; the root niche separation model, the phenological niche separation model, the balanced competition model and the hydrologically driven competition-colonization model.

2.2.1.1 The root niche separation model

The theory of niche separation, developed by Walker *et al*. (1981), was based on the idea of two layer hypothesis by Walter's (1939). According to this theory, water is the limiting factor for woody species as well as grasses. It was assumed that grasses were the better competitors for topsoil moisture (usually < 30 cm), but because woody species could develop deeper roots they were able to persist by exploiting subsoil resources (usually > 30 cm). Depending on several field experiments conducted to verify this theory, it was believed that tree-grass composition of savannas is based on the two-layer theory (Knoop and Walker, 1985; Smith and Goodman, 1986; Skarpe, 1990; Scholes and Archer, 1997; Scanlon *et al.*, 2005). The existence of an equilibrium ratio of grass and woody vegetation for a given set of soil and mean climatic conditions has been demonstrated analytically for savannas modeled on these assumptions (Walker *et al.*, 1981; Walker and Noy-Meir, 1982; van Langevelde *et al.*, 2003). Although these models predict a characteristic tree–grass ratio for a given set of soil and climatic conditions, factors that alter the ratio of subsoil to topsoil water (e.g. variable rainfall patterns, grazing) can cause realized tree–grass ratios to deviate from this predicted ratio (Walker and Noy-Meir, 1982; van Langevelde *et al.*, 2003).

This theory raised a number of questions which prompted more experiments that rather reported facilitative effects of trees on grass biomass (Belsky *et al.*, 1989; Ludwig *et al.*, 2004). This means that rooting niche separation fails to generally explain tree–grass co-dominance in the savanna system since more grass biomass was found under tree canopies than away in some instances. Further, in ecosystems where the soil was too shallow to allow for a two-soil layer differentiation as in the Kalahari and Namib deserts, trees and grasses coexisted (Hipondoka *et al.*, 2003, Wiegand *et al.*, 2005).

2.2.1.2 The phenological niche separation model

Savanna trees are able to store water and nutrients and thereby achieve full leaf expansion either prior to, or within a few weeks following the onset of the rains (Scholes and Archer, 1997) while peak leaf area of grasses is achieved much later. Deciduous savanna trees also tend to retain leaves for several weeks following grass senescence (Scholes and Archer, 1997). Thus, trees have potentially exclusive access to resources early and late in the growing season. For grasses to persist, they would then have to be superior competitors for resources during periods of growth overlap with trees. The implications of such phenological niche separation for patterns of change in tree–grass ratios across broad gradients of rainfall are not immediately apparent because the eventual outcome is contingent not only on total rainfall but also on the length and predictability of the growing season (Scholes and Archer, 1997). However, space, the parameter that favours tree–grass coexistence under scenarios of phenological niche partitioning in savannas has not been investigated in detail over the years (Sankaran *et al.*, 2004).

2.2.1.3 The balanced competition model

This model does not make explicit assumptions about the presence of exclusive tree niches resulting from separation of either rooting depths or phenology. Here, equilibrium coexistence arises because the superior competitor (trees) becomes self limiting at a biomass insufficient to exclude the inferior competitor (grasses) (Scholes and Archer, 1997; House *et al.*, 2003). In the absence of external perturbations, this model predicts an abrupt threshold with increasing rainfall above which tree cover should be relatively high and below which grasses dominate (Scholes and Archer, 1997). At the lower end of the rainfall gradient, water availability is insufficient to support tree growth. Above the critical threshold of rainfall required to permit tree growth, trees, by virtue of being better competitors, should dominate the system. Tree density above this threshold is then limited by tree-on-tree competition for water, and is presumably determined by the rooting volumes required to meet trees water demands. The predicted tree density for any level of rainfall above the threshold is fairly high in this model as tree-on-tree competition is unlikely to be a limiting factor at low tree densities (Scholes and Archer, 1997). For low levels of rainfall above the threshold, grasses can persist in this system by surviving in the interspaces between trees. However, as rainfall continues to increase, rooting volumes required to meet the water demands of trees correspondingly decrease, thereby permitting a greater packing of trees within a given area. A further increase in rainfall leads to a closed-canopy scenario where grasses are out-competed, and the system converges to closed woodland. According to this model, the only equilibrium savanna states are wooded savannas, with open savannas representing disequilibrium states maintained by fire and grazing (Scholes and Archer, 1997).

2.2.1.4 The hydrologically driven competition-colonization model

This is a non-equilibrium competition-based model of savannas (Fernandez-Illescas and Rodriguez-Iturbe, 2003). This model invokes the trade-off between competitive ability and colonization potential (Kneitel and Chase, 2004), with the added caveat that the competitive rankings of trees and grasses and their colonization potential change in response to fluctuations in soil water stress caused by inter-annual rainfall variability (Fernandez-Illescas and Rodriguez-Iturbe, 2003). The model predicts long-term coexistence of both life forms in the system, with the balance between trees and grasses sensitive to the magnitude and variance of inter-annual rainfall fluctuations. In terms of broad scale patterns of tree cover across precipitation gradients, the predictions of this model match those of the root niche separation model with average tree cover increasing, albeit displaying more variability, with mean growing season rainfall (Fernandez-Illescas and Rodriguez-Iturbe, 2003).

2.2.2 The theory of demographic bottleneck

Because of the inability of the niche separation theory to explain tree-grass coexistence in several cases, new theories were proposed to explain savanna stability and tree–grass co-dominance. The demographic bottleneck theory proposes that savannas are unstable systems that are constantly perturbed by disturbances such as fire, herbivory and climatic variability (Jeltsch *et al*., 2000; Higgins *et al*., 2000). Ideally, in the absence of such disturbances, a savanna would turn into woodlands or into grassland (Jeltsch *et al*., 2000). Demographic bottleneck models take life stages explicitly into account and emphasize the role of disturbances and climatic variability in limiting tree establishment and growth in arid areas, and preventing tree dominance in mesic areas (Higgins *et al*., 2000; Sankaran *et al*., 2004). Fire is typically considered to be the most important driver limiting tree dominance in mesic areas, thereby maintaining the system as a savanna (Jeltsch *et al*., 2000; Higgins *et al*., 2000; Roques *et al*., 2001; Sankaran *et al*., 2004, Bond, 2008). In contrast, in arid savannas, the primary demographic bottlenecks for woody species are germination and seedling establishment (Higgins *et al*., 2000). Here, tree recruitment is pulsed in time following stochastic rainfall patterns. The fact that trees are long-lived enables them to persist and 'store' reproductive potential over periods when precipitation is sufficient only for grass and not for tree germination (Higgins *et al.*, 2000).

2.2.3 The theory of patch dynamics

This theory was developed from ideas by Gillson (2004a; 2004b) and Wiegand *et al.* (2005; 2006) who suggested that savannas are hierarchical patch dynamic systems. These ideas came up after an establishment that dominant *Acacia* species were not able to recruit under themselves, but various broad-leaved shrubs (both deciduous and evergreen) did so, and thus self thinning would occur (Smith and Goodman, 1986; 1987). Earlier theories of niche separation and demographic bottlenecks were described on small scales and thus the need to think about tree-grass dynamics at larger scales. Scale is a fundamental problem in ecology because different processes occur at different scales and are linked to patterns at other larger scales (Levin, 1992). In patch dynamics, it is assumed that the landscape consists of distinct patches of variable size and that in every patch the same cyclical succession progresses (Meyer *et al.*, 2007). Successional states may vary in duration and occur spatially asynchronously. The proportion of each state is approximately constant at a landscape scale. As a result, at large spatial scales an equilibrium can persist, although at smaller scales non equilibrium dynamics occur (Levin, 1992; Meyer *et al.*, 2007). Most theories trying to explain savanna tree–grass co-dominance did not explicitly state the scale of their applicability (Gillson, 2004a).

According to the patch dynamics theory, savannas are patch-dynamic systems composed of many patches in different states of transition between grassy and woody dominance. In arid savannas, key factors for patches are rainfall, which is highly variable in space and time, and intraspecific tree competition. According to the savanna patch dynamics theory, bush encroachment is part of a cyclical succession between open savanna and woody dominance (Wiegand *et al.*, 2006). The conversion from a patch of open savanna to a bush-encroached area is initiated by the spatial and temporal overlap of several (localized) rainfall events sufficient for germination and establishment of woody species (trees and bushes). With time, growth and self-thinning of the species that are present will transform the bush-encroached area into a mature woody species stand (of the same species identity) and eventually into open savanna again (Wiegand *et al.*, 2006). Patchiness is sustained because of the local rarity (and patchiness) of rainfall sufficient for germination of woody plants, as well as by plant–soil interactions. According to this theory, there is spatial and temporal variation in savannas. Temporally, a specific patch will pass through an encroached phase and sequentially to a more open savanna, until it is encroached again. Spatially, when a savanna is viewed at a specific time step, there are some encroached patches, while some other patches comprise of an open savanna.

2.3 Rangeland dynamics in relation to biophysical drivers and human interaction

Unlike other land use and cover forms, rangelands are not "natural climax" vegetation types that can persist in absence of human interaction (Lambin *et al.*, 2001). Climatic variations and change cause significant changes in rangeland ecosystem and therefore maintenance of rangelands requires strong interactions between human and biophysical drivers (Sneath, 1998). Therefore, reduction, elimination or over use of rangelands by humans elicits considerable changes in the ecosystem that may either be favourable or unfavourable to the ecosystem and subsequent rangeland utilization.

The dominance of woody species in savannas is a global phenomenon often associated with suppression of the grass component and loss of biodiversity (Hudak and Wessman, 2001; Archer, 1989; Burrows *et al.*, 1990b; Khavhagali and Bond, 2008; Ward, 2009). According to van Auken (2000), the term encroachment is used in cases where an increase in woody species cover is driven by native species otherwise the involvement of alien species is termed invasion. Therefore, the increase in cover of indigenous woody species is believed to be caused by changes in local abiotic or biotic conditions (van Auken, 2000). There have been attempts to explain the causes of bush encroachment with notable drivers being changes in management such as use of fire (Sabiiti and Wein, 1987; Higgins *et al.*, 2000; Roques *et al.*, 2001; Briggs *et al.*, 2002), herbivory (Belsky *et al.*, 1999; Bartolome, 1993; Noy-Meir, 1993; Patten, 1993; van Auken and Bush, 1997), competition (Knoop and Walker, 1985; Bush and van Auken, 1995), climatic change (Neilson, 1986; Archer *et al.*, 1995), elevated carbon dioxide levels (Knapp, 1993; Polley *et al.*, 1994).

2.3.1 Competition between woody and grass species

Competitions between grasses and trees and tree – tree competitions for water often reduce the growth of trees (Knoop and Walker, 1985; Smith and Goodman, 1986; Kraaij and Ward, 2006). Factors like herbivory that alter the competitive ability of one savanna component over the other often result into an increase of the favoured component (Skarpe, 1990). Both intra-specific and inter-specific competitions have been reported and play important roles in modification of plant communities (Scholes and Archer, 1997). Changes in competition between grasses and woody plants are implicated in the encroachment of woody plants into semiarid grasslands (Bush and van Auken, 1989; van Auken and Bush, 1997). Grasses inhibit the woody species most during the germination, establishment, and early growth of the woody plants (Bush and van Auken, 1995). However, the interaction seems to be reversed once the woody plant roots are below the root zone of the grasses and the woody plant shoot is above the shoot zone of the grasses (Berendse, 1981; Brown and Archer, 1989; Bush and van Auken, 1991; Knoop and Walker, 1985). Although high density or biomass of grass reduces germination, survival, and growth of woody seedlings, some seedlings survive and escape the grass zone of suppression and ultimately convert the grassland into shrubland or woodland (Brown and Archer, 1999; Brown and Archer, 1989)

2.3.2 Climate variability and change

Climatic variability and change has been pointed out as a contributing factor to increased woody encroachment in savanna ecosystems (Dempewolf, 2007). Shifts in rainfall and dry seasons alter the competitive advantage of grasses to trees in favour of the latter. Trees have an efficient tap root system which enables them to survive periods of long drought as compared to grasses that have shallow roots. Also, some trees have devised drought tolerance mechanisms of shedding off leaves and water storage during the dry season that are absent in grasses. The implication is that frequent and elongated droughts reduce grass cover and increases the competitive ability of trees, thus increased woody cover. However, the uneven nature of woody encroachment in a given area seems to disapprove this line of thought (Bahre and Shelton, 1993).

2.3.3 Increase in atmospheric carbon dioxide concentration

Increasing levels of global carbon dioxide favour the growth of trees and bushes which are C3 species rather than grasses which are mainly C4 species (Knapp 1993; Ward 2010). Knapp (1993) reported a two fold increase in C3 species due to differences in response of stomatal conductance between C3 and C4 species during periods of sunlight variability. C3 plants have a metabolic pathway which is more energy efficient, and if water is plentiful, the stomata can stay open and let in more carbon dioxide. However, carbon losses through photorespiration are high. Thus, elevated levels of carbon dioxide would be expected to increase the abundance of C3 species as carbon availability levels would increase (Moustakas *et al.*, 2010). High carbon dioxide levels are also known to lower the transpiration rates of grasses, which results in deeper percolation of water and, consequently, greater growth rates of trees due to increased availability of water in the tree root zone. This hypothesis of elevated carbon dioxide accounts for the widespread encroachment of shrubs and other woody plants into semi-arid grasslands and savannas throughout the world (Polley *et al.*, 1992; Johnson *et al.*, 1993).

2.3.4 The role of fire in driving woody encroachment

Of the many factors described in driving woody cover changes in savannas, the role of fire is undisputable, and is a major factor controlling woody-grass dynamics in mesic savanna ecosystems (Knoop and Walker, 1985; Higgins *et al.*, 2000; Roques *et al.*, 2001; Hudak and Wessman, 2001). Prescribed burning is required to control or reduce the establishment and growth of woody plants in most if not all rangelands. Experiments on the use of fire have indicated that elimination of fire from savanna ecosystems for a period of three to four years increases woody species cover and reduces grass cover and diversity (Sabiiti and Wein, 1987; Knapp, 1993; Briggs *et al.*, 2002). Fire interacts with other factors such as topography, soil, herbivores, and amount of herbaceous fuel to determine the nature, density, and location of woody plants in a landscape (Humphrey, 1958). The effectiveness of fire in controlling woody species encroachment in savannas is greatly dependent on the fire regime (the frequency, intensity and seasonality of fire) (Dempewolf, 2007). Annual burning eliminates the possibility of woody dominance while infrequent fires or total elimination favours woody dominance. Also, fires of high intensity are more effective in controlling woody species than fires of low intensity (Sabiiti and Wein, 1987). Since the intensity of fire is determined by the amount of biomass fuel available at the time of burning, factors that reduce biomass such as overgrazing, subsequently reduces the intensity of fire and hence lead to increases in woody cover (van Auken, 2000).

Although seedlings of most woody plants are sensitive to fire, the use of fire promotes the germination of some woody species like *Acacia sieberiana,* through breaking of dormancy and killing bruchids that eat their seeds (Sabiiti and Wein, 1987). Once established *Acacia sieberiana* easily escape fire after two years, out compete grasses and establishes thickets. In this case, the increased dominance of woody cover after burning has to be controlled through regular use of fire, preferably annually before saplings become resistant to fire.

The expansion of woody species into grasslands may also be due in part to relatively recent species adaptation to fire (van Auken, 2000). Location of the buds (above or below the soil surface) affects the ability of fire treatments to kill the species. Factors that favour the burial of the bud zone such as plant size, slope, and soil surface stability will favour regeneration of the shrubs after fire treatments. For example, *Acacia hockii*, one of the troublesome species on Ugandan rangelands has its buds below ground and therefore regenerates fast after a fire.

2.3.5 Herbivory

Herbivores have both direct and indirect effects on woody plant abundance in savanna ecosystems (Higgins *et al.,* 2000; Briggs *et al.,* 2002). The presence of browsers that directly feed on shrubs eliminates the potential of woody domination. However, the presence of grazers and the associated consequences of overgrazing favours the recruitment of more woody plants and thus rapid woody encroachment through reduced tree-grass competition and elimination of fire since the biomass fuel is removed (Brown and Archer, 1999; Higgins *et al*., 2000; Jeltsch *et al*., 2000; van Auken, 2000). Introduction of animals often results into alterations in the grass species composition as well as reductions in herbaceous plant basal area, density, and aboveground biomass hence resulting into woody encroachment in grasslands. Herbivory at low density and frequency may cause little change in a grassland community, but at high density and frequency, it can alter grassland composition, changing it to shrub land or woodland (Archer, 1994).

2.3.6 Increased dispersal of woody plant seeds

Among the theories explaining increases in woody species abundance is the increase in the number of seed dispersal agents in savannas (van Auken, 2000). When animals feed on fruits of woody species, they scarify the seeds during digestion and on passage with dung, the germination potential of the seeds is increased resulting into rapid establishment of woody species (Brown and Archer, 1989; Brown and Archer, 1999). Kamp *et al.* (1998) reported that *Prosopis glandulosa*, a native legume, has a thick seed coat that requires scarification which occurs during mastication; the seed survives passage through the gut of cattle and thus easily germinates. The introduction of domestic herbivores may have increased the dispersal of *P. glandulosa* and other woody plant seeds, but many native herbivores could and probably still do the same thing (Brown and Archer, 1989).

2.4 The implication of human driven land use and cover change on the environment

Humans have played a great role in environmental change that has resulted into deforestation, desertification, loss of biodiversity, and climate change (Tolba *et al.*, 1992; Houghton *et al.*, 1999; Sala *et al.*, 2000; Jetz *et al.*, 2007; McAlpine *et al.*, 2009). Land use and land cover change, which are the major consequences on the earth's surface impacted by humans (Lambin *et al.*, 1999) contribute various gases to the biosphere that may drive unwanted consequences in an already carbon – conscious world (Stern, 2006; IPCC, 2007). Globally, croplands increased by 392% to 466% from 1700 to the mid- 1980's at the expense of forests, grasslands and wetlands (Richards, 1990) while about 6 million km^2 of forests/woodlands and 4.7 million km^2

of savannas/grasslands/steppes have been converted to croplands since 1850 (Ramankutty and Foley, 1999). Within the same period, 1.5 and 0.6 million km^2 of cropland were abandoned and converted to forests/woodlands and savannas/grasslands respectively (Ramankutty and Foley, 1999).

Livestock production is among the human activities that greatly contribute to global climate change through methane production and expansion of managed grazing systems (McAlpine *et al.*, 2009). Feed lot production involves the use of grain and legume crops that require high inputs of nutrients, water and energy, conversion of native ecosystems to agriculture and increased methane production through elevated enteric fermentation and manure deposition. On the other hand, expansion of managed grazing lands involves conversion of natural systems to pastures and thus contributes a lot of carbon dioxide to the atmosphere (Ramankutty and Foley, 1999) through deforestation and desertification. Therefore, improved rangeland management is the only pathway to increased beef production with minimum impact on the environment.

2.4.1 Effects of land use and cover change on surface characteristics of savanna ecosystems

Climate exerts a dominant control over distribution of terrestrial plants and surface properties which in turn affect the climate by changing the atmospheric water and energy budget (Brovkin and Claussen, 2008; Kropelin *et al.*, 2008; Bathiany *et al.*, 2010; Dekker *et al.*, 2010). Forests for example modifies the fluxes of energy, water and momentum at the land surface and thus can counteract the carbon drawdown and even overcompensate it if large albedo differences occur between forest canopy and the replaced vegetation (Bathiany *et al*., 2010). Because carbon dioxide is well mixed in the atmosphere, carbon-cycle effects of deforestation and afforestation (adding carbon dioxide to the atmosphere and eliminating the possible increased carbon storage in trees) are manifested globally, but biogeophysical effects (decreasing evapotranspiration and decreasing the surface albedo) are most strongly felt at local and regional scales (Bala *et al*., 2007). As such, the carbon-cycle effects have been taken into account in the promotion of afforestation as a climate change mitigation strategy and the biogeophysical effects of land-cover change have been largely ignored (Watson *et al*., 2000).

Land surface albedo, the fraction of incident solar irradiance reflected by the Earth's surface is one of the most important parameters characterizing the earth's radiative regime and thus strongly impacts on climate through biogeophysical effects (Dickinson, 1995; Claussen *et al*., 2004). The conversion of highly reflecting surfaces such as grasslands into forests reduces the albedo of such surfaces and consequently affects the climate (Bonan, 2008; Brovkin *et al*., 2009).

2.4.2 Carbon sequestration and climate change interface in savanna ecosystems

Carbon sequestration through increased removal and storage of carbon dioxide from the atmosphere by trees is a major form of climate change mitigation (Bird and Schwaiger, 2008). For this reason, transformation of non-forest lands into forests is of major interest to environmentalists. However, the increase in tree cover as a climate change mitigation measure possess many questions in areas with high reflectance since the darkening of the surface (decrease in albedo) contributes to radiative forcing and adds to the warming of the earth (Betts, 2000; Bala *et al.*, 2007). Only in cases where the carbon sequestration potential exceeds the albedo changes can forest establishment contribute to climate change mitigation (Brovkin *et al.*, 1999; Matthews *et al.*, 2004).

2.5 Effects of land cover change on rangeland productivity

Changes in land cover types are associated with several ecological consequences, changes in soil characteristics, surface characteristics and local as well as regional and global climate. Woody encroachment in rangelands for example, reduces the grazing area and lowers the suitability of land for animal production (Schlesinger *et al.*, 2000), increases above ground net primary productivity (Geesing *et al.*, 2000; Asner *et al.*, 2003a) and enriches the ecosystem's carbon and nitrogen stocks (Asner *et al.*, 2004). Despite an increase in above ground carbon and nitrogen, the trends in soil organic carbon and nitrogen are highly variable. Some studies have reported an increase in soil carbon and nitrogen under woody encroachment in grasslands (Hibbard *et al.*, 2001) while others have indicated a net reduction in carbon and nitrogen stocks especially in regions with annual precipitation of more than 500 mm (Jackson *et al.*, 2002).

Although the increased carbon sequestration potential of woody plants may provide an opportunity for climate change mitigation, woody products and services and payment for ecosystem services that may compensate for decreased animal production, these mechanisms and opportunities are still poorly understood (Hudak *et al.*, 2003; Wessman *et al.*, 2004). More so, such benefits can only be accrued when both below ground and above ground carbon stocks (biogeochemical) are increased to levels high enough to offset the effects of woody species on surface characteristics (biogeophysical) (Brovkin *et al.*, 1999; Matthews *et al.*, 2004).

On the other hand, clearing of natural vegetation (forests, woodlands and grasslands) for crop farming often increases the release of carbon into the atmosphere and thus significantly contributing to climate change (Lambin *et al.*, 1999; Stern, 2006; IPCC, 2007; McAlpine *et al.*, 2009). Therefore, changes in land use and cover that involves replacement of natural vegetation cover are associated with complex interactions that affect the productive potential, sustainability as well as the livelihoods of dependant communities.

Chapter 3

The magnitude and patterns of land use and land cover changes in Nakasongola District

Abstract

Land use and land cover changes were determined through analysis of satellite images. Landsat (TM) of 1986 and 1990 and Landsat (ETM+) of 2000 and 2004 for Nakasongola District were analyzed using the ILWIS 3.6 software using unsupervised classification. An overlay analysis of satellite images for different years was conducted in order to understand the patterns of land use and cover change. The area covered by grassland decreased by 13.1% from 90,020 ha in 1986 to 78,199 ha in 2004. Between 1986 and 1990, much of the grasslands were converted into bush land (38,608 ha), woodland (19,659 ha) and cropland (9,159 ha) while between 1990 and 2000, 21,838, 5,912 and 4,506 ha of grassland were converted to woodland, cropland and bush land respectively and between 2000 and 2004, 33,354, ha were converted to woodland, 12,029 ha to bush land and 6,114 to crop land. In general, bush and woody encroachment engulfed approximately 65%, 50% and 54% of grasslands in the periods of 1986 – 1990, 1990 – 2000 and 2000 – 2004 respectively. Cultivation, coniferous plantations, bush and woody encroachment are the most pervasive land use and cover types encroaching on grasslands. However, the increment in bare land has great ecological and economical consequences since their rehabilitation could require more time and investment. The rate at which grassland is lost to other land use and cover types is greater than the rate of grassland expansion meaning that grasslands are at the verge of disappearing if no conservation measures are instituted to protect them.

3.1 Introduction

Changes in land cover (the vegetational and artificial constructions covering the land surface) and land use (human purpose or intent applied to the biophysical attributes of the earth's surface) are a significant human alternation of the earth's surface (Goldewijk and Battjes, 1997; Lambin *et al.*, 1999). Land use and cover change directly affect biotic diversity (Andrieu *et al.*, 2007; Seabrook *et al.*, 2007), contribute to local and regional climate change (IPCC, 2001) as well as to global climate warming (IPCC, 2007), and is a primary source of soil degradation (Ruysschaert *et al.*, 2007). Land use change also contributes to regional and global changes in atmospheric composition (IPCC, 2007) thus affecting the quality and quantity of primary production (Lindroth *et al.*, 2009). Changes in atmospheric composition directs new forms of plant growth and chemical composition that not only affect livestock production, but also influence trophic interactions that may accelerate further land use changes. The subsequent conversion of land cover types may alter ecosystems so greatly and shift them to a different stable state. Consequently, the livelihood of communities that depend on the integrity of natural ecosystems for products and services become increasingly threatened.

Rangelands cover about 44% of Uganda's total land area, are home to more than 90% of total ruminant livestock population and provide about 85% of the total marketed milk in the country (MAAIF and UBOS, 2009). One major challenge in the management of rangeland ecosystems of Uganda is the perceived wide spread encroachment of woody species, which reduce grazing area, suppress palatable grass species and increases production costs (Mugasi *et al.*, 2000; Byenkya, 2004). Woody encroachment is often associated with alteration of above and below ground productivity and litter quality, altered hydrology and changes in microclimate and earth's surface albedo among others (Chapin *et al*., 2005; Huxman *et al*., 2005; Weintraub and Schimel, 2005; Hughes *et al*., 2006). Alteration of ecosystem characteristics due to woody plant encroachment in previously herbaceous dominated ecosystems can greatly affect the energy balance, carbon dynamics and storage potential and thus impact climate at local, regional and global scale through feedback interactions (Schlesinger *et al*., 1990; Ojima *et al*., 1999; Asner *et al*., 2004). In order to protect rangelands from pervasive land use and cover changes, prevent major impacts on ecological and economical systems as well as the livelihood of pastoral communities, detailed studies on the extent and patterns of change and their drivers are needed.

In Uganda, land use and cover change has taken place in terms of conversion of natural ecosystems (forests, wetlands and rangelands) to cultivation, the gradual intensification of agriculture on land already cultivated, bush/woody encroachment on grasslands as well clearing of woodlands for grazing (Sabiiti and Wein, 1987; NEMA, 2006/2007; Mwavu and Witkowski, 2008; Owoyesigire *et al*., 2008; Odada *et al*., 2009). The rangeland ecosystems of Uganda have undergone extensive land use and cover changes over time that has seen increases in woody species, crop cultivation and bare land. Earlier surveys of vegetation cover in the rangelands of Uganda described them as open grassland savannas with occasional woody plants in the range of 5 – 20% (Langdale-Brown *et al*., 1964; Sabiiti and Wein, 1987). This description greatly differs from what is observed today, with major transition from grass dominated to woody dominated ecosystems (Mugasi *et al*., 2000; Byenkya, 2004; NEMA, 2006/2007; Owoyesigire *et al*., 2008). Many factors; cultivation, grazing, fire, charcoal burning, population increase, political instability and climatic variations are cited among the notable drivers of land use and cover changes in Uganda (NEMA, 2006/2007; Odada *et al.*, 2009; Maitima *et al.*, 2010; Ebanyat *et al.*, 2010). However, authentic assessments of the patterns and magnitudes of change and disaggregation of their causes are still elusive in the rangelands of Uganda are still elusive.

Although rangelands are regarded as the second most fragile ecosystems in Uganda after the highlands, limited basic research has been put in place to address the threats to rangelands (NEMA, 2006/2007). Extensive review of literature revealed that no previous study has been conducted to provide a comprehensive estimate of land use and cover change in the rangelands of Uganda over time. The few existing studies on land use and cover changes in the rangelands have reported bush and woody encroachment into grazing lands of between 25 to 75% (Mugasi *et al.*, 2000; Byenkya, 2004; NEMA, 2006/2007; Owoyesigire *et al.*, 2008). However, many of these assessments are so subjective, conducted at farm level and some are visual assessments which cannot be used on to develop strategies for protection of rangeland resources. There is a need to obtain detailed understanding of the patterns of land use and cover change as fundamental precept for development of strategies that promote sustainable management and utilization of fragile ecosystems. This study will therefore benefit from the vast availability of remote sensing data to monitor the changes in land use and cover in the rangelands of Uganda.

3.2 Methodology

The study area is covered by Landsat images consisting of two scenes of path/row 171/059 and 172/059. The Landsat (TM) and ETM+ images used had a resolution of 30m (Table 3.1) and are composed of seven spectral bands. ILWIS 3.6 software was used for image processing and GIS analysis. The images were imported into the ILWIS 3.6 and transformed under the raster operation using the World Geodetic System 1984 datum (WGS 84) co-ordinate system. Unsupervised classification (Heckbert, 1982; Richards, 1993) of images was conducted using the clustering functions of ILWIS. A total of 15 clusters were derived from the images similar to ones used by the National Biomass Unit of Uganda in mapping land use/cover of Uganda in 1986. Eight land cover classes were obtained for the study area through digitizing, polygonising segments and labeling the polygons (Geneletti and Gorte, 2003) based on ground reference points and focus group discussions. Built-up area/exposed area, bush land, coniferous plantation/plantation forest, grassland, small scale farming/cultivated area, water body, wetland and woodlands were the land cover classes identified in Nakasongola area.

Table 3. 1: Satellite images used for digital image processing

Date of acquisition	**Type of satellite image**	**Spatial Resolution**
10/1/1986	Landsat-5 Thematic Mapper (TM)	30m
18/5/1990	Landsat-5 Thematic Mapper (TM)	30m
23/5/2000	Landsat-7 Enhanced Thematic Mapper plus (ETM+)	30m
27/5/2004	Landsat-7 Enhanced Thematic Mapper plus (ETM+)	30m

To determine the patterns of land cover change, a land cover change detection (Singh, 1989) was conducted in ILWIS 3.6 to identify the differences in the state of land cover over years using a post-classification change detection method (Yuan *et al.*, 2005). Overlay of two raster maps was performed using the cross operation to compare pixels on the same positions. A cross table showing the combinations of input values, classes, number of pixels that occur for each combination and the area for each combination was obtained after ignoring all undefined values.

3.3 Results

Variation in the extent of cover types of Nakasongola District are presented in Table 3.2 and their patterns shown in Figures 3.1 – 3.4.

Table 3. 2: Land cover types of Nakasongola District in 1986, 1990, 2000 and 2004

Land cover type	**1986**		**1990**		**2000**		**2004**	
	Area (Ha)	**%**	**Area (Ha)**	**%**	**Area (Ha)**	**%**	**Area (Ha)**	**%**
Built-up area	1264	0.36	1161	0.33	5464	1.55	18263.1	5.2
Bush land	51613	14.68	139056	39.57	44500	12.66	35684	10.2
Coniferous forests	0	0	2339	0.67	5110	1.46	6150.9	1.75
Grasslands	90020	25.62	53228	15.15	84408	24.02	78199	22.3
Small scale farming	13149	3.74	41327	11.76	40914	11.64	54709	15.6
Water bodies	26156	7.44	25620	7.29	27437	7.81	24555	6.99
Wetlands	14495	4.13	13503	3.84	17581	5	14986	4.26
Woodlands	154742	44.03	75205	21.39	126025	35.86	118892	33.8

Maps showing land use and land cover for Nakasongola District from 1986 - 2004

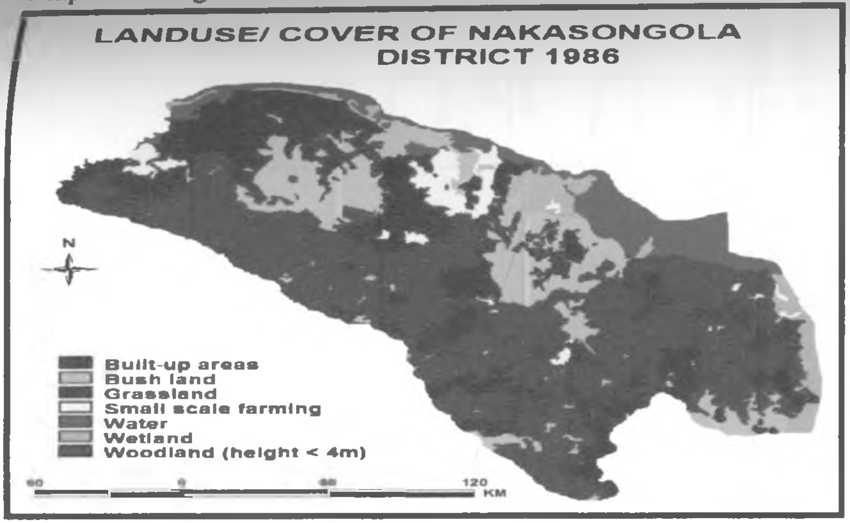

Figure 3. 1: Land use/cover map of 1986

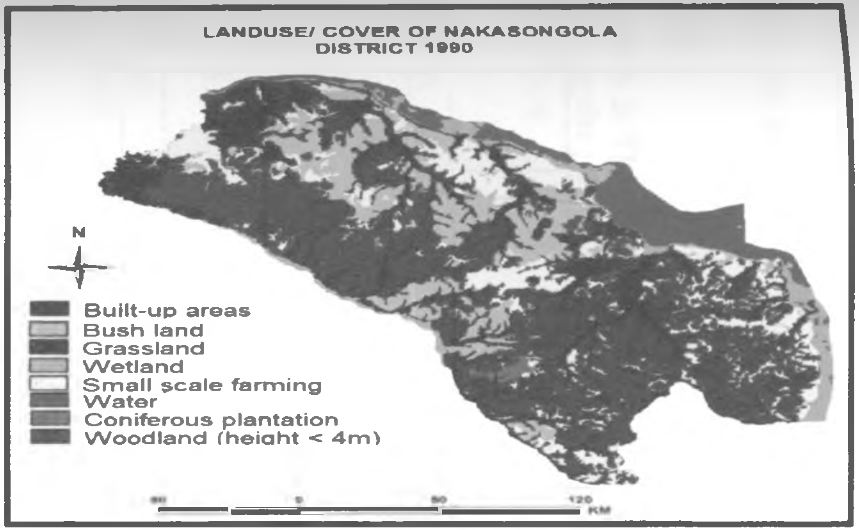

Figure 3. 2: Land use/cover map of 1990

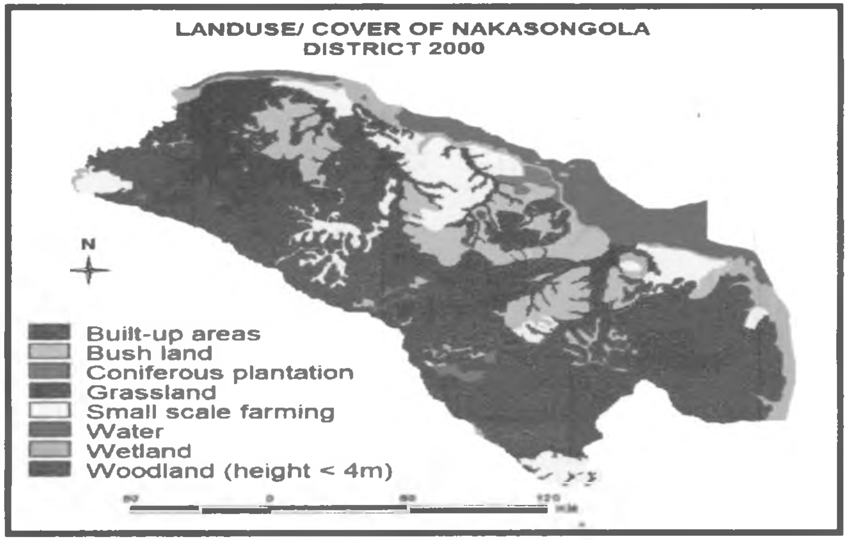

Figure 3. 3: Land use/cover map of 2000

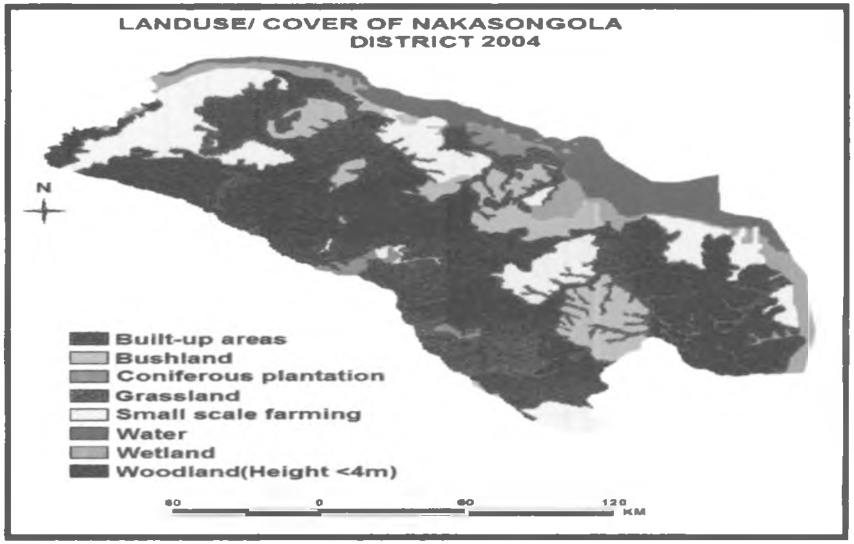

Figure 3. 4: Land use/cover map of 2004

Tables 3.3 – 3.5 present results of overlay analysis of land cover maps for two different years. In each table, the rows represent what a particular land cover type gains from others over time while the columns represent what a given land cover type loose to others in the same period of time. The totals for each year indicate the coverage of the land cover types in the year of the image.

Table 3. 3: The change detection matrix for Nakasongola for the year 1986 and 1990 showing the patterns of land cover changes; the gains and losses for each cover type.

Cover type	Built -up	Bush	Coniferous	Grass land	Small scale farming	Water	Wet land	wood land	**Totals 1990**
Built-up	1	620	0	331	3	0	0	206	**1161**
Bush	588	26567	0	38608	2865	1373	1333	67722	**139056**
Coniferous	0	0	0	1768	0	0	0	571	**2339**
Grassland	207	4426	0	19218	2715	1200	1407	24055	**53228**
Small scale farming	289	4383	0	9159	4556	391	1416	21133	**41327**
Water	0	1967	0	105	330	20727	2374	117	**25620**
Wetland	13	1131	0	1175	464	1808	6726	2186	**13503**
Woodland	166	12519	0	19656	2216	657	1239	38752	**75205**
Totals 1986	**1264**	**51613**	**0**	**90020**	**13149**	**26156**	**14495**	**154742**	

Table 3. 4: The change detection matrix for Nakasongola for the year 1990 and 2000 showing the patterns of land cover changes; the gains and losses for each cover type

Cover type	Built -up	Bush	Coniferous	Grass land	Small scale farming	Water	Wet land	wood land	**Totals 2000**
Built-up	266	3810	72	279	157	0	5	875	**5464**
Bush	45	23610	15	4506	3544	0	55	12725	**44500**
Coniferous	0	1596	1468	1066	734	0	0	246	**5110**
Grassland	551	42079	313	18421	8167	0	877	14000	**84408**
Small scale farming	131	14941	0	5912	12605	0	235	7090	**40914**
Water	0	231	0	4	1716	24376	1093	17	**27437**
Wetland	0	2666	0	1202	1217	1244	9787	1465	**17581**
Woodland	168	50123	471	21838	13187	0	1451	38787	**126025**
Totals 1990	**1161**	**139056**	**2339**	**53228**	**41327**	**25620**	**13503**	**75205**	

Table 3. 5: The change detection matrix for Nakasongola for the year 2000 and 2004 showing the patterns of land cover changes; the gains and losses for each cover type

Cover type	Built -up	Bush	Conif erous	Grass land	Small scale farming	Water	Wet land	wood land	**Totals 2004**
Built-up	1816	11433	0	3628	879	0	0	507	**18263.1**
Bush	103	11979	370	12029	276	0	1910	9017	**35684**
Coniferous	0	146.9	2339	2267	307	0	105	986	**6150.9**
Grassland	2217	8309	0	26826	15121	0	3207	22519	**78199**
Small scale farming	416	2519	607	6114	18733	67	2570	23683	**54709**
Water	0	0	0	0	0	24388	167	0	**24555**
Wetland	0	318	0	190	608	2982	8945	1943	**14986**
Woodland	912	9795	1794	33354	4990	0	677	67370	**118892**
Totals 2000	**5464**	**44500**	**5110**	**84408**	**40914**	**27437**	**17581**	**126025**	

3.3.1 Built-up area

This category also includes un-vegetated/bare areas because it was difficult to treat them as a separate land cover types. This land cover type was covering a relatively small area in 1986, but increased steadily to the year 2004. Overall, built-up areas increased by 25 times covering 5.2% of the total land area in 2004 compared to 0.36% in 1986 (Figure 3.5). Greatest increment in built-up and un-vegetated areas occurred in the period between 2000 and 2004 with an average annual increment of 3200 ha, approximately 59% increase in un-vegetated areas annually. Land cover change detection indicated that built-up/un-vegetated areas develop from former bush land, grassland and woodlands with major recruitments from bush lands. On the other hand, some built-up/un-vegetated areas are converted to bush land, grassland, farming and woodland (Table

3.3, 3.4 and 3.5). Between 2000 and 2004, 11,433 ha of bush land were converted to built-up area hence making bush land the greatest contributor to un-vegetated areas.

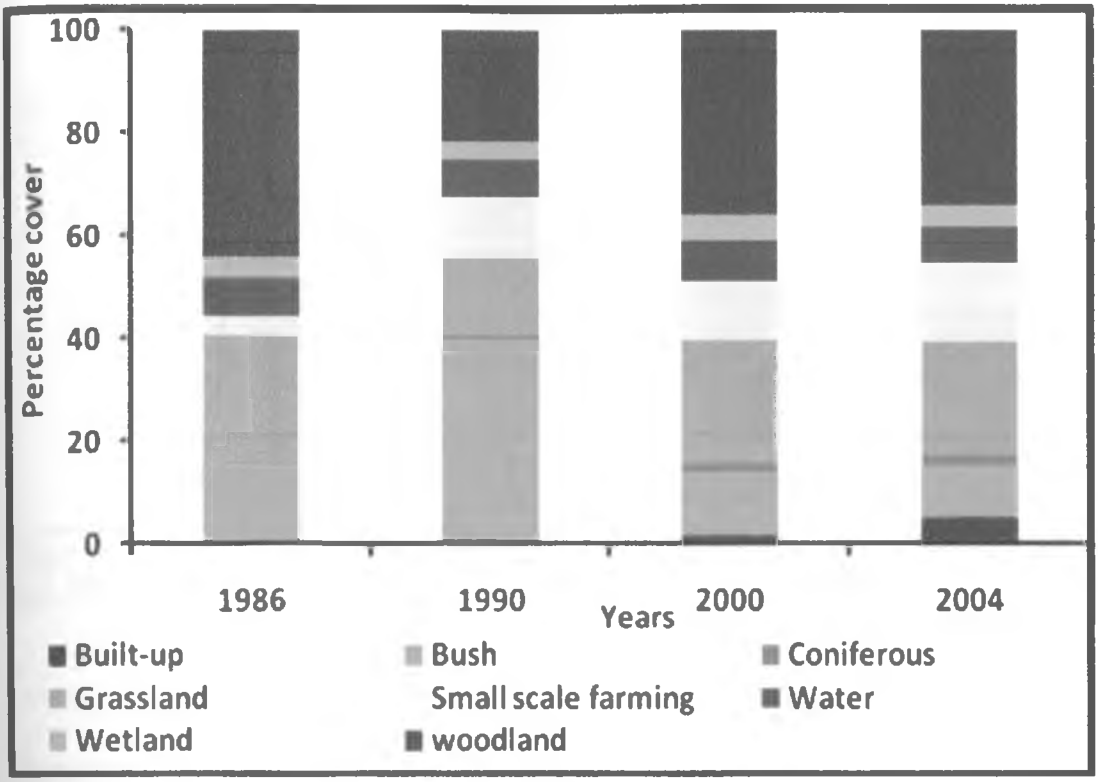

Figure 3. 5: The percentage cover of different land use/cover types for the four study years.

3.3.2 Bushland

Generally, the area under bush decreased from 51,613 ha in 1986 to 35, 684 ha in 2004 respresenting 31% decline in bush cover. However, there was an increase in area covered by bush between 1986 and 1990 from 14.68% of total land cover to 39.57% respectively. This was then followed by a drastic decline in bush land to cover 44500 ha (12.66%) and 35,684 ha (10.15%) of the total area in 2000 and 2004, respectively (Figure 3.6). The greatest decline in bush land was observed between 1990 and 2000 where there was a decline of 68% in bush land.

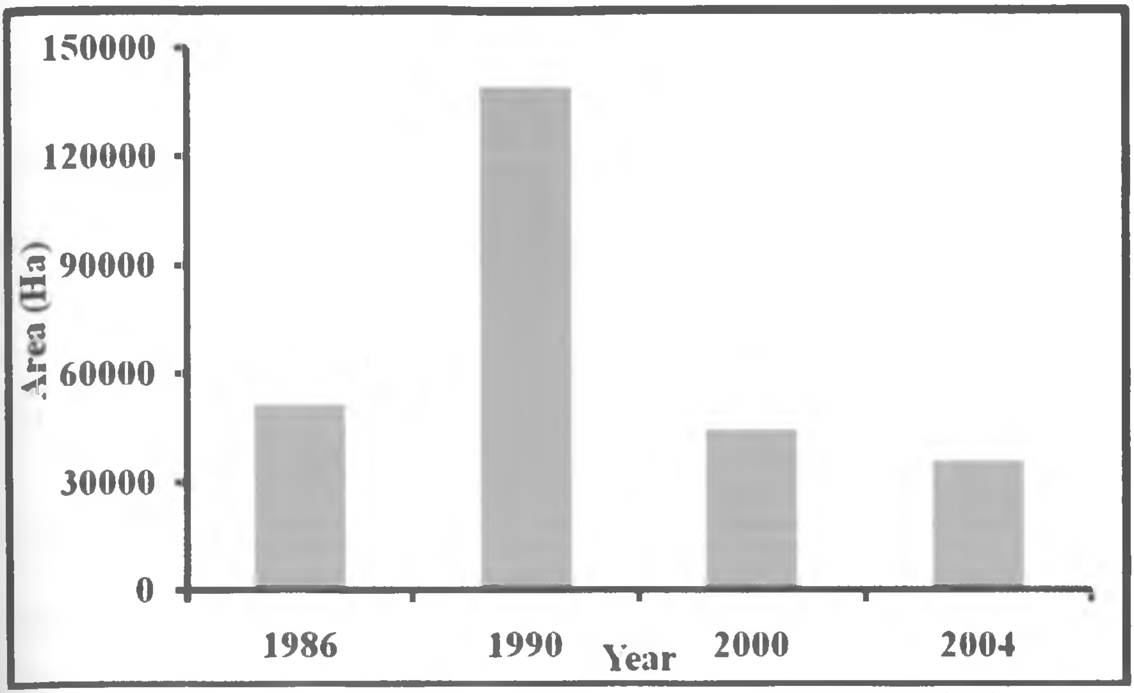

Figure 3. 6: Changes in area covered by bush land in Nakasongola District between 1986 and 2004

Overlay analysis of land cover maps showed that between the year 1990 and 2000 when most bush land disappeared, major conversions were into woodland, followed by grassland, crop land, built-up/un-vegetated, wetland and coniferous plantations (Table 3.4)

3.3.3 Coniferous forests

This is an alien land use type in the area that was first recognized in the satelite image of 1990 in Katugo forest reserve. From then, the area under pine plantations has steadily increased from 2,339 ha in 1990 to 5,110 ha in 2000 and 6,150.9 ha in 2004. Overlay analysis of images indicated that coniferous plantations have been mainly established in areas formally under bushes, grasslands, croplands and woodlands but with major establishments on grasslands. From 1986 to 2004, the total grassland area converted into coniferous plantations is 5,101 ha while

1742.9 ha of bush, 1803 ha of woodland and 1041 ha of cropland had been converted to coniferous plantation. 83% of the total area under coniferous plantations was converetd from grasslands hence making grasslands the most threatened land cover type by coniferous plantations.

3.3.4 Grassland

The area covered by grassland decreased by 13.1% from 90,020 ha in 1986 to 78,199 ha in 2004 (Figure 3.7). There was a decline of 41% and 7.4% in grasslands during the period of 1986 - 1990 and 2000 - 2004 respectively. However, there was an increase in grasslands of 58.6% between between 1990 and 2000. Between 1986 and 1990, much of the grasslands were converted into bush land (38,608 ha), woodland (19,659 ha) and cropland (9,159 ha) (Table 3.3) while between 1990 and 2000, 21,838 ha of grassland were converted to woodland, 5,912 ha to cropland and 4,506 ha to bush land (Table 3.4) and between 2000 and 2004, 33,354 ha were converted to woodland, 12,029 ha to bush land and 6,114 to crop land (Table 3.5). In general, bush and woody encroachment engulfed approximately 65%, 50% and 54% of grasslands in the periods of 1986 – 1990, 1990 – 2000 and 2000 – 2004 respectively (Table 3.6).

Table 3. 6: Extent of bush and woody encroachment into grasslands

Period	Original grassland cover (Ha)	Area encroached by bush and woodland (Ha)	Percentage of bush woody encroachment	Annual percentage encroachment
1986-1990	90020	58264	65	16
1990-2000	53228	26344	50	5
2000-2004	84408	45383	54	14

Apart from conversion of grasslands into other land cover types, there are also notable changes involving the conversion of mostly bush, crop and woodlands into grasslands. 4,426 ha of bush, 2,715 ha cropland and 24,055 ha of woodland were converted into grassland between 1986 and 1990. Between 1990 and 2000, 42,079 ha of bush land, 8,167 ha of cropland and 14,000 ha of woodland were converted to grassland while 8,309 ha of bush, 15,121 ha of cropland and 22,519 ha of woodland were converted into grassland between 2000 and 2004. Therefore, the woodlands and bush lands were the major land cover types cleared for expansion of grazing lands.

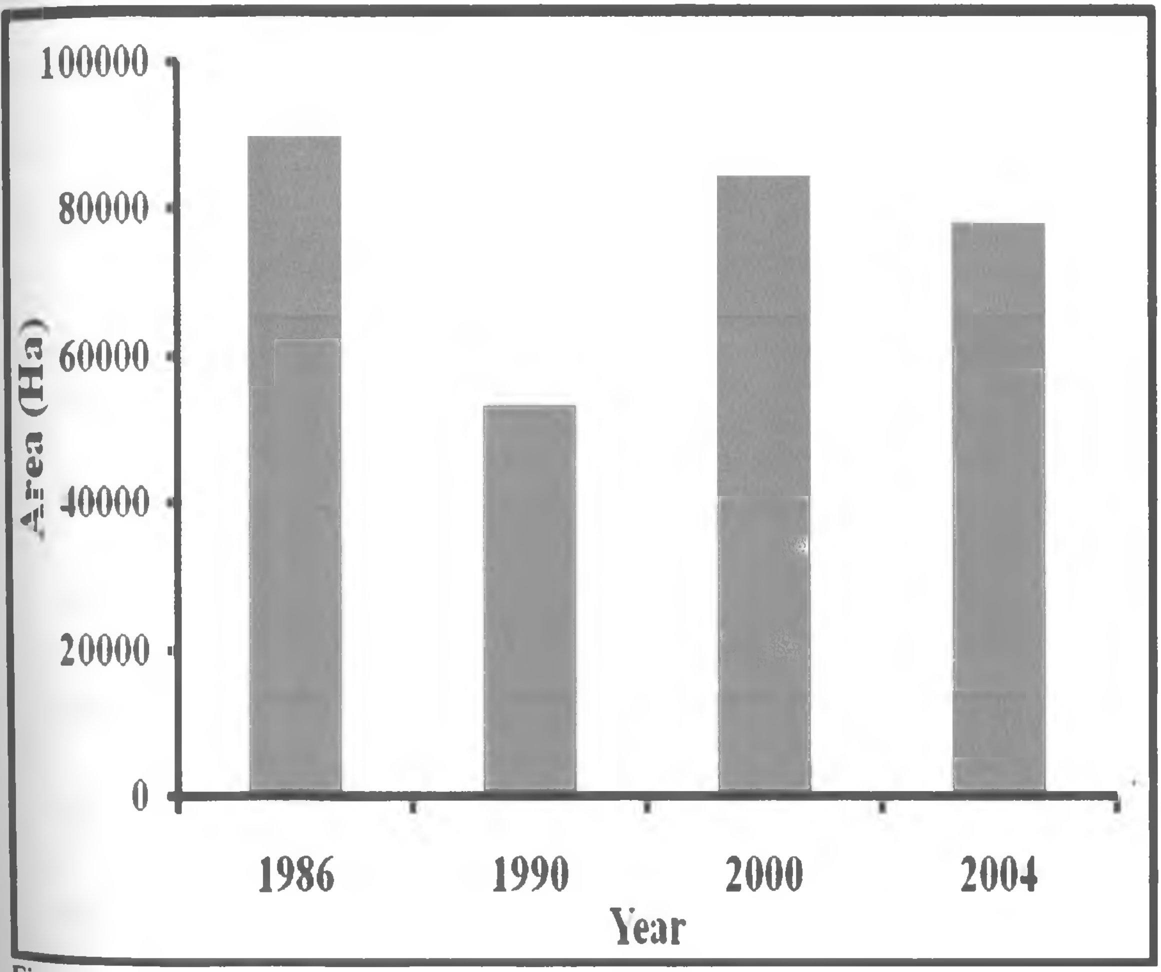

Figure 3. 7: Area covered by grasslands between 1986 and 2004

3.3.5 Small scale farming

This category includes rural villages (dispersed settlements) and homesteads. Generally, the area under small scale farming increased by 41,560 ha between 1986 and 2004 (a net increase of 316% during a period of 18 years) (Figure 3.8). Overlay analysis of maps showed that small scale farming (cropping and settlements) has generally encroached on all cover types but with severe infringement on woodlands, bushlands and grasslands. Between 1986 and 1990, woodlands lost 21,133 ha to farming, grasslands lost 9,159 ha while bush land lost 4,383 ha to farming (Table 3.3). Between 1990 and 2000, woodlands lost 7,090 ha, grassland 5,912 ha and bush land 14,941 ha to farming (Table 3.4) while between 2000 and 2004, woodland lost 23,683 ha, grassland 6,114 ha and bush land 2,519 ha to farming (Table 3.5).

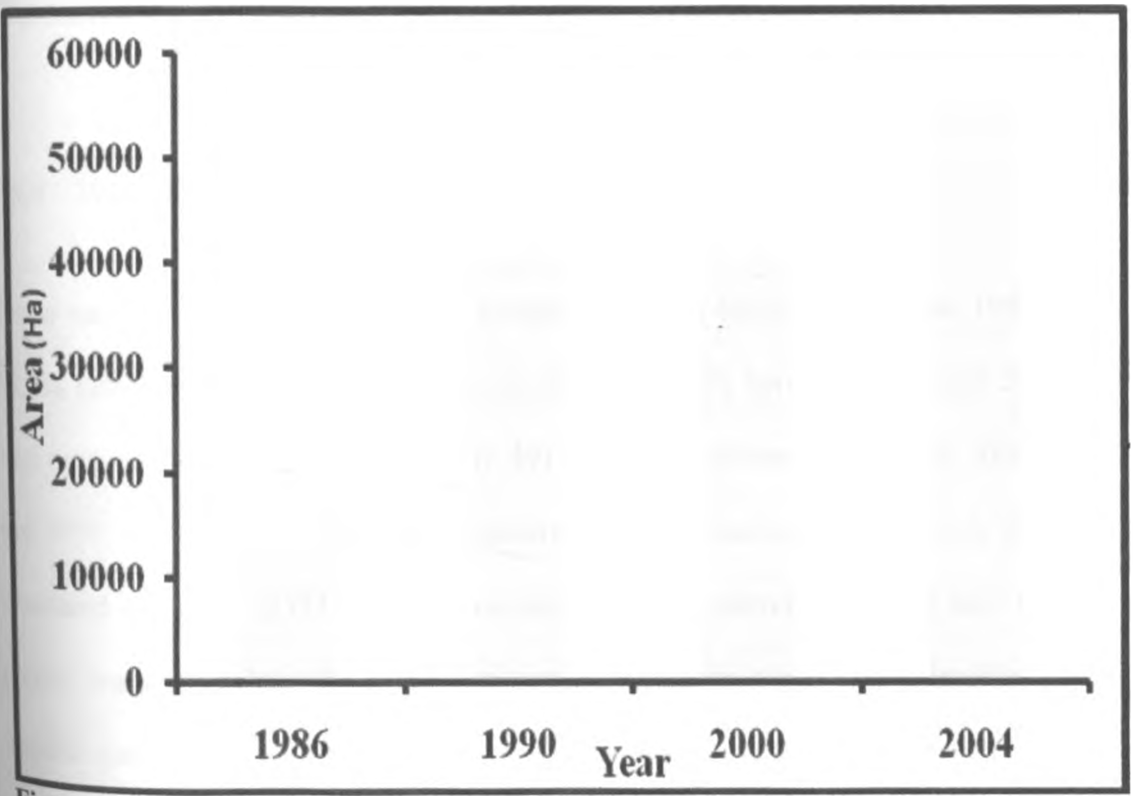

Figure 3. 8: Area covered by smallscale farming between 1986 and 2004

3.3.6 Water bodies

There was a 6% decrease in the area covered by wetlands bodies between 1986 and 2004 from 26156 ha to 24555 ha (Table 3.2). There was a 2% decrease in the area covered by water between 1986 and 1990, an increase of 7.1% between 1990 and 2000, and finally a decrease of 10.5% between 2000 and 2004. A notable change in area covered by water was the presence of many small sized water bodies (valley dams) in 1986 which completely disappeared on the map of 2004. 4893 ha of land were inundated by water between 1986 and 1990 and 5429 ha were converted into other land cover types during the same period (Table 3.3). Between 1990 and 2000, water inundated 3061 ha of land and lost 1244 ha to wetlands (Table 3.4) while between 2000 and 2004, the area covered by water increased by only 167 ha but lost 3049 ha to other land cover types (Table 3.5) with cultivation and wetlands being the land cover types mostly taking over former water covered areas and being affected by increases in water levels.

3.3.7 Wetlands

There was a 6% decrease in the area covered by water between 1986 and 1990, an increase of 30.2% between 1990 and 2000 and a decrease of 14.8% between 2000 and 2004. Overall, the area covered by wetlands increased by 491 ha (3.4%) between 1986 and 2004. Between 1986 and 1990, 7769 ha of wetland were converted to other land cover type with the majority being inundated by water (2374 ha) and encroached on by cultivation (1416 ha). During the same period, wetlands gained 6777 ha from other land cover types hence leading to a decline in wetland area by 992 ha. Between 1990 and 2000, wetland lost 3716 ha to other cover types but gained 7795 ha in the same period causing a net increase of 4078 ha in wetlands. Between 2000 and 2004, wetland lost 8636 ha and gained 6041 ha from other cover types leading to a net decrease of 2595 ha in this period.

3.3.8 Woodlands

There was a 23% decline in the area covered by woodlands over an 18 year period from 154742 ha in 1986 to 118892 ha in 2004 (Figure 3.9). There was a 51.4% decline in area covered by woodland between 1986 and 1990, with an annual decline of 12.9%. There was an increase in woodland between 1990 and 2000 of 67% and a decline of 5.7% between 2000 and 2004. Overlay analysis shows that 115,990 ha of woodland were converted into other land cover types particularly to bush land (67,722 ha), grassland (24,055 ha) and cultivation (21,133 ha) between 1986 and 1990. However during the same period 19,656 ha of grassland and 12,519 ha of bush land were converted into woodland (Table 3.3). 87,238 ha and 36,418 ha of woodland were gained and lost respectively between 1990 and 2000, with woodlands encroaching on 21,838 ha of grasslands and 50,123 ha of bush land (Table 3.4). Between 2000 and 2004, woodlands expanded by 51,522 ha while 58,655 ha were converted to other land cover types. During this period, 33,354 ha of grassland were encroached on by woodlands whereas 23,683 ha and 22,519 ha of woodlands were cultivated and converted into grazing lands respectively (Table 3.5).

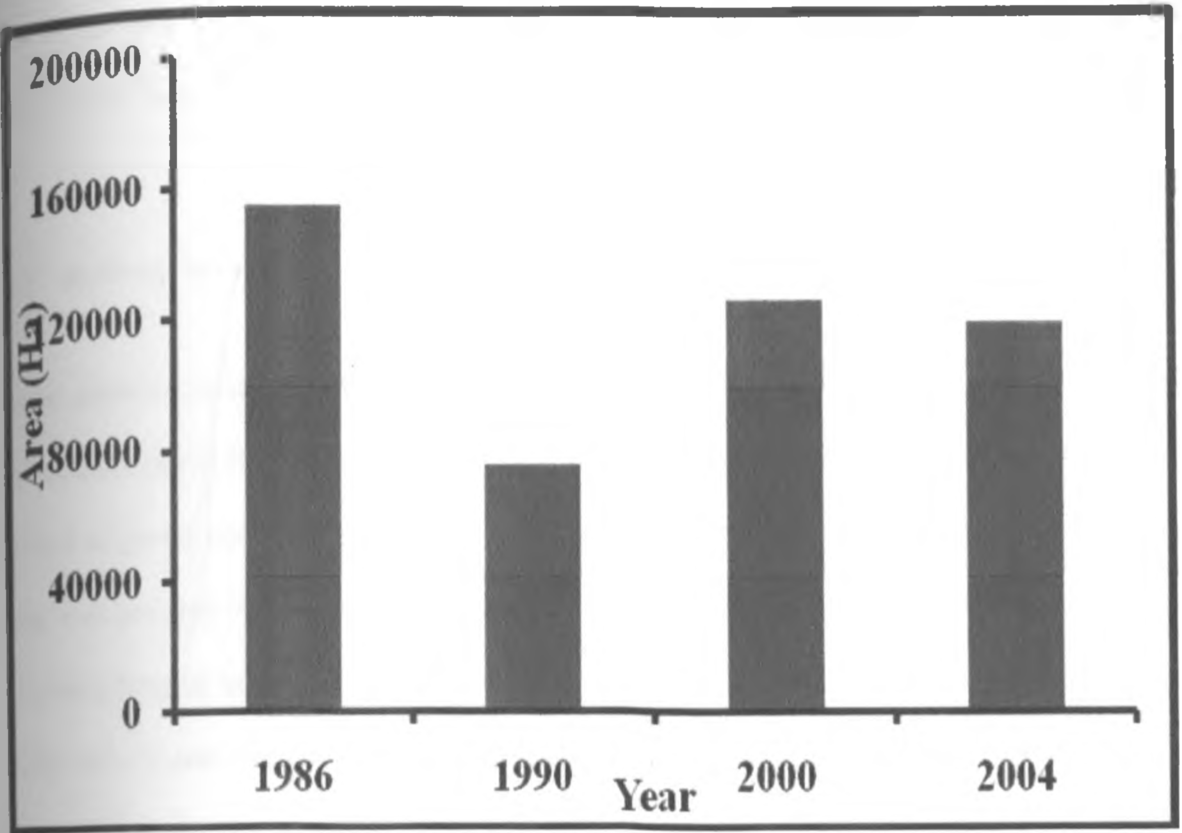

Figure 3. 9: Area covered by woodlands between 1986 and 2004.

3.4 Discussion

Land cover changes in Nakasongola District are reflected in both temporal and spatial scales. Spatial changes in land cover include expansion of cultivated lands in natural vegetation types (grasslands, bush land, wetland and woodland), expansion of grasslands into bush land and woodlands, introduction and expansion of pine plantations into woodlands, bush lands and grasslands, encroachment of bushes and woodlands into grasslands and increase in bare ground. On the other hand, temporal changes include the regeneration of woodlands after clearance for wood and charcoal production and resting and cultivation of the same piece of land after some years. With the exception of bush and woody encroachment into grasslands all other spatial changes are driven by direct alteration of man on natural vegetation for food production, economic and social gains (Odada *et al*., 2009; Ebanyat *et al*., 2010; Maitima *et al*., 2010).

3.4.1 Built-up area

Human settlements and establishments account for this land cover between 1986 and 1990. The restoration of peace in this area after the bush war that ended in 1986 led to emigration of people that had migrated into Nakasongola from other parts of the country hence leading to a decrease in the area covered by built-up area. The division of ranches into small landholding in 1994 led to overstocking in several places that limited the regeneration of pastures. This coupled with termite activity and charcoal burning exacerbated the land degradation problem that created bare patches of land hence explaining the immense increases in built-up/open areas from 1990 up to 2004. Anecdotal information from this area also suggests that land degradation and intensified termite damage and charcoal burning became problems in Nakasongola District around 1996 and 1998 and have led to the creation of large patches of bare land.

3.4.2 Bush land

The increasing human population, demand for food and increased cultivation in Nakasongola District are major factors explaining the gradual decline in the area covered by bush lands. In most areas, bush has occurred as a transitional succession stage leading to establishment of woodlands in the area. The reduction in livestock populations in the area after the 1986 insurgency meant that the few remaining animals could not effectively graze and browse the entire area and this promoted the growth of shrubs leading to their increment in 1990. This therefore explains why immense areas formerly covered by grassland were converted into bush land. Overgrazing of land exposed it to soil erosion leading to reduction in soil fertility and a decline in growth of pastures. In so doing, this shifts the competition between grasses and shrubs which have a deeper root system to survive and recruit in masses in such areas hence taking over former grasslands. Bushes and shrubs have also been seen to take over former cultivated and woodland areas. This is because the crop production system practiced in the area of low input agriculture where soils easily loose fertility and cultivators abandon them in search for new fertile areas. The abandoned areas may be used as grazing areas shortly and then recruit into bush furrows. Also, the increased cutting down of trees for wood and charcoal eliminates the intra-species competition between woody species and their saplings. This results into recruitment of hundreds of saplings into mature trees that first appear as shrubs before eventually becoming trees. Thus bushes/shrubs are a transitional stage to woody trees in some areas.

3.4.3 Grassland

Cultivation, bush and woody encroachment are the major land cover types taking over grasslands in Nakasongola District. However, although bare ground still covers a small area, it is the most undesirable land cover type in ecological, environmental and economic aspects. Bare land is non productive, causes degradation of other ecosystem (soil erosion and runoff that sediments water reservoirs), leads to a reduction in biodiversity and requires more investment and time to rehabilitate. Increased conversion of grasslands into crop farming is basically an anthropogenic activity driven by the increasing human population and demand for food especially by mmigrants from high potential areas that carry with them their former land use practices. However, the conversion of grasslands into bush and woodland is rather an ecological process hat involves interplay of several factors that include management, climatic and atmospheric composition with complex feedback mechanisms involved.

3.4.4 Small scale farming

Extensive land cultivation for food production started around 1990 in Nakasongola District following the increased settlement of people with crop production background. The division of ranches into small farms and individualization of land in 1994 led to increased fencing and further sub-division of land into smaller patches that could no longer support livestock grazing hence the adoption of crop production as the most appropriate land use form for the small land holdings. However, because of the limited potential of soils in this area to support crop growth and the practice of low input agricultural production with no fertilizer use, farmers often open up new areas in search of fertile soils on an annual basis. In this regard, woodland, bush land, grassland and wetland are greatly encroached on by cultivators. Cultivation and the associated fencing of land to protect destruction from animals not only reduce livestock grazing resources but also restrict animal movements in search for water and forage especially during dry season. This leads to increased overgrazing of the remaining land thus accelerating degradation of grasslands. Overgrazing also means that animals eat most of the available plant material, both fresh and dry in the struggle to survive. In this situation, the deposition of litter which is a major source of food for the majority of termite species in Nakasongola is restricted. The litter feeding termites resort to fresh vegetation, competing with livestock and therefore increasing the pressure on grasslands resulting into unprecedented levels of land degradation and creation of immense patches of bare soil. Termite damage is unequivocal in both grasslands and croplands since they resort to feeding on fresh vegetation due to scarcity of dry materials and are thus regarded as a major threat to food security in Nakasongola District (Mugerwa *et al.*, 2011a; 2011b). Because crop residues are not utilized in livestock feeding to alleviate the burden of overgrazing from grasslands during the dry season, the introduction and intensification of crop production in pastoral rangeland communities has no linkage with livestock production and therefore greatly contributed to the present high levels of land degradation and decrease in livestock grazing areas.

3.4.5 Water bodies and wetland

Changes in the area covered by water and wetlands follow the same pattern and are attributed to changes in the amount of rainfall received as well as the droughts experienced in the area. Increase in water levels as a result of high rainfall amounts result into a corresponding increasing in wetlands due to inundation of nearby areas. Conversely, long dry spells result in a reduction of area under water and wetland coverage. The area experienced long dry spells between 1983 and 1989 which led to the reduction in water levels and drying up of valley dams and tanks hence reducing the area under water in 1990 as well as increased cultivation in wetlands hence reducing their coverage. The increment in water and wetland cover in 2000 was attributed to relatively high rainfall years 1995, 1997 and 2000 while their decline in 2004 was attributed to long droughts of between 2001 and 2004. Satellite imageries show that the area had many small water bodies (valley dams and tanks) in 1986 which contributed to high water coverage in this year. However, high rates of land degradation following the division of ranches and the resultant overgrazing led to increased soil erosion and deposition of soil in valley dams and tanks which led to a reduction in their volume and complete disappearance of most of these surface water reservoirs. For example, Bizibitukula valley dam in Migyera catchment had a surface area of 6000 m^2 in early 1980's but is now only 600 m^2 due to excessive soil deposition from the bare upper catchment as a result of overgrazing, indiscriminative tree cutting for charcoal and high levels of termite damage. The size of many surface reservoirs has been substantially reduced to levels that cannot be detected on a 30 x 30 m resolution image.

3.4.6 Woodlands

The continued decrease in area covered by woodlands from 1986 to 2004 would be attributed to increased anthropogenic activities that include cutting down trees for cultivation, plantation forests, grasslands and charcoal production as has been the case elsewhere worldwide (Lambin *et al.*, 1999; 2001; Mwavu and Witkowski, 2008; Ebanyati *et al.*, 2010; Maitima *et al.*, 2010). However the increase of woodland in grasslands takes a rather more complex process with many contributing factors. Some of the forces driving reductions in woodland area have a positive feedback mechanism that drives more woody growth in the same area.

The encroachment of bush and woody species in grassland ecosystem involves a sequence of ecological events and is driven by a complex of factors involving changes in management practices, climate and atmospheric composition (Archer *et al.*, 1995; van Auken, 2000; Asner *et al.*, 2004) which may act singly or in combination. A conceptual framework (Figure 3.10) was developed to explain the factors contributing to the encroachment of bushes and woody plants in grassland ecosystems.

Overgrazing, suppression of active fires and increase in termite activity are primary factors that led to alterations in tree-grass competition, reduction in herbaceous layer and consequently to reduced fire frequencies. There exists a feedback within these factors; for example, suppression of annual active fires is believed to have contributed to increased activity of termites in the rangelands. The scotching fires were a natural control over soft bodied ants and termites killing them even several centimeters below the ground. As herbaceous biomass declined and the frequency and intensity of fires decreased, termites populations started to build destroying more grass.

Reduction in herbaceous layer and fire frequencies shifted the competition between grasses and woody plants in the favour of trees, leading to increased recruitment of saplings into mature trees and increased density of woody vegetation in former grass dominated systems. Similar findings were reported by Brown and Archer (1999), Kraaij and Ward (2006) and van Auken and Bush (1997) who noted that the co-existence of grasses and trees in the savanna ecosystem is as a result of competition for resources and that alteration in the competition to favour one of the components leads to its dominance in the system.

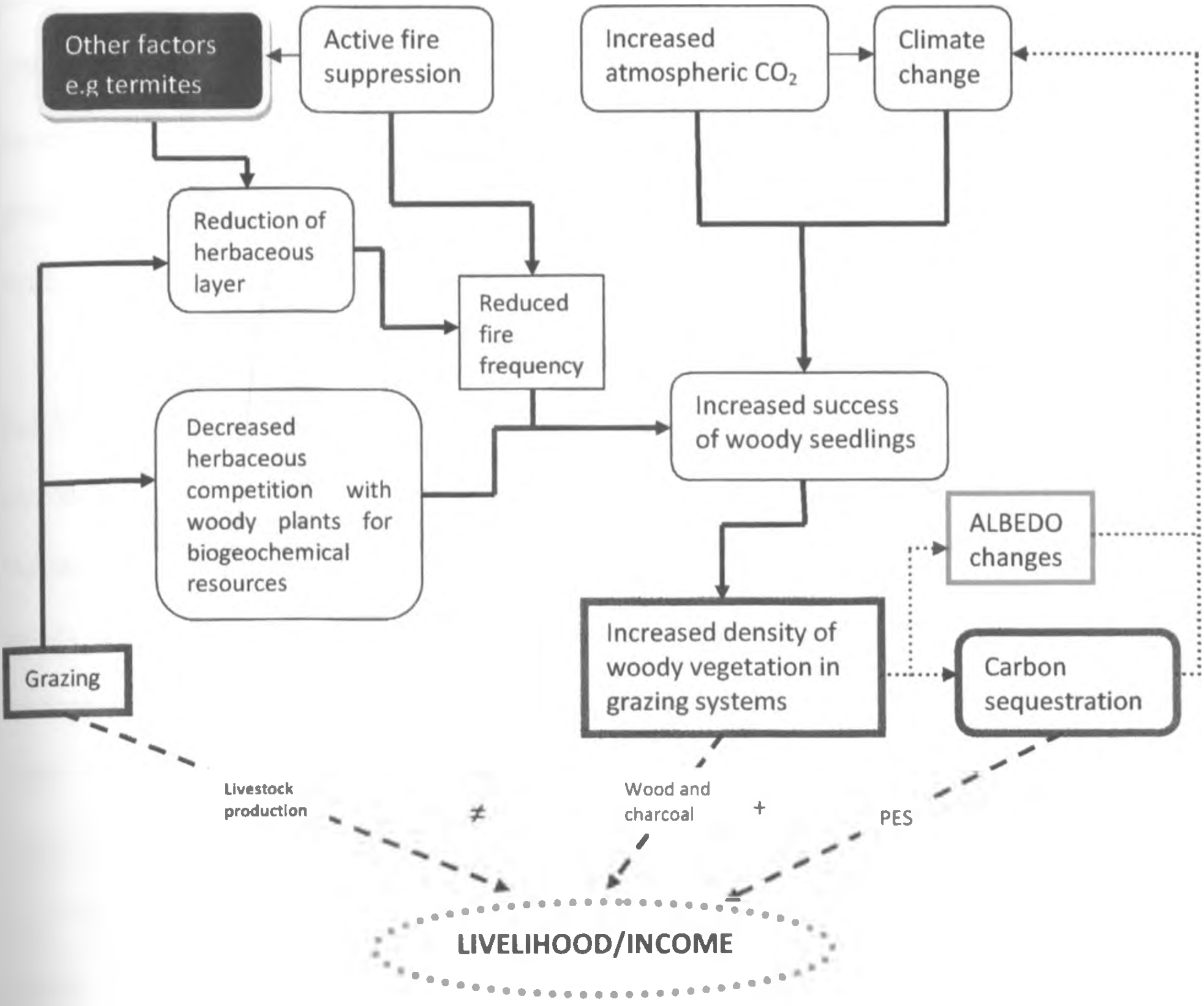

Figure 3. 10: A conceptual framework displaying interplay of factors driving woody encroachment and the impacts of increased woody density in the rangelands. Modified from Asner *et al.*, 2004

Trees, being C3 plants are known to have a more efficient photosynthetic process under elevated carbon dioxide conditions compared to grasses (C4 plants). On this basis, the global increase in atmospheric carbon dioxide concentration above the upper safety limit (350 ppm) in 1988 is believed to have had a significant contribution on the increased woody encroachment in the savanna ecosystems in Nakasongola. Since farmers started noticing woody encroachment in 1990 and consequently becoming a rangeland management problem from 1994 (NEMA, 1996), the elevated CO_2 levels must have contributed to the increased dominancy of woody species into grasslands of Nakasongola rangelands as earlier observed in other regions by Knapp (1993), Polley *et al.* (1992) and Johnson *et al.* (1993).

Rainfall and temperature are among the climatic forces that could be contributing to woody encroachment in grassland ecosystems. There have been notable changes in the rainfall of Nakasongola between 1961 and 2010 (Figure 3.11) and these must have strong bearing on woody encroachment since water is a major resource that determines tree – grass existence in savanna ecosystem (Knoop and Walker, 1985; Smith and Goodman, 1986; Kraaij and Ward, 2006). There exists a variation in rainfall amounts between months and over years with the area experiencing several droughts every 8 – 10 years. These droughts were however followed by wet years which could balance the competition between trees and grasses and keep a balanced composition of the two components. However, the area has received more frequent droughts since 1990 which shifted the competition between grasses and trees in the favour of the latter and leading to its dominance since trees are better competitors than grasses under drought conditions (Fernandez-Illescas and Rodriguez-Iturbe, 2003).

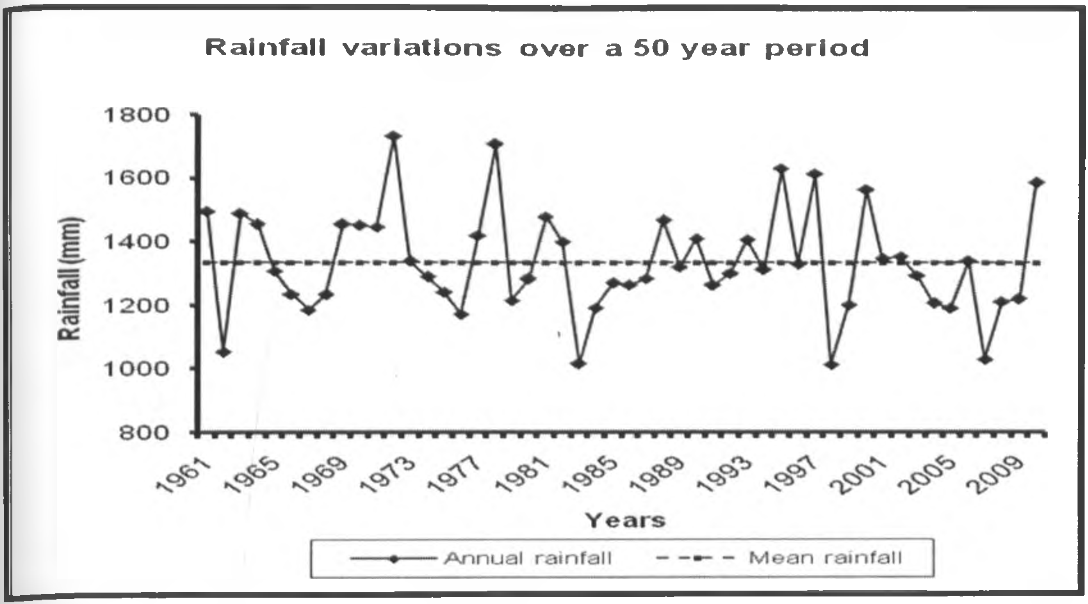

Figure 3. 11: Variation of rainfall in Nakasongola District between 1961 and 2010

Source: Department of Meteorology, Prime Ministers' Office, Uganda

The years in which woody encroachment became a problem (1990 – 1994) are consistent with the years when droughts became more frequent and prolonged in the area. Since droughts leads evaporation of all water in the grass root zone and subsequently leading to death of shallow rooted grasses, deep rooted trees recruit in numbers at the expense of grasses and thus become more dominant as observed by (Skarpe, 1990; Scholes and Archer, 1997; Scanlon *et al*., 2005).

Variations in temperatures of Nakasongola over a 50 year period reflect high temperatures above the mean since 1990 (Figure 3.12). At high temperatures, the evapotranspiration rate of grasses reduces due to stomata closure. This reduces photosynthesis in grasses resulting into decreased performance of the grass component. The water stored in the soil therefore become accessible to trees only. This coupled with elevated carbon dioxide increases the performance and dominance of trees over grasses as suggested by Knapp (1993).

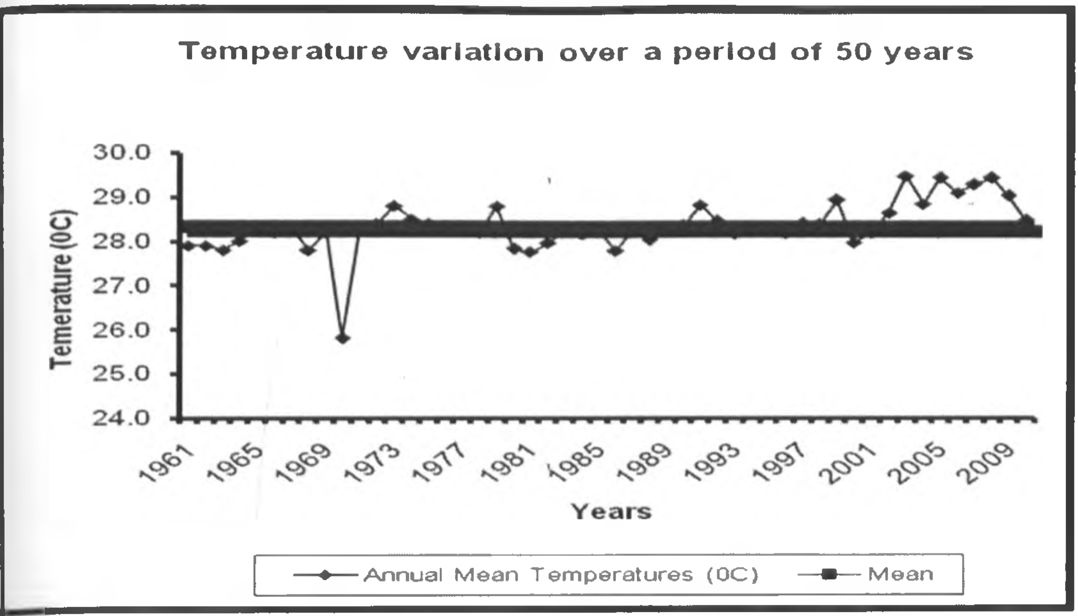

Figure 3. 12: Temperature variation in Nakasongola District between 1961 and 2010

Source: Department of Meteorology, Prime Ministers' Office, Uganda

The increase in woody cover in formerly grass dominated environments with high reflective capacities is known to reduce the surface albedo and even cause more warming as indicated by Bonan *et al.* (1992) and Foley *et al.* (1994). Therefore, the darkening of rangeland surfaces through introduction of pine plantations and woody encroachment has a feedback mechanism that forces the temperatures to increase. This could limit the growth of grasses and favour recruitment of more trees.

The reasons for temporal changes in woodland cover vary from social economic drivers which increase the demand for charcoal and cropping land resulting into reduction in woody cover (Mwavu and Witkowski, 2008; Ebanyati *et al.*, 2010; Maitima *et al.*, 2010) as well as ecological and climatic drivers that result into increased woody cover (Figure 3. 13).

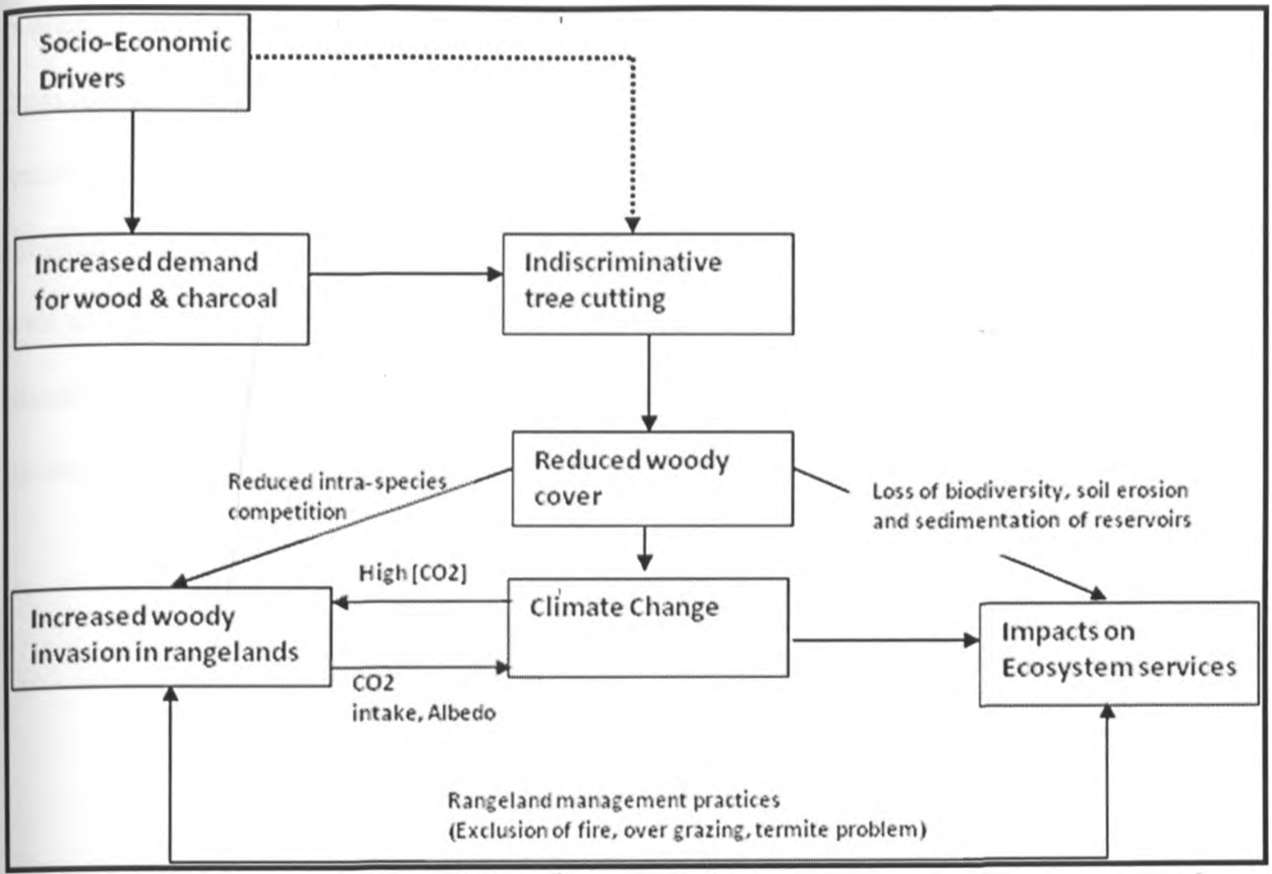

Figure 3. 13: Conceptual framework showing factors driving temporal changes in woody cover.

3.5 Conclusion

Opening of natural grassland systems for cultivation and pine establishment and bush and woody encroachment are the most pervasive land cover changes in the rangelands of Nakasongola District which have both economic and environmental implications. Although clearing of encroaching bush and woody vegetation for grazing has been noted, the increased decline in grasslands indicate that the rate at which bush and woody encroachment occur greatly surpasses the rate which they are cleared for grazing purposes. This therefore indicates that if sustainable rangeland management practices are not adopted, the grasslands are likely to be converted into bushes and woodlands. Intensification of cropping systems and transformation of agriculture from low input to high input agriculture so as to reduce opening up of new land every season in search for fertile soils is a precious step in averting the conversion of grasslands into croplands. Integration of crop residues into livestock feeding systems so as to lift the pressure on land as well as exploiting the potential of land use and cover types (grasslands, woodlands and pine plantations) for economic benefits (PES) should also be undertaken in order to improve the income base of farmers.

Chapter 4

Assessing the effect of land use and cover change on physical and chemical properties of soil

Abstract

A modified-Whittaker sampling design was used to collect soil samples in three land cover types (bare, herbaceous and woody) under three production systems (settled, semi-settled and non-settled) and analyzed for selected chemical (pH, OC, OM, N, Ca, Mg, K, Na, CEC and available Phosphorus) and physical (bulk density, porosity, conductivity, structure and texture) properties. Analysis of variance, discriminant analysis and principle component analysis were conducted using XL-Stat software. Soils from bare land under non-settled production systems had significantly high levels of clay ($p<0.0001$) and bulk density ($p<0.02$) and significantly lower levels of sand ($p<0.04$) and porosity ($p<0.001$). Herbaceous vegetation had significantly high levels of organic matter and total nitrogen ($p < 0.001$) compared to woody and bare soils, while woody had significantly high levels of available P ($p < 0.04$). The semi-settled production systems had high levels of pH ($p < 0.04$), Ca ($p < 0.038$) and CEC ($p < 0.001$) compared to the settled and non-settled systems. Herbaceous vegetation under the semi-settled production system had significantly high levels of organic matter ($p<0.004$), total nitrogen ($p<0.003$) and Ca ($p<0.028$) compared to other land use and cover types. The observations of bare and woody cover slightly overlap (5.6%) while a great overlap exists between woody and herbaceous cover (72%). The distinctiveness of bare from herbaceous cover indicates that grazing areas have been degraded to levels below their recuperative capacity and therefore rehabilitation back to herbaceous cover would require more time and external investments other than resting alone.

4.1 Introduction

The increasing pressure exerted on land resources is driving major land use and land cover changes in the rangelands of Uganda and consequently leading to a reduction in the quantity and quality of services they provide. The rangelands of Uganda are well known as the cheapest source of food for livestock production that sustain more than 90% of the ruminant population and supply more than 85% of the total milk and meat in the country (Kisamba-Mugerwa *et al.*, 2006). Grazing is therefore a major rangeland use on which pastoral livelihoods revolve. However, the escalating changes in land use and land cover that lead to a reduction in grasslands are posing a great threat to the sustainability of rangeland ecosystems, livestock production, food security and livelihoods of rangeland inhabitants. The most conspicuous land cover change in the grassland of Uganda is the wide spread encroachment by woody species and bare ground which have affected more than 50% of the grazing land in Nakasongola District with an annual encroachment rate of 15% (refer to chapter 3).

Bare and woody encroachment on grassland is often associated with major changes in soil cover, soil erosion, and affects several physical, chemical and biological properties of soil and biodiversity (Andrieu *et al.*, 2007; Seabrook *et al.*, 2007). Because of the present and envisaged detrimental impacts of land use and cover change on ecosystem products and services and their threat on livelihoods, rangeland inhabitants are attempting several management practices to adapt to the imposed consequences. However, in a bid to adapt, land cover changes have been accelerated in some areas while in others unexpected and undesirable feedbacks have been initiated that drive more changes and continue to compromise the grassland ecosystem. Because the soils in most rangeland communities of Uganda have a limited production potential (Radwanski, 1960; Langdale-Brown *et al*., 1964) land use and cover changes have immensely impacted on soil properties and imparted challenges on rangeland restoration processes since alleviation of suspected causes of degradation does not take the system to its original state. More to that, high level management practices that involved reseeding of degraded rangelands failed because the soils could no longer support plant growth (Mugerwa *et al*., 2008). Land use and land cover change have also compromised the resilience of rangelands to climatic variability and change as some ecosystems are altered that a slight perturbation in climate makes them fail to return to their original states. The adaptive capacities of pastoral communities to the effects of climate variability and change are increasingly lowered thus making them more vulnerable to food insecurity and poverty.

The high dependence on land resources for subsistence possess a growing threat for widespread natural resource degradation (Rohit *et al*., 2006). The extensive degradation of soils and reduction in biodiversity following the conversion of natural land cover systems and implementation of different land use practices is greatly impacting on the sustainability of agricultural production systems throughout the world. The rangelands of Uganda are regarded as severely degraded land forms (NEMA, 2006; 2008). This degradation is believed to be associated with changes in soil chemical and physical properties as reflected in increasing crop failures and low pasture production. However, the only existing information on classifications of soils in Uganda and their potential productivity levels were conducted over sixty years back by Radwanski (1960) and Langdale-Brown *et al*. (1964). Given the increasing changes in land use as a result of increased population pressure and changes in management system, there is a growing need to evaluate the quality of soils in these areas so as to advise on the production potential and devise informed management practices for land utilization in rangelands. The objective of this study was therefore to assess the effect of land use and cover change on selected physical and chemical properties of soil in the rangelands of Nakasongola District.

4.2 Methods

4.2.1 Description of study area

The study was conducted in Nabiswera and Nakitoma sub counties of Nakasongola District (Figure 4.1). The study area was characterized into three rangeland management (land use) systems (settled, semi-settled and non-settled) which were stratified into three land cover types (herbaceous, woody and bare) in which six locations were randomly selected for establishment of the sampling sites.

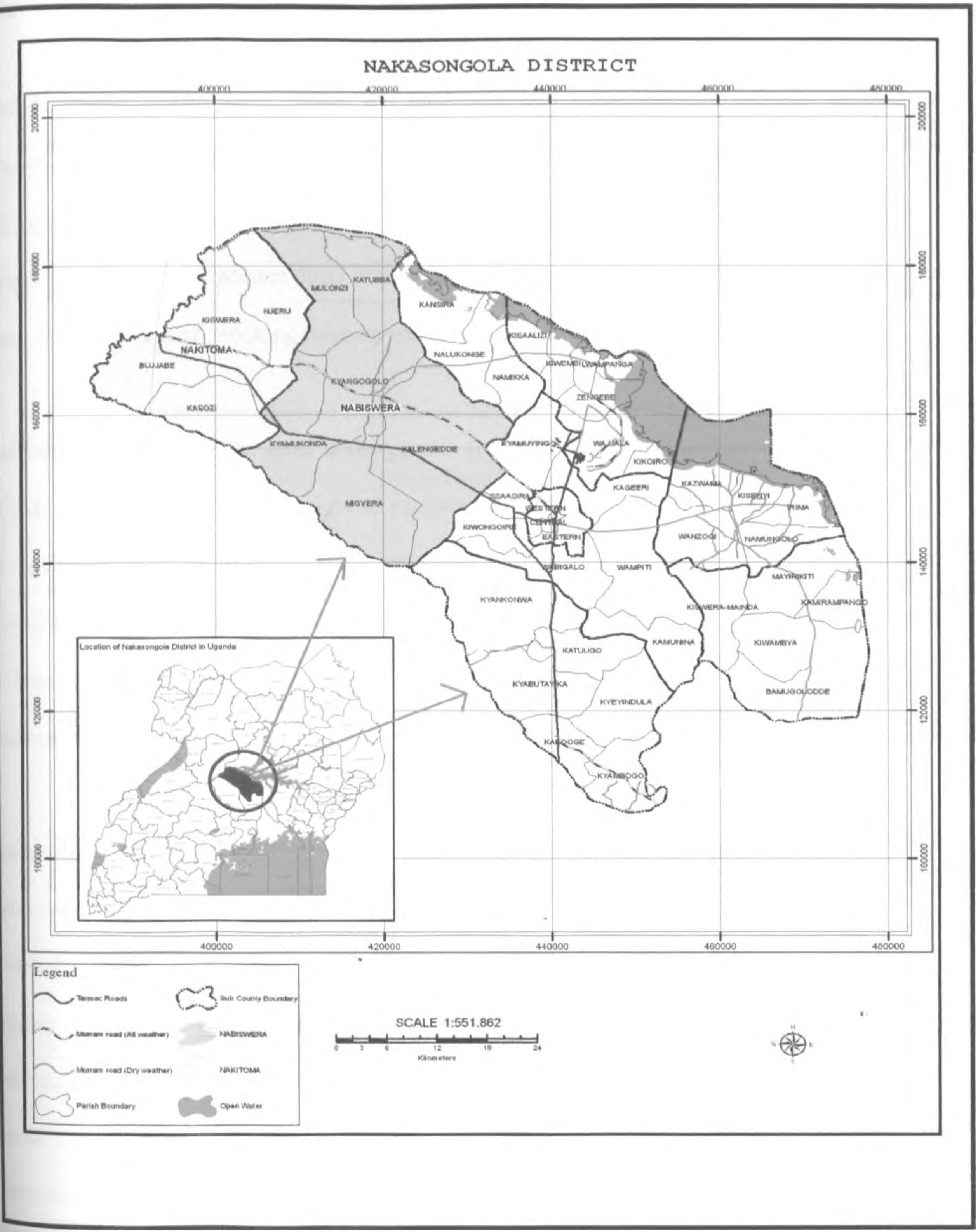

Figure 4. 1: Map of Nakasongola showing the two study areas (coloured) of Nakitoma and Nabiswera sub counties.

4.2.2 Description of rangeland use systems

Settled: These include areas where the rangeland was individualized, fenced and planned rotational grazing is practiced. There are high investments in these production systems for water development and fencing of paddocks and there is limited or no migration even in dry seasons. Because of the high investment costs incurred, producers often strive to obtain more profits and hence tend to have high stocking rates on well managed paddocks and water resources.

Semi-settled: These include areas under private and communal property rights. In this case, the individual or community has the right to exclude others from using the resource and regulate its use. However, there is limited fencing and control of stock movement over the land. In some areas only perimeter fencing is provided but there is no planned rotational grazing (no paddocks) and they are also characterized with stock movement from one area to another during dry periods (sedentary pastoralism and transhumance are still practiced in these areas).

Non-settled: These are systems where exclusion or control of access of potential users is problematic. There is no fencing (neither perimeter nor paddocks) and thus controlling access of potential users is virtually impossible. There is therefore open access making land a common property and its continued use involves subtractability (Berkes *et al.*, 1989). In the non-settled systems, land is subjected to unknown and uncontrolled numbers of livestock where each herder intends to maximize the use of resources thus leading to resource degradation, the tragedy of the commons (Hardin, 1968).

4.2.3 Field plot layout and sample collection

A Modified-Whittaker plot measuring 20 m × 50 m (Figure 4.2) was placed with the long axis parallel to the environmental gradient as described by Stohlgren *et al.* (1995). In each plot of 1000 m^2 was nested subplots of three different sizes. A 5 m × 20 m (100 m^2) subplot in the center, two 2 m × 5 m (10 m^2) subplots in opposite corners and ten 0.5 m × 2 m (1 m^2) subplots (six arranged systematically inside and adjacent to the 1000 m^2 plot perimeter and four arranged systematically outside and adjacent to the 100 m^2 subplot perimeter.

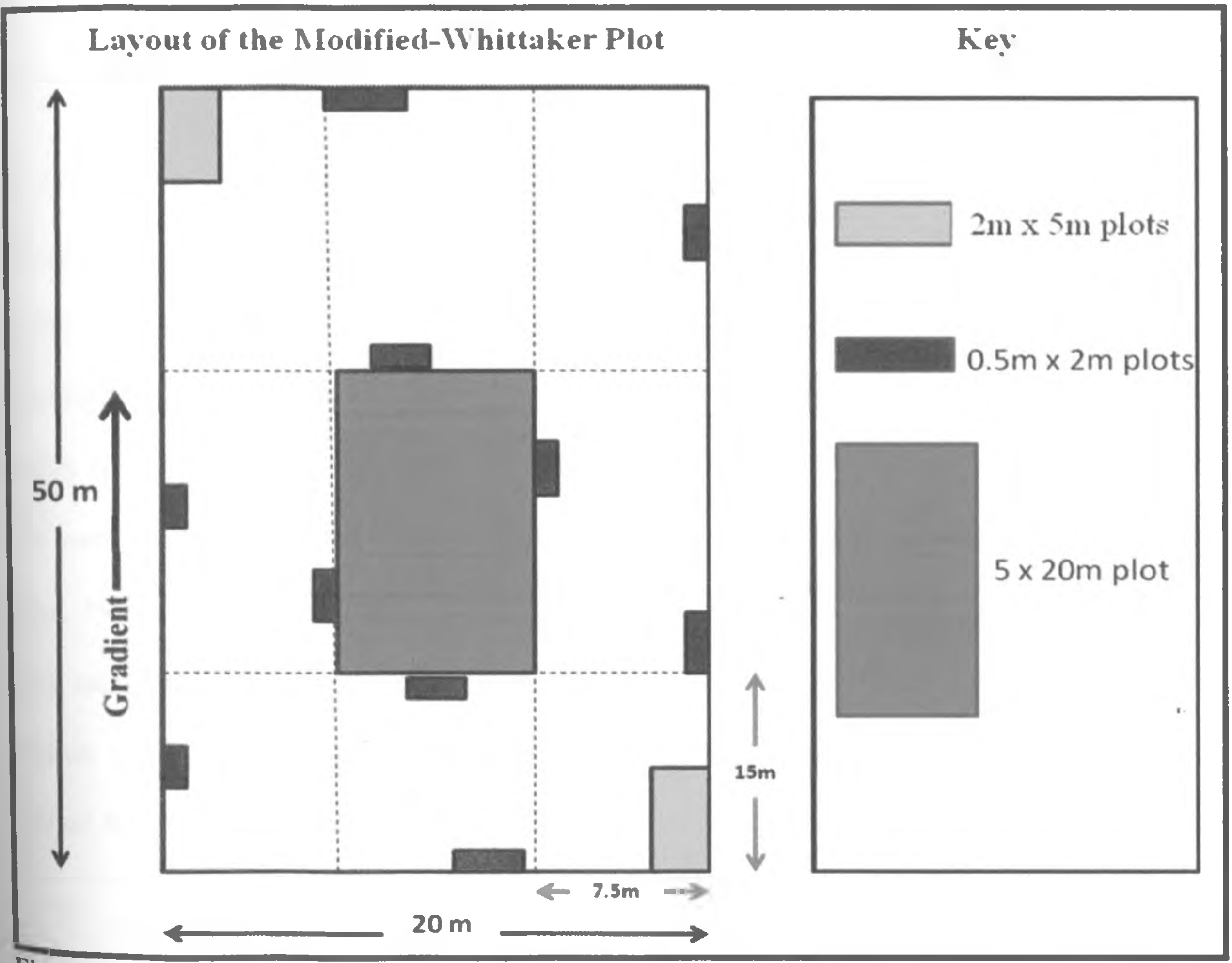

Figure 4. 2: Field layout of a Modified-Whittaker plot design showing the three different sizes of sample plots nested into a large plot of 50 X 20 m

Five soil samples were taken from each of the four corners and center of each Modified-Whittaker plot using cores of 5 cm diameter and a depth of 15 cm. Due to the presence of rocks in some areas, it was hard to maintain a consistent core depth and thus core depths were varied between 8 cm and 15 cm. The five samples obtained were then pooled into a basin, mixed thoroughly to form one composite sample that was packed in a labeled plastic bag for laboratory analysis. Near the sites where soil cores were obtained, an undisturbed block of soil was also dug and taken for determination of soil structure and bulk density.

4.2.4 Laboratory analysis

The soil samples were air-dried for 48 hours, sieved with a 2 mm sieve, oven-dried at 60^0C for 24 hours and then analyzed for pH, OC, OM, N, Ca, Mg, K, Na, CEC, available P, bulk density, porosity, conductivity, structure and texture. Soil particle size distribution (texture) was determined by the Bouyoucos hydrometer method (Gee and Bauder, 1986) while soil aggregate stability was determined by the wet sieving technique (Kemper and Rosenau, 1986). The soil cores were used in the determination of bulk density by the gravimetric method (Blake and Hartge, 1986). Soil pH was measured using a pH meter in a 1:2 soil: water ratio (Allen *et al.*, 1976), nitrogen by the Kjeldahl procedure (ISSCAS, 1978), total P by the perchloric acid digestion method (Mehta *et al.*, 1954) and soil organic carbon was determined using the modified Walkley-Black method (Mebius, 1960).

4.2.5 Data analysis

Analysis of variance was conducted using XLSTAT 2011 software to obtain the effects of land use, land cover and the interaction on soil physical and chemical properties using Fishers' LS means to separate the means at 95% confidence interval. Discriminant Analysis using XLSTAT 2011 was used to test whether differences exist among soil parameters in the three land cover types (bare, woody and herbaceous cover) and to visualize how different the land cover types are on a 2-dimensional map. The hypothesis tested here is that land cover change has no effect on soil properties and therefore the covariance matrices are equal within and between land cover types. Chi square test was used to analyze within class variation and Wilks' Lambda test was used to test whether there are differences between the vectors of the means for the various land cover types.

4.3 Results

4.3.1 Effect of land cover change on soil physical properties

Bare areas had significantly lower levels of sand ($p<0.0001$) and porosity ($p<0.0001$) and significantly high levels of clay content ($p<0.0001$) compared to herbaceous and woody covered areas (Table 4.1). There were no significant differences in percentage silt ($p>0.822$) and bulk density ($p>0.421$) between the three land cover types. Across production systems, the settled had significantly high levels of sand ($p<0.0001$) and porosity ($p<0.0001$) compared to semi-settled and non-settled while the non-settled had significantly high levels of clay ($p<0.0001$) followed by semi-settled and least in settled systems (Table 4.2).

Table 4.1: Least square means of percentage sand, clay and silt, bulk density (BD) and porosity across land cover types.

	Soil physical property				
Land cover type	%Sand	%Clay	%Silt	BD	Porosity
Herbaceous	75.556^a	12.389^b	12.056^a	1.481^a	49.633^a
Woody	76.889^a	11.222^b	11.889^a	1.397^a	48.328^a
Bare	66.278^b	22.611^a	11.111^a	1.462^a	40.078^b

Means in the same column followed by different superscripts are significantly different at $p<0.05$

Table 4.2: Least square means of percentage sand, clay and silt, bulk density (BD) and porosity across production systems.

	Soil physical property				
Production system	%Sand	%Clay	%Silt	BD	Porosity
Settled	79.778^a	9.722^c	10.5^a	1.455^a	49.811^a
Semi-settled	71.056^b	15.667^b	13.278^a	1.457^a	47.844^b
Non-settled	67.889^b	20.833^a	11.278^a	1.428^a	40.383^c

Means in the same column followed by different superscripts are significantly different at $p<0.05$

The interaction between production system and land cover types showed that non-settled*bare had significantly high levels of clay ($p<0.0001$) and bulk density ($p<0.02$) and significantly lower levels of sand ($p<0.04$) and porosity ($p<0.001$) (Table 4.3).

Table 4. 3: Effect of interaction between production system and land cover type on percentage sand, clay and silt, bulk density (BD) and porosity.

	Soil physical property				
Interaction	%Sand	%Clay	%Silt	BD	Porosity
Settled*Herbaceous	82.333^{a}	8.5^{bc}	9.167^{b}	1.403^{ab}	57.033^{a}
Settled*Woody	80.333^{a}	7.833^{c}	11.833^{ab}	1.550^{a}	46.417^{b}
Settled*Bare	76.667^{ab}	12.833^{bc}	10.5^{ab}	1.412^{ab}	45.983^{b}
Semi-settled*Herbaceous	71.667^{b}	12.5b^{c}	15.833^{a}	1.482^{a}	47.117^{b}
Semi-settled*Woody	77.667^{ab}	10.0b^{c}	12.333^{ab}	1.442^{a}	57.367^{a}
Semi-settled*Bare	63.833^{c}	24.5^{a}	11.667^{ab}	1.448^{a}	39.05^{c}
Non-settled*Herbaceous	72.667^{b}	16.167^{b}	11.167^{ab}	1.558^{a}	44.75^{b}
Non-settled*Woody	72.667^{b}	15.833^{b}	11.5^{ab}	1.2^{b}	41.2^{c}
Non-settled*Bare	58.333^{c}	30.5^{a}	11.167^{ab}	1.527^{a}	35.2^{d}

Means in the same column followed by different superscripts are significantly different at $p<0.05$.

4.3.2 Effect of land use and cover change on soil chemical properties

Table 4.4 summarizes the Least Square means used to separate the effects of land cover change on selected chemical properties of soil. The pH was significantly different between bare and herbaceous and bare and woody cover ($p < 0.0001$) but no significant differences between woody and herbaceous ($p > 0.05$). Organic carbon and organic matter were high in herbaceous followed by woody and least in bare with significant differences existing among the three cover types (herbaceous vs bare, $p < 0.0001$; herbaceous vs woody, $p < 0.007$; woody vs bare, $p < 0.0001$). Nitrogen was significantly different between herbaceous and bare ($p < 0.0001$) and between woody and bare ($p < 0.0001$) but was not significant between herbaceous and woody ($p > 0.09$). Ca was significantly different between woody and bare and herbaceous and bare ($p < 0.001$) but not significant between woody and herbaceous ($p > 0.96$). There were no significant differences in Mg ($p>0.131$), Na ($p>0.247$) and CEC ($p>0.06$) among the three cover types but high levels were found in herbaceous and least in bare. K was significantly different between herbaceous and bare ($p < 0.01$) but not different among other cover types. Available phosphorus was significantly different between woody and herbaceous vegetation ($p < 0.04$) but not significant between other cover types.

Across production systems (Table 4.5), the semi-settled system had significantly high pH ($p<0.04$) and Ca ($p<0.038$). Organic carbon ($p>0.21$), organic matter ($p>0.21$), total nitrogen ($p>0.72$), Mg ($p>0.331$), Ka ($p>0.6$), Na ($p>0.46$) and available phosphorus ($p>0.41$) were not significantly different across production systems whereas CEC was significantly lower in non-settled production systems ($p<0.001$).

The interaction between production system and vegetation type (Table 4.6) showed that the herbaceous vegetation under the semi-settled production system had significantly high levels of organic matter ($p<0.004$), total nitrogen ($p<0.003$) and Ca ($p<0.028$) while the interaction had no significant difference on pH ($p>0.08$), organic carbon ($p>0.1$), Mg ($p>0.19$), K ($p>0.340$), Na ($p>0.57$) and available phosphorus ($p>0.18$).

Table 4. 4: Least square means used to separate chemical properties across vegetation types.

Land cover type	Soil chemical property pH	OC (%)	OM (%)	N (%)	Ca (me/100g)	Mg (me/100g)	K (me/100g)	Na (me/100g)	CEC (me/100g)	Av.P (ppm)
Herbaceous	4.753^{a}	1.669^{a}	2.879^{a}	0.153^{a}	3.907^{a}	1.347^{a}	0.394^{a}	0.067^{a}	12.867^{a}	3.062^{b}
Woody	4.783^{a}	1.149^{b}	1.981^{b}	0.131^{a}	3.933^{a}	1.3^{a}	0.320^{ab}	0.052^{a}	11.908^{a}	5.604^{a}
Bare	3.844^{b}	0.389^{c}	0.671^{c}	0.063^{b}	2.113^{b}	0.91^{a}	0.271^{b}	0.051^{a}	11.756^{a}	4.351^{a}

Means in the same column followed by different superscripts are significantly different at $p<0.05$

Table 4. 5: Least square means used to separate chemical properties across production systems.

Production system	Soil chemical property pH	OC (%)	OM (%)	N (%)	Ca (me/100g)	Mg (me/100g)	K (me/100g)	Na (me/100g)	CEC (me/100g)	Av.P (ppm)
Settled	4.361^{b}	1.005^{a}	1.733^{a}	0.112^{a}	2.894^{b}	1.094^{a}	0.304^{a}	0.058^{a}	12.350^{a}	5.047^{a}
Semi-settled	4.742^{a}	1.249^{a}	2.153^{a}	0.121^{a}	4.024^{a}	1.388^{a}	0.354^{a}	0.062^{a}	13.053^{a}	4.502^{a}
Non-settled	4.278^{b}	0.954^{a}	1.644^{a}	0.113^{a}	3.035^{b}	1.075^{a}	0.328^{a}	0.049^{a}	11.128^{b}	3.468^{a}

Means in the same column followed by different superscripts are significantly different at $p<0.05$

Table 4. 6: Effect of interaction between vegetation cover and production system on soil chemical properties.

	Soil chemical property									
Production system*cover type	pH	OC (%)	OM (%)	N (%)	Ca (me/100g)	Mg (me/100g)	K (me/100g)	Na (me/100g)	CEC (me/100g)	Av.P (ppm)
Settled*Herbaceous	4.5^{ab}	1.212^{bc}	$2.090b^{c}$	0.115^{cd}	2.402^{bcd}	0.888^{ab}	0.315^{ab}	0.067^{ab}	12.167^{a}	2.812^{bc}
Settled*Woody	4.85^{a}	1.373^{abc}	2.367^{abc}	0.132^{bc}	4.373^{a}	1.293^{a}	0.315^{ab}	0.055^{ab}	13.15^{ab}	5.3^{abc}
Settled*Bare	3.733^{c}	0.431^{de}	0.743^{de}	0.090^{de}	1.907^{cd}	1.102^{ab}	0.282^{b}	0.053^{ab}	11.733^{bc}	7.028^{a}
Semi-settled*Herbaceous	5.075^{a}	1.984^{a}	3.42^{a}	0.181^{a}	4.797^{a}	1.524^{a}	0.481^{a}	0.085^{a}	13.433^{ab}	2.372^{c}
Semi-settled*Woody	5.033^{a}	1.214^{bc}	2.093^{bc}	0.141^{abc}	4.01^{ab}	1.444^{a}	0.358^{ab}	0.048^{b}	11.975^{bc}	6.838^{ab}
Semi-settled*Bare	4.117^{b}	0.548^{de}	0.945^{de}	0.041^{f}	3.267^{abc}	1.195^{ab}	0.223^{b}	0.053^{ab}	13.75^{a}	4.297^{abc}
Non-settled*Herbaceous	4.683^{ab}	1.98^{4a}	3.123^{ab}	0.163^{ab}	4.523^{a}	1.628^{a}	0.387^{ab}	0.048^{b}	13.0^{ab}	4.002^{abc}
Non-settled*Woody	4.467^{ab}	0.861^{cd}	1.485^{cd}	0.120^{cd}	3.417^{abc}	1.163^{ab}	0.288^{b}	0.052^{ab}	10.60^{cd}	4.673^{abc}
Non-settled*Bare	3.683^{c}	0.189^{e}	0.325^{e}	0.057^{ef}	1.165^{d}	0.433^{b}	0.310^{b}	0.048^{b}	9.783^{d}	1.728^{c}

Means in the same column followed by different superscripts are significantly different at <0.05

4.3.3 Differentiating land cover types based on soil properties

Soil physical and chemical properties significantly varied within ($p < 0.0001$) and among the three land cover types (Wilk's Lambda test $p < 0.0001$). Presentation of centroids on factor axes shows that the land cover types are very well discriminated from one another using soil properties as the explanatory variables (Figure 4.3a). Factor 1 (F1) which explains 89.45% of the variation among land cover types is correlated with N, OM, OC, pH, Porosity, Base saturation, Ca, Ksat and Mg (Table 4.7) while Factor 2 (F2) which explains 10.55% of the variation is correlated with K, C:N, CEC, Na, Av.P and Bulk density (Figure 4.3b). The factor loadings for the bare, herbaceous and woody vegetation cover were -2.891, 1.516 and 1.374 respectively on F1 and 0.028, 0.846 and -0.874 respectively on F2. Soils under herbaceous cover had higher levels of OM, N, Na, CEC, K, OC and porosity while bare/un-vegetated soils were high in bulk density. As the land cover is converted from herbaceous to bare, the bulk density increases whereas other properties associated with herbaceous cover decrease. Also, conversion of herbaceous cover to woody vegetation causes an increase in pH, Ca, hydraulic conductivity of the soil and available phosphorus. This showed that the soil properties of the three land cover types are distinguished on F1. Therefore, the three land cover types (bare, herbaceous and woody) significantly affect soil properties and can be properly differentiated on this basis.

Table 4. 7: Correlations between soil properties and the two factors explaining their variability among the three land cover types

	Factors	
Variable	F1	F2
pH	0.677	-0.06
OC	0.714	0.449
OM	0.714	0.449
N	0.774	0.254
C:N	0.254	0.322
Ca	0.541	-0.034
Mg	0.299	0.032
K	0.303	0.329
Na	0.133	0.344
CEC	0.186	0.355
Ksat	0.482	-0.335
BD	-0.053	0.283
Av.P	-0.011	-0.476
Base saturation	0.553	-0.135
Porosity	0.625	0.095

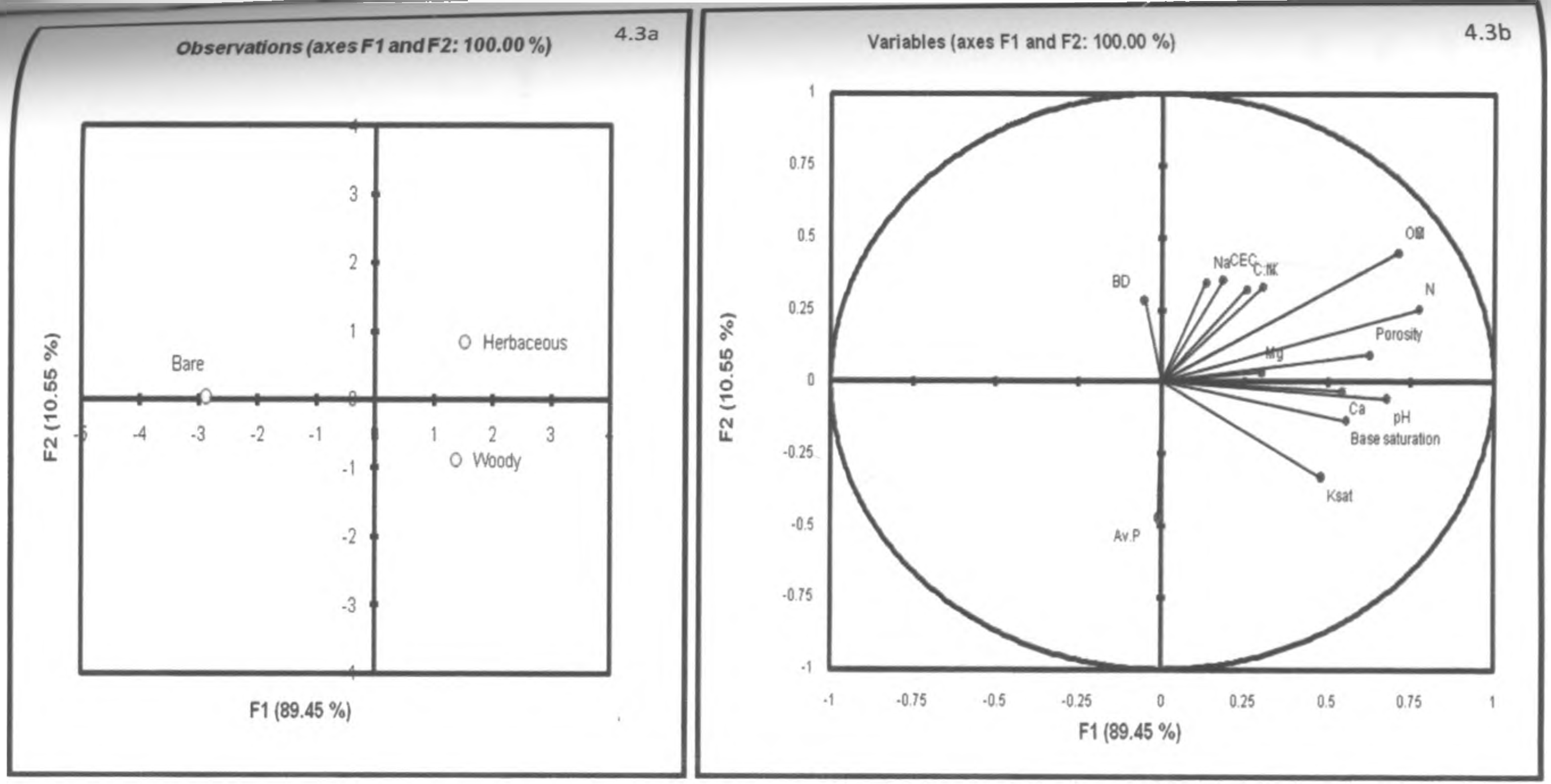

Figure 4. 3a & b: Ordination graphs showing centroids (weighted averages) of land cover types (4.3a) and soil properties (4.3b). Factor one (F1) on the horizontal axis accounts for 89.45% of the variability and factor two (F2) on the vertical axis accounts for 10.55% of the variability

Presentation of centroids together with the observations used in calculating them on the same factor axes (Figure 4.4) shows that the bare land is very distinctive from the herbaceous and woody cover types. There is no overlap in the observations (soil properties) contributing to bare and herbaceous cover but a very slight overlap exists between the observations for bare and woody vegetation (5.6% overlap). The observations of herbaceous cover however overlap with those of woody cover by 72%.

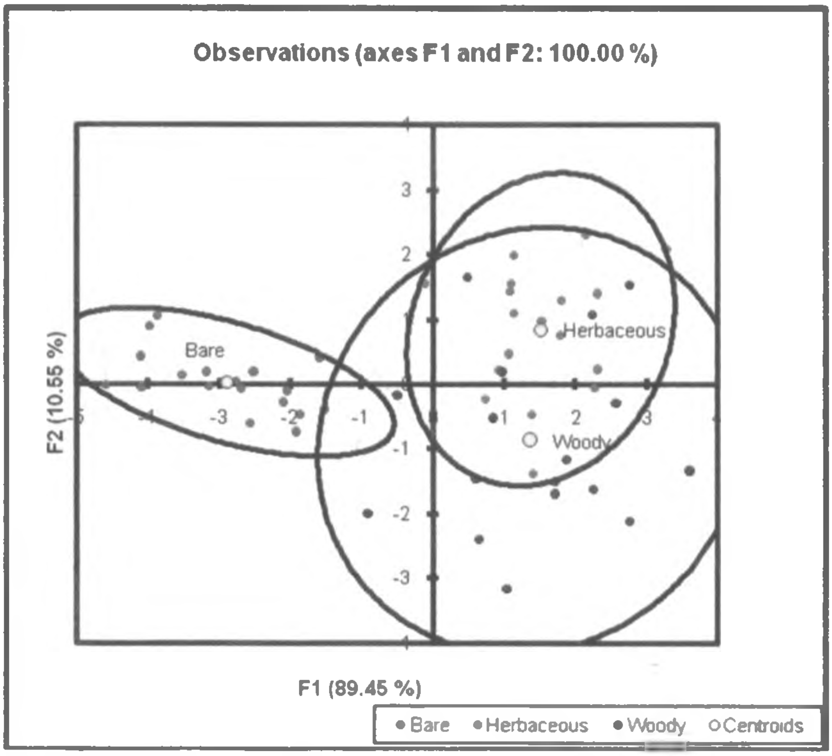

Figure 4. 4: Ordination graph showing centroids of cover types and their observation

4.4 Discussion

Generally, the soil nutrient pools under all land use and land cover types in the study area are lower than the required nutrient levels for sustainable crop production. Therefore, the significant differences in nutrient levels across land use and cover types are brought by the fact that rangelands have been consistently subjected to poor management practices that have exposed them to nutrient losses through soil erosion, increased plant uptake and emissions from soil surfaces. This is in line with the findings of Asner *et al.* (2004) who noted that any decline in nutrient levels from soils of relatively small stocks significantly affects the nutrient stocks and greatly impacts on productivity.

The prevalence of high levels of soil organic carbon, organic matter, nitrogen, Mg, K, Na, and CEC in soils under herbaceous cover and presence of lower levels of these nutrients under bare and woody cover can be explained by the increased loss of nutrients from bare and woody covers as a result of accelerated surface runoff. Overgrazing of the herbaceous vegetation is the most notable factor for increased bare and woody encroachment in grassland ecosystems of Nakasongola. Overgrazing compacted the soils leading to reduced infiltration and increased runoff (Branson *et al.*, 1981; Trimble and Mendel, 1995) that caused a decline in soil nutrients in the bare and woody cover as compared to the herbaceous cover. These findings are supported by earlier studies in Nakasongola rangelands where high levels of nutrients were found in water sampled from valley tanks receiving surface runoff from un-vegetated catchments while low nutrients levels were found in valley tanks receiving water from a vegetated catchment (Zziwa *et al.*, 2008). Similar results were obtained by Verity and Anderson (1990) who reported that organic C, P, N and S decreased with increasing rates of soil erosion down the slope. Asner *et al.* (2003b) also reported that increased bare and woody cover caused a reduction of 25% and 80% in soil organic carbon and nitrogen, respectively. This therefore shows that accelerated runoff from bare and woody covers increases nutrient loss from soils. Although grazing also contributes to nutrient losses from grazing systems (Asner *et al.*, 2004), the losses from soil erosion are enormous that bare soils are left with lower nutrient levels compared to herbaceous cover. More so, some of the nutrients lost through grazing are recycled back through manure deposition but those lost through erosion are not recycled back to the system. Hartley (1997) and Hartley and Schlesinger (2000) also reported that woody encroachment on grasslands increases nitrogen losses through increased nitrous oxide emission and reduces the nitrogen stocks, while Jackson *et al.* (2002) reported that woody encroachment on grasslands with more than 500 mm annual rainfall reduced soil carbon and nitrogen levels. Since annual rainfall for Nakasongola ranges between 1000 mm and 1500 mm, it is so probable that woody encroachment can result into a decrease in soil carbon and nitrogen.

The soil erosion greatly reduces N, Mg and K levels in soil and consequently leads to an increment in Calcium levels because calcium carbonates are not easily eroded. As a result, woody soils which are more exposed to erosion in areas where the underground herbaceous cover is lost have slightly high pH and Ca levels. Because calcium carbonates bind phosphorous, soils with high Ca levels (woody and bare) consequently had high levels of phosphorous compared to herbaceous cover where Ca and pH were low. Similar findings were also obtained by Sparrow *et al.* (2003) who reported that soils exposed to erosion had less carbon and nitrogen but high levels of phosphorus. Verity and Anderson (1990) also found that increased soil erosion resulted into increased levels of calcium carbonate in surface horizons while inorganic P remained constant. Because sand is more easily eroded than clay (Verity and Anderson, 1990; Brady, 1990), bare areas remain with more clay content, less sand and this subsequently lowers the porosity compared to woody and herbaceous vegetation covers.

Herbaceous vegetation under semi-settled production system had high levels of pH, organic carbon, organic matter, nitrogen, Mg, K, Na and CEC compared to a combination of other land use and cover systems practiced in Nakasongola. This is because semi-settled production systems that basically involve continuous grazing exert marginal pressure on land and allow for regeneration of pasture and soil reserves during movements from place to place. On the contrary, under the settled production systems, animals have to be kept on available land throughout the year. The inclusion of rotational grazing in settled production systems increases the grazing pressure on land compared to semi-settled systems where continuous grazing and transhumance are practiced (Heitschmidt and Taylor, 1991). Under the non-settled systems, there is less control over livestock numbers and movements hence exposing land to immense pressure that leads to intense degradation and loss of soil nutrients. Livestock grazing is a major component of rangeland ecosystems as far as their integrity and production are concerned. Therefore land use and cover types that limit livestock activity impacts on ecosystem functioning and nutrient recycling, reduces soil organic carbon component and the sustainability of rangelands over the long term. The results of this study are consistent with those of Schuman *et al*. (2009) who found that continuously grazed lands had more soil organic carbon than in rotational grazing systems. Also, Smoliak (1960) and Briske *et al*. (2008) found that plant and animal production were better in continuous grazing than in rotational grazing systems.

The settled production systems involve more production costs in terms of initial and maintenance costs for fencing and water development. In turn producers tend to increase the stocking rates in order to substantially increase profits and keep their farms at break-even points (Manley *et al.*, 1997; Dunn *et al.*, 2010; Knight *et al.*, 2011). This however exerts a lot of pressure on the land and in the long term leads to reduction in the ecological condition and sustainable production of rangeland resources as noted by Norton (2003).

The existing distinction between land cover types based on soil properties signifies that the three systems have potentially different production potentials. With herbaceous cover being richer in the chemical and desirable physical properties, it is expected to be the most productive land cover system for rangeland ecosystems. As grasslands become degraded, leading to a reduction in herbaceous layer, woody cover increase as a result of reduced competition (Scholes and Archer, 1997; van Auken and Bush, 1997; Kraaij and Ward, 2006). Because woody encroachment can progress on both herbaceous and bare ground and co-exist with the two land cover forms, there is an overlap between woody cover the other cover types. Asner *et al.* (2004) also reported that increase in woody component in grassland ecosystems may occur without significant reduction in herbaceous cover (woody encroachment) or with complete disappearance of herbaceous layer (desertification). The greater overlap between woody and herbaceous cover however indicates that woody encroachment in grasslands can proceed without prior degradation of the grassland ecosystem. This is supported by earlier findings which indicated that changes in rainfall, temperature and carbon dioxide concentrations and elimination of fire use can significantly contributes to woody encroachment in grasslands (Kraaij and Ward, 2006; Dempewolf, 2007; Moustakas *et al.*, 2010; Ward 2010).

Although bare ground is basically derived from former herbaceous covered lands, there is no interaction between the two systems. This therefore indicates that there is a limited ability of herbaceous vegetation to naturally re-establish on completely bare ground. Rehabilitation of bare land to herbaceous will thus require more time and external inputs because the soils have limiting levels of organic matter and other nutrients. Earlier studies in the this area and in Mount Kenya region found that fencing off degraded bare lands did not cause recovery of pastures in a period of two years. Possibly, more time is needed for pastures to regenerate in such areas. These studies suggested that effective rehabilitation of degraded rangelands (re-establishment of pasture on bare lands) should involve ploughing of land, use of manure and reseeding (Kironchi, 1998; Mugerwa *et al*., 2008).

4.5 Conclusion

The conversion of grazing lands into different cover types (woody and bare) have caused enormous levels of soil degradation with the conversion to bare ground having surpassed the recuperative capacity of land to regain its original state. The soils are so degraded, lost their production potential and thus more external investment is needed to rehabilitate the bare grounds back into pasture lands. Because woodlands have a potential of encroaching on pasture lands that have been eventually left bare due to degradation, failure to devise management intervention to reclaim bare ground back into herbaceous and failure to develop and impose stringent rangeland management practices to protect the integrity of rangelands may lead to their ultimate conversion into woodlands.

Chapter 5

Developing and evaluating a multifunctional general indicator of soil quality in assessing the effect of land use and land cover change on soil productivity

Abstract

Four sub-indicators of soil quality were formulated and combined into a single indicator. Multivariate analysis for 18 properties of soil was evaluated for physical (5), chemical (7), organic matter (3) and aggregate stability (3) for the upper 15 cm of soil from three land cover types (bare, herbaceous and woody) and three production systems (settled, semi-settled and non-settled). When the equation developed for calculation of the General Indicator of Soil Quality (GISQ) (GISQ = 0.015PHYSICAL + 0.02CHEMICAL + 0.017ORGANIC MATTER + 0.024AGGREGATE STABILITY) was applied to all sites, GISQ was significantly affected by production system ($p < 0.05$) and the interaction between production system and cover type ($p < 0.001$), but not by cover type alone. Herbaceous cover under semi-settled production systems had the highest GISQ of 0.64 that ranged from 0.41 – 1.00, while bare cover under non-settled systems had the lowest GISQ of 0.23 that ranged from 0.1 – 0.53. Most soils in Nakasongola had lower levels of organic matter and soil nutrients and thus the generally low GISQ. From this study, semi-settled production systems and herbaceous vegetation cover have been identified as the most appropriate land use and cover types for the semi-arid rangelands of Nakasongola District. Because semi-arid rangelands are non-equilibrium ecosystems, there is an urgent need to revise land use systems in order to improve the soil status for sustainable production and ecosystem functioning.

5.1 Introduction

Soil quality is the ability of a specific kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen *et al.*, 1997). It is a composite measure of both a soil's ability to function and how well it functions relative to a specific use (Gregorich *et al.*, 1994). Determination of soil quality has received various debates with various methods being advanced but with no universal conformity on their interpretation (Doran, 2002; Filip, 2002). However, the concept of soil quality can still be undertaken using minimum data sets with some degree of success (Doran and Parkin, 1994; Gregorich *et al.*, 1994; Velasquez *et al.*, 2007). Soil attributes such as texture, organic matter, pH, bulk density and rooting depth form a minimum data set that can be used to assess soil quality, with organic matter being the most important attribute because it has a great control on many of the key soil functions (Doran and Parkin, 1994; Gregorich *et al.*, 1994).

The soil's natural or inherent composition, which is a function of soil formation factors and the changes related to human use and management are the major factors that determine the quality of any soil (Pierce and Larson 1993). Soil quality may be evaluated based on four critical soil functions: (i) accommodating water entry; (ii) retaining and supplying water to plants; (iii) resisting degradation; and (iv) supporting plant growth (Karlen *et al.*, 1997). Indicators of soil quality can be defined loosely as those soil properties and processes that have greatest sensitivity to changes in soil function (Andrews *et al.*, 2004). Doran and Parkin (1996), emphasized that soil quality indicators should correlate well with ecosystem processes, integrate soil properties and processes, be accessible to many users, sensitive to management and climate, and whenever possible, be components of existing databases.

Encroachment of woody vegetation into savanna ecosystems is generally thought to increase the amount of carbon stored while degradation to bare areas reduces carbon storage as well as other chemical, physical and biological properties of soil (Ibrahim *et al.*, 2007). Changes in soil properties following encroachment by woody species or conversion to bare land is highly dependent on climate, soils, management practices (grazing and burning), tree species and shade tolerance of herbaceous species (Nyberg and Hogberg 1995; Jackson and Ash 1998; Jackson *et al.*, 2002; Follett and Reed, 2010). For example, invasion of woody vegetation into mesic grasslands with over 1,000 mm/year was noted to decrease soil organic carbon while invasion into dry grasslands increased soil organic carbon levels (Jackson *et al.*, 2002). Also, intermediate grazing intensity in arid and semi arid rangelands increases soil organic matter whereas intense grazing decreases organic matter (Schnabel *et al.*, 2001).

The existing knowledge on analysis of soil quality involves long lists of putatively relevant variables to be measured although no general agreement has been reached on their interpretation (Arshad and Martin, 2002; Knoepp *et al.*, 2000). No multifunctional index has ever been developed to combine several variables into a single formula to allow comparisons of soil quality among different sites or production systems in Uganda. As such, assessments of soil quality and land production potential are based on levels of soil nutrients and do not provide any guideline on the sustainability of the systems.

In this chapter, selected soil physical, chemical, organic matter and stability properties were used to develop quality indicators which were then combined into a general index of soil quality. Biological quality was not taken into account because the ecosystem in Nakasongola District has been greatly altered to the detriment of beneficial microorganisms in the area (Mugerwa *et al.*, 2011a and 2011b). This has led to a shift in soil fauna with great numbers of destructive termite species and a reduction in other native microorganisms. The objective of this study was therefore to develop a general indicator of soil quality that can be used to identify the most sustainable land use and cover system for the rangeland communities of Nakasongola District.

5.2 Methods

The location and sampling sites used in this study are similar to those described in detail under chapter four of this thesis. Soil assessments were made in three land cover types (Bare, Herbaceous and Woody) under three pastoral production systems (Settled, Semi-settled and Non-settled) in the rangelands of Nakasongola District using the Modified Whittaker sampling techniques (Stohlgren *et al.*, 1995) as earlier described in chapter four. Eighteen variables physical (5), chemical (7), Organic matter (3) and aggregate stability (3) were measured from 54 sampling points taking six points from each land cover type in each production system and were used to develop sub-indicators of soil quality which were then combined into a general index of soil quality for the study area.

5.2.1 Data Analysis

Principal component analysis (PCA) and discriminant analysis were conducted using the XLSTAT software for each group of variables (physical quality, chemical fertility, organic matter, and aggregate stability). Linear combinations of the original data (principal components) were constructed by the PCA to explain a large part of the total original variability. The discriminant analysis permitted computation of the mathematical distances between the land use systems (Mahalanobis distance). This analysis uses a permutation test that calculates the total interclass inertia for each random distribution of the individuals within the groups. Coinertia analyses were carried out to test the significance of covariation among the four data sets: (i) chemical fertility; (ii) soil organic matter variables; (iii) physical parameters; (v) aggregate stability variables.

5.2.2 Steps followed in the formulation of the general indicator of soil quality (GISQ)

(i) PCA analysis of each of the four sets of variables was conducted to allow the testing of the significance of their variation among land use types and to select the most influential factors that explain at least 60% of the total variability

(ii) Identification of the variables that best differentiate the sites according to soil quality. Variables that contribute to the construction of the two factors accounting for at least 60% of the total variation were obtained by dividing the greater value of the variables for each factor by two to obtain a selection index for variables and then choosing variables that had equal or superior value to the index.

(iii) Creation of subindicators of soil physical quality, chemical fertility, organic matter and aggregate stability with values ranging from 0.10 to 1.00.

The original variables for each sub set were reduced in a rank of between 0.1 and 1.00 using transformation formulas Y = 0.1+(x-b)/(a-b)*0.9 and Y = 1.1-(0.1+(x-b)/(a-b)*0.9) for variables whose values increase in grounds of good and bad quality, respectively. Where a = maximum value of variable, b = minimum value of variable and x = variable to transform.

The resultant transformed variables were multiplied by F1 and F2 values, the multiplication results for variables and factors were then added (Variable*F1 + Variable*F2) and the summation of all variables for a given site were obtained and transformed using the transformation formulas to obtain a sub-indicator index.

(iv) Combination of all five subindicators into a general one.

The sub-indicator indexes for the four categorizes analyzed were then subjected to a PCA to obtain the variances and contribution of each sub indicator to formations of both first components and the total inertia explained by both factors. The values obtained with factor 1 and 2 were added and divided by 1000 to obtain formulates of the general indicator of soil quality. The formula was then applied to all sites to obtain the GISQ for all locations which were subjected to ANOVA tests in Genstat to assess the effect of land cover type and production system on GISQ.

After the formulation of the GISQ, it was applied to each of the 54 sampled sites under the three production systems and three cover types (six sites under settled bare, six under settled herbaceous, six under settled woody, six under semi-settled bare, six under semi-settled herbaceous, six under semi-settled woody, six under non-settled bare, six under noon-settled herbaceous and six under non-settled woody). Principle Component Analysis (PCA) and Discriminant Analysis were carried out using ADE_4 (Data Analysis functions for Ecological and Environmental data in the framework of Euclidean Exploratory methods) software (Thioulouse *et al.*, 1997). The PCA was used to obtain correlations between variables used in calculation of the GISQ and factors. Scatter classification was used to plot graphs of groups of vegetation cover types and their respective barycenters while DA was used to test for significant differences between vegetation cover types and to graph variable projections by matching two scatters.

5.3 Results

5.3.1 Physical variables

Soil physical properties significantly (p<0.001) differentiated the three land cover types. Principle Component Analysis of soil physical properties indicated that the first two factors explained 75.6% of the total variability and could thus be used to explain differences between land cover types (Table 5.1).

Table 5. 1: Cumulative variability explained by four factors and contribution of variables to factors.

Eigenvalues:

	F1	F2	F3	F4
Eigenvalue	2.393624	1.320722	0.784409	0.408652
Variability (%)	48.77574	26.91283	15.98418	8.32725
Cumulative %	48.77574	75.68857	91.67275	100

Contribution of the variables (%):

	F1	F2	F3	F4
%sand	**36.8396**	1.946267	0.864705	16.44237
%clay	**34.86353**	5.431651	3.773097	11.16986
%Silt	0.045055	**54.44029**	32.38964	1.793916
BD	0.788865	**35.23279**	62.75947	1.218872
Porosity	**27.46294**	2.948999	0.213085	69.37498
Selection index	*18.4198*	*27.2202*		

Variables whose contribution to factors 1 & 2 were superior than the selection index (shaded) were selected for developing a quality index.

Since all physical variables in this study had a contribution to either of the factors that was superior to the selection index, they can be used to differentiate land cover types based on soil quality. Percentage sand and porosity were strongly correlated to factor 1 (r = 0.95 and r = 0.82 respectively) while percentage silt was strongly correlated with factor 2 (r = 0.86). % clay and bulk density were negatively correlated with factor 1 (r = -0.92) and factor 2 (r = -0.7) respectively (Figure 5.1a). Projection of sites on ordination plots (Figure 5.1b) show that bare land was associated with high clay content and high bulk density, whereas herbaceous cover was more common in areas with high porosity and high percentage of sand. An interface between bare and woody vegetation occurred in places with high percentages of silt.

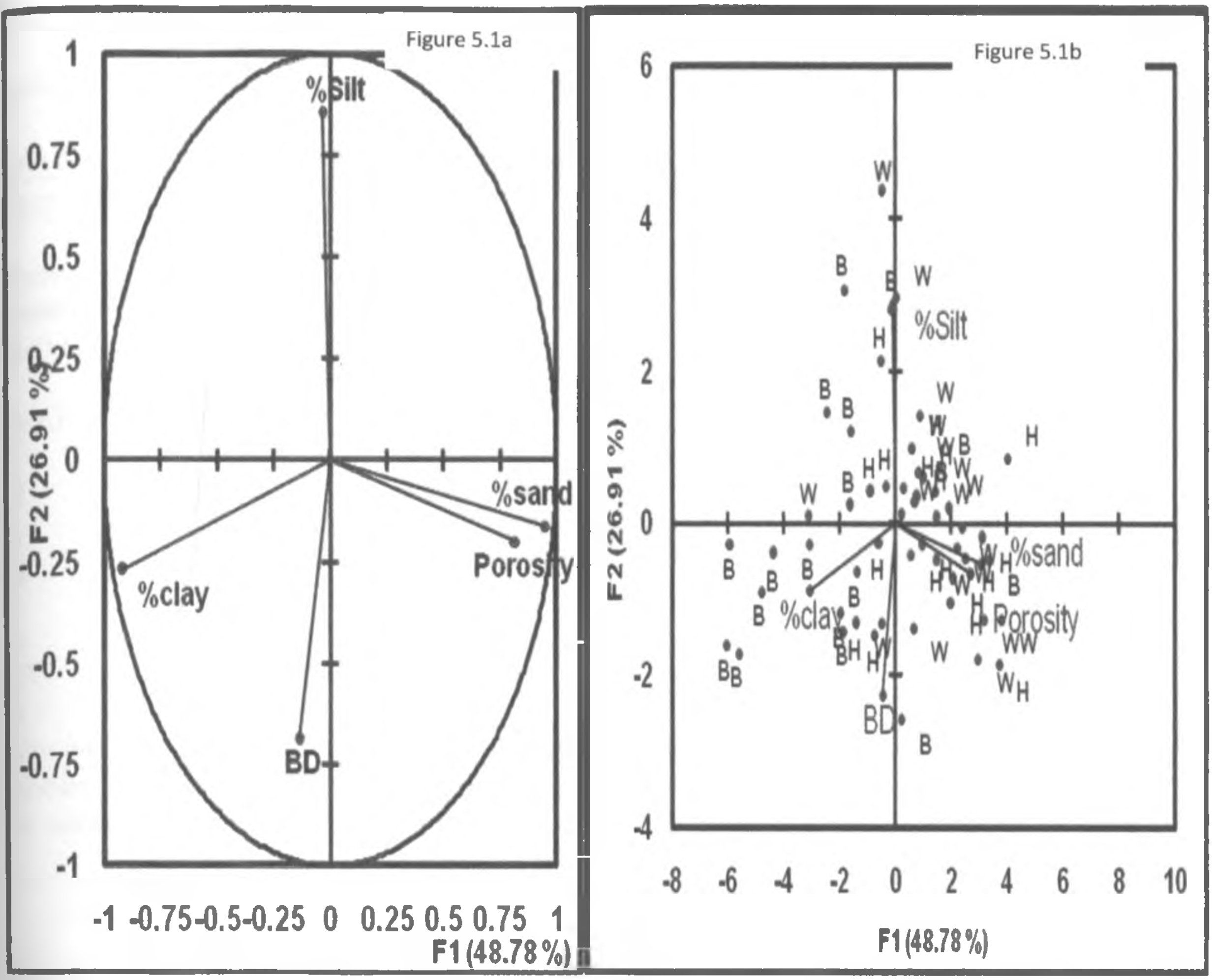

Figure 5. 1: Correlation of variables with factors 1 and 2 (5.1a) and Ordination biplot of soil physical properties and land cover types on factor 1 (Horizontal axis) and factor 2 (Vertical axis) which explain 48.78 and 26.91% of the variation respectively (5.1b). B – Bare, H – Herbaceous and W - Woody

5.3.2 Chemical properties

There were significant differences in chemical properties of soil between land cover types ($p < 0.0001$). The first two factors of Principal Component Analysis explained 60% of the variation in chemical properties (Table 5.2). With the exception of pH, the contribution of all other chemical variables to either factor one or two were greater than calculated index used to select variables that differentiate land cover types. pH was therefore dropped from the list of variables used to calculate the sub-indicator for chemical variables

Table 5. 2: Eigenvalues, variability and contribution of variables to PCA factors.

Eigenvalues:

	F1	F2	F3	F4	F5	F6	F7
Eigenvalue	2.794	1.322	0.949	0.790	0.556	0.373	0.085
Variability (%)	40.674	19.247	13.816	11.502	8.094	5.431	1.236
Cumulative %	40.674	59.921	73.737	85.239	93.333	98.764	100.000

Contribution of the variables (%):

	F1	F2	F3	F4	F5	F6	F7
pH	14.057	1.989	8.545	37.294	30.006	4.434	3.674
Ca	**30.444**	2.023	3.050	0.141	0.001	6.700	57.643
Mg	**27.055**	1.190	7.290	0.391	4.252	21.851	37.971
K	6.244	**27.876**	1.103	30.125	33.470	0.948	0.233
Na	1.731	**26.619**	51.920	0.472	7.293	11.741	0.224
CEC	**19.025**	3.743	6.834	10.857	15.413	43.879	0.248
Av.P	1.444	**36.561**	21.257	20.720	9.565	10.447	0.007
Selection index	*15.222*	*18.280*					

Variables whose contribution to factors 1 & 2 were superior than the selection index (shaded) were selected for developing a quality index.

Factor one was strongly correlated with Ca (r = 0.92), Mg (r = 0.87) and CEC (r = 0.73) while available P was strongly correlated with factor two (r = 0.7) (Figure 5.2a). Herbaceous cover was associated with high levels of Ca, Mg, and CEC while bare and woody cover were associated with high levels of K, Na and available P (Figure 5.2b).

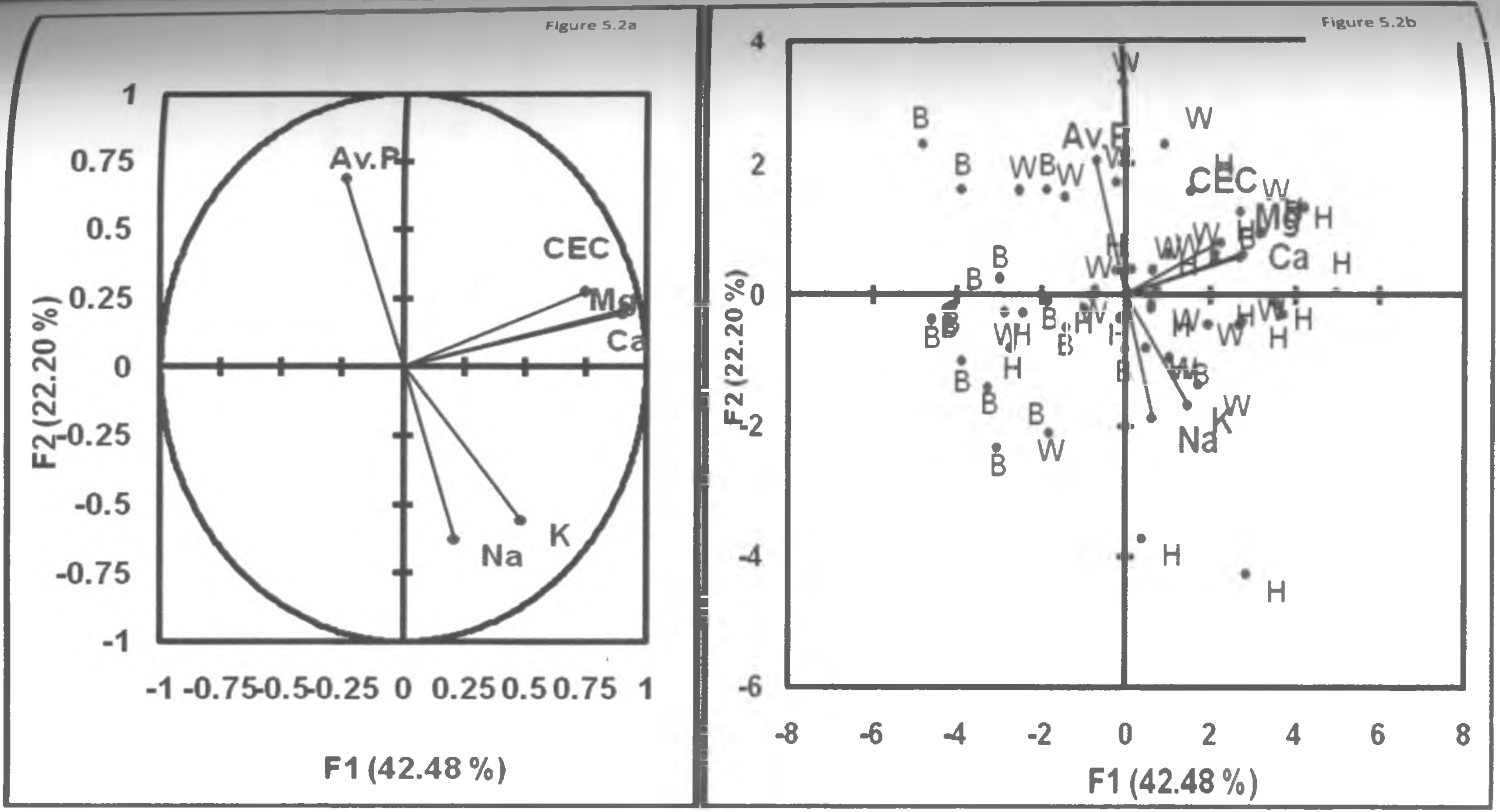

Figure 5. 2: Correlation of chemical properties with factors 1 and 2 (5.2a) and Ordination biplot of soil chemical properties and land cover types on factors 1 and 2 which explain 40.67 and 19.25% of the variation respectively (5.2b). B – bare, H – herbaceous and W – woody

5.3.3 Organic matter variables

There are significant ($p < 0.0001$) differences in organic matter variables between land cover types. Factor 1 and 2 explained 98.6% of the variation in organic matter components (Table 5.3) with factor one having a strong correlation with organic matter ($r = 0.99$) and total nitrogen ($r = 0.75$) while factor two is strongly correlated with C:N ($r = 0.71$) (Figure 5.3a). The contribution of all organic matter variables to the two factors were greater than the selection index and were thus selected for formulation of the quality index.

Table 5. 3: Eigenvalues, variability and contribution of variables to PCA factors.

	Factors		
	F1	F2	F3
Eigenvalue	2.035	0.922	0.043
Variability (%)	67.829	30.727	1.444
Cumulative %	67.829	98.556	100.000
Contribution of the variables (%):			
OM	**48.035**	0.005	51.960
N	**27.913**	**45.621**	26.466
C:N	**24.052**	**54.375**	21.574
Selection index	*24.0175*	*27.1875*	

Variables whose contribution to factors 1 & 2 were superior than the selection index (shaded) were selected for developing a quality index.

Herbaceous cover was associated with more organic matter, total nitrogen and C:N that decreased in woody cover and was least in bare soils (Figure 5.3b). As the natural herbaceous cover get exposed to intensified utilization and degradation, the soil organic matter components decline leading to conversion of the herbaceous to woody or bare land depending on the type and magnitude of the driving force.

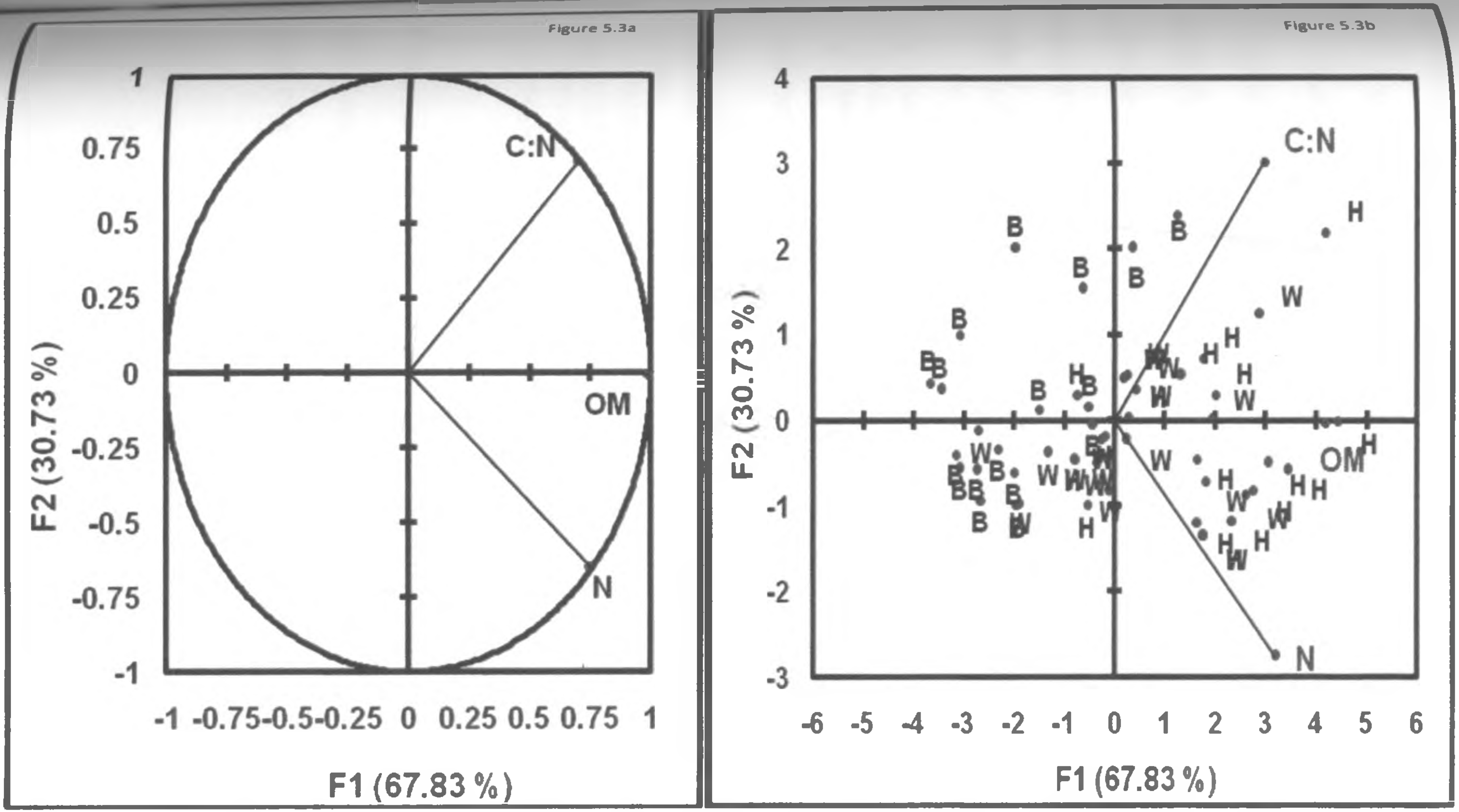
Figure 5.3a

Figure 5.3b

Figure 5. 3: Correlation of variables with factors 1 and 2 (5.3a) and Ordination biplot of soil organic matter properties and land cover types on factor 1 (Horizontal axis) and factor 2 (Vertical axis) which explain 48.78 and 26.91% of the variation respectively (5.3b). B – bare, H – herbaceous and W - woody

5.3.4 Aggregate stability

There were significant ($p < 0.003$) differences in aggregate stability variables among land cover types. Factor 1 and 2 explained 100% of the variation in aggregate stability components (Table 5.4). Factor one was strongly correlated with low aggregate stability ($r = 0.99$), factor two was correlated with high aggregate stability ($r = 0.83$), whereas medium aggregate stability was negatively correlated with both factors ($r = -0.67$ for F1 and $r = -0.74$ for F2) (Figure 5.4a). All aggregate stability variables contributed to either of the factors with a magnitude higher than the selection index and were thus used in development of the quality indicator.

Table 5. 4: Eigenvalues, variability and contribution of variables to PCA factors.

	Factors	
	F1	F2
Eigenvalue	1.734	1.210
Variability (%)	58.905	41.095
Cumulative %	58.905	100.000
Contribution of the variables (%):		
	F1	F2
High stability	17.747	**55.675**
Moderate stability	25.730	**44.232**
Low stability	**56.523**	0.094
Selection index	*28.2615*	*27.8375*

Variables whose contribution to factors 1 & 2 were superior than the selection index (shaded) were selected for developing a quality index.

Herbaceous cover was associated with low aggregate stability whereas bare and woody covers were associated with medium and high stability with the later being more prominent in bare ground (Figure 5.4b).

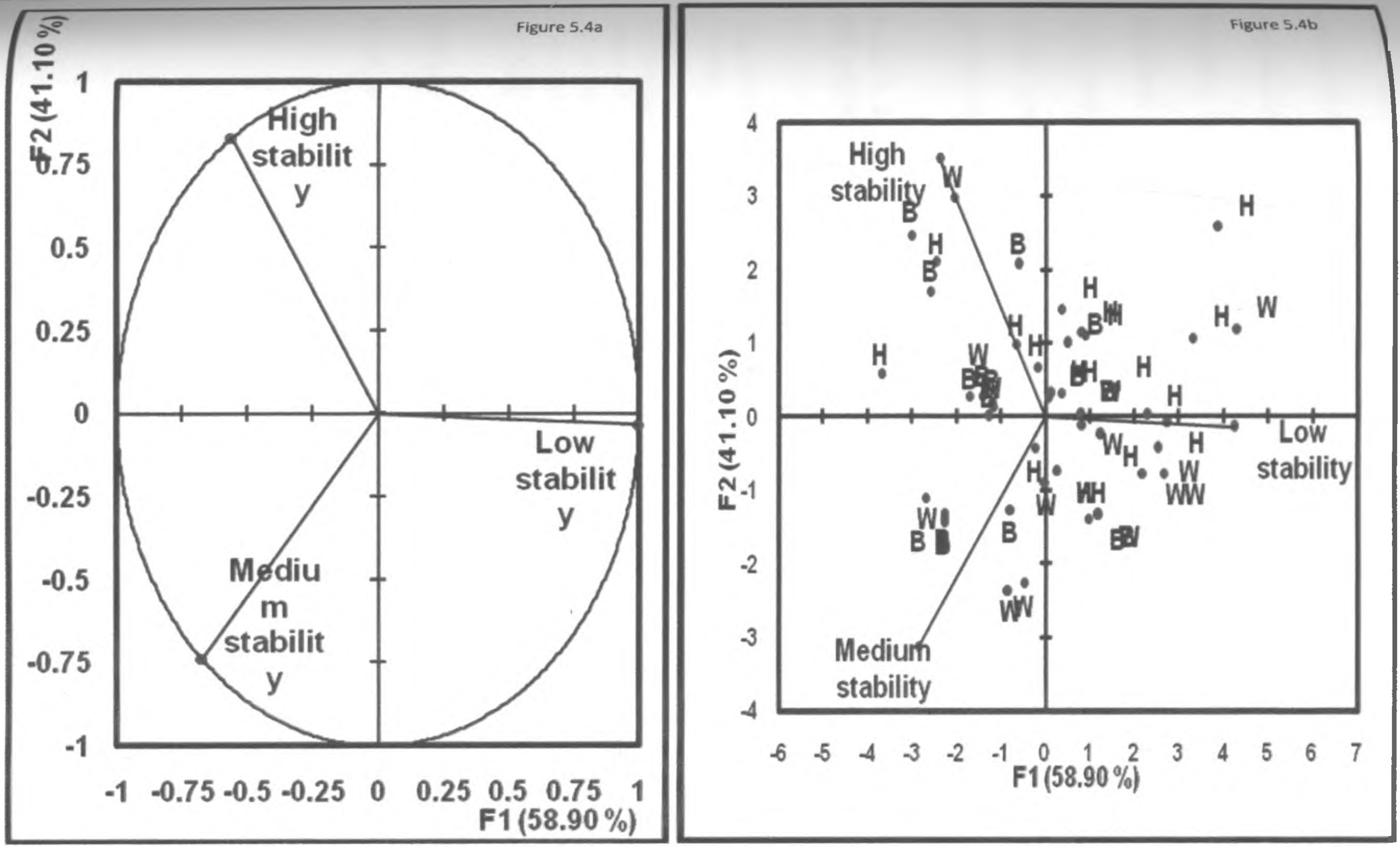

Figure 5. 4: Correlation of variables with factors 1 and 2 (5.4a) and Ordination biplot of soil stability and land cover types on factor 1 (Horizontal axis) and factor 2 (Vertical axis) which explain 48.78 and 26.91% of the variation respectively (5.4b). B- bare, H– herbaceous and W - woody

5.3.5 The general indicator of soil quality

After identification of variables that can be used to distinguish soils based on soil quality, sub-indicators of soil physical quality, chemical fertility, organic matter and aggregate stability were formulated that ranged from 0.10 to 1.00. Subjection of soil quality sub indicators for physical, chemical, organic matter and aggregate stability to PCA showed that the first two factors explained 76.3% of the total variation with F1 explaining 52% and F2, 24.3% (Table 5.5). F1 had a strong correlation with chemical quality (r = 0.85) and organic matter (r = 0.81), F2 had a strong correlation with aggregate stability (0.93) while physical quality had a negative correlation with factor one (-0.77) (Figure 5.5a).

Table 5. 5: Eigenvalues, variability and contribution of physical, chemical, organic matter and aggregate stability to PCA factors.

	Factors			
	F1	F2	F3	F4
Eigenvalue	2.078	0.971	0.601	0.350
Inertia	0.520	0.243	0.150	0.088
Contribution of the variables (%):				
PHYSICAL	28.730	0.524	59.877	10.869
CHEMICAL	35.036	6.999	0.384	57.582
ORGANIC MATTER	31.352	2.677	36.475	29.497
AGGREGATE STABILILITY	4.883	89.800	3.264	2.052

Herbaceous cover was associated with high chemical and organic matter quality while bare and woody cover were associated with high physical quality and aggregate stability (Figure 5.5b).

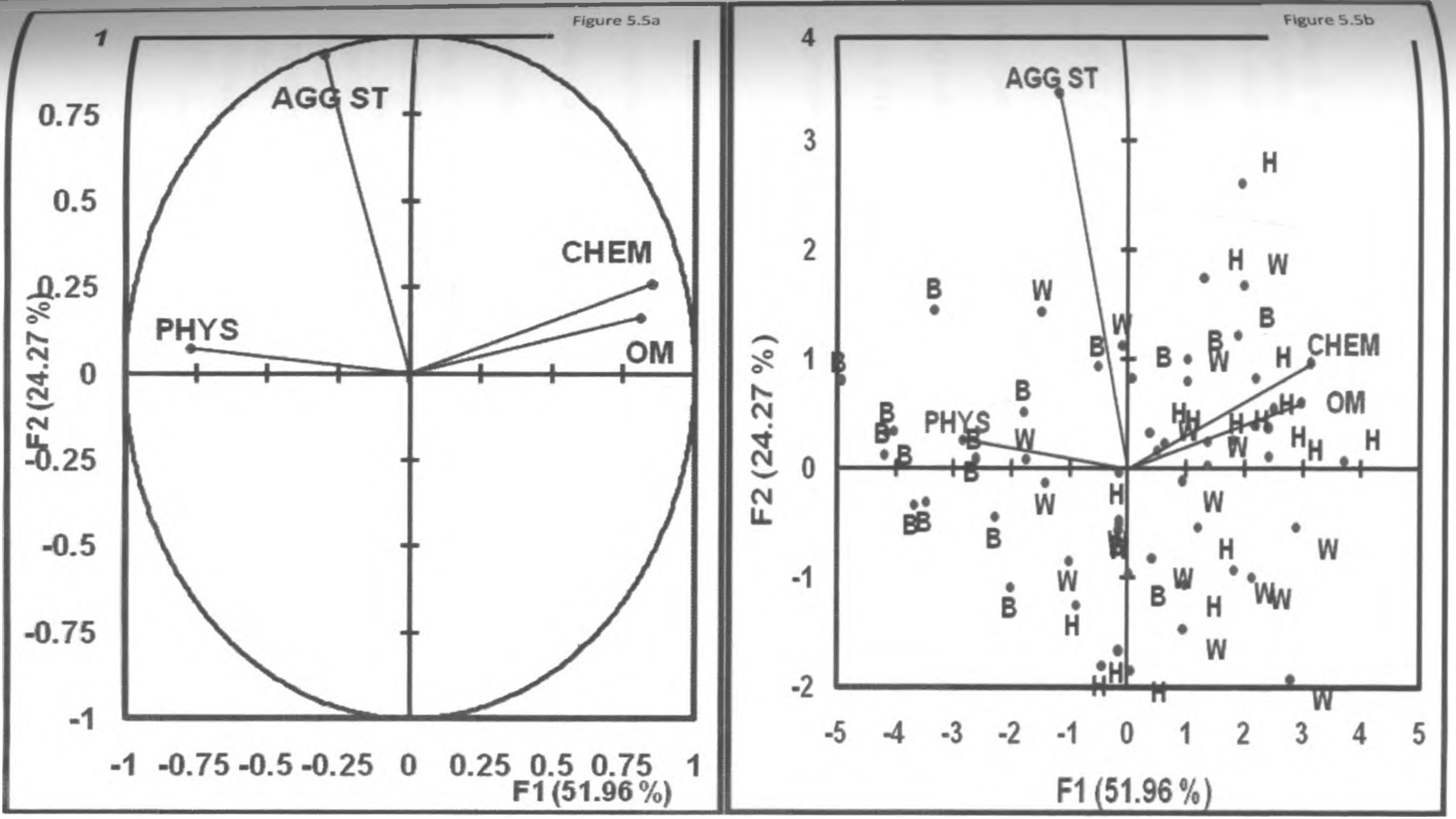

Figure 5. 5: Correlation of physical, chemical, organic matter and aggregate stability with factors 1 and 2 (5.5a) and Ordination biplot of these properties and land cover types on factor 1 (Horizontal axis) and factor 2 (Vertical axis) which explain 48.78 and 26.9% of the variation respectively (5.5b). PHYS – Physical, CHEM – Chemical, OM – Organic matter, AGG ST – Aggregate stability, B – bare, H – herbaceous and W - woody

Multiplication of category contribution of soil properties to factors one and two with their respective inertias showed that aggregate stability had the highest sub-indicator of soil quality followed by chemical quality, organic matter quality and least in physical quality (Table 5.6).

Table 5. 6: Products of contribution to factors and inertias used to calculate soil quality indicators for each property and deriving the GISQ equation

Sub-Indicator	Contribution F1*Inertia F1	Contribution F2*Inertia F2	Indicator (Sum/1000)
PHYS	14.94	0.13	0.015
CHEM	18.22	1.70	0.020
OM	16.30	0.65	0.017
AGG ST	2.54	21.82	0.024

The equation for calculation of the general indicator of soil quality (GISQ) is therefore;

$$GISQ = 0.015PHYS + 0.02CHEM + 0.017OM + 0.024AGG\ ST$$

Where PHYS (Physical quality), CHEM (Chemical quality), OM (Organic matter) and AGG ST (Aggregate stability)

When the GISQ formula was applied to all sites to obtain a soil quality index for individual sites, the results showed that significant differences ($p < 0.05$) in GISQ existed between production systems and the interaction between production system and vegetation cover ($p < 0.001$) but there were no significant differences between vegetation cover types (Table 5.7)

Table 5. 7: Analysis of variance for the effect of vegetation cover, production system and their interaction on GISQ

Source of variation	d.f.	s.s.	m.s.	vr.	Fpr.
Vegetation cover	2	0.085	0.043	1.76	0.184
Production system	2	0.154	0.077	3.2	0.05
Vegetation cover*Production system	4	0.76	0.19	7.86	0.001
Residual	45	1.09	0.024		
Total	53	2.08			

The highest soil quality index (1.0) was found in a herbaceous site under the semi-settled production system (Table 5.8), while the least soil quality index (0.1) was found in a bare land under the Non-settled production system. On average, highest soil quality value was found in herbaceous vegetation under the semi-settled production system (0.64) and lowest soil quality value was found in bare land under the Non-settled production system (0.23).

Table 5. 8: Range and average GISQ for the different production systems and vegetation types in Nakasongola rangelands

Production System* Vegetation cover	GISQ range	Average GISQ
Non-settled Bare	0.1 - 0.53	0.23
Non-settled Herbaceous	0.49 - 0.70	0.60
Non-settled Woody	0.21 - 0.65	0.43
Settled Bare	0.15 - 0.46	0.30
Settled Herbaceous	0.27 - 0.56	0.39
Settled Woody	0.28 - 0.80	0.54
Semi-settled Bare	0.27 - 0.68	0.48
Semi-settled Herbaceous	0.41 - 1.00	0.64
Semi-settled Woody	0.12 - 0.46	0.27

The first two PCA factors explained 60.4% of the total variability and separated the sites based on the values of the subindicators (Figure 5.6). The sites with the high values of GISQ were: semi-settled herbaceous (1.00), settled woody (0.80) and non-settled herbaceous (0.69). The sites with high values of chemical and organic matter quality were those under herbaceous cover, followed by woody and least in bare. The second factor separated the sites based on the subindicators of aggregate stability and physical properties. The bare sites had high values of physical properties followed by woody and least in herbaceous whereas sites under woody cover had high values of aggregate stability, followed by bare and least in herbaceous sites (Figure 5.7).

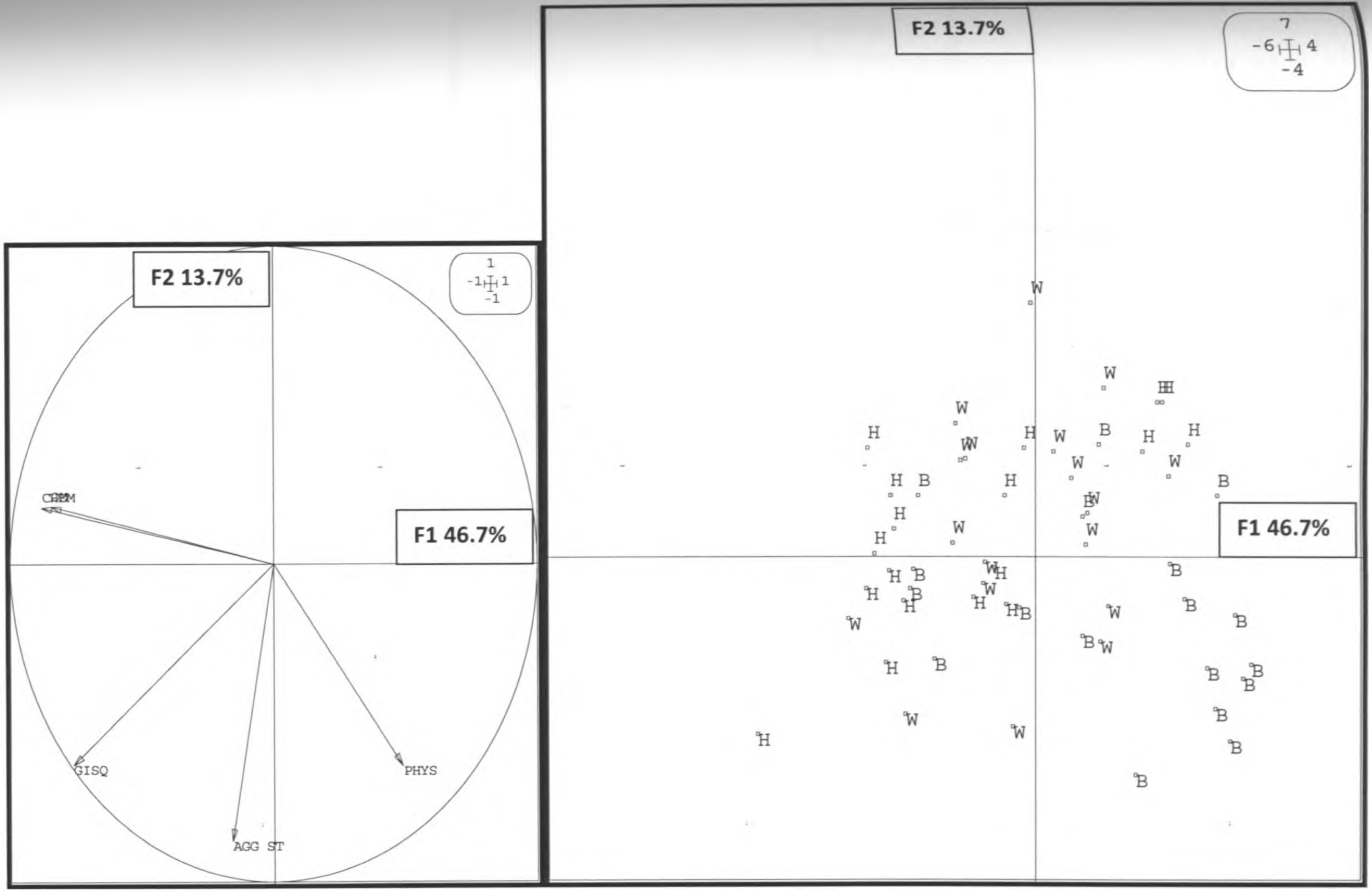

Figure 5. 6: Projection of sites in factorial space defined by PCA analysis of subindicators. Correlation circle of subindicators and GISQ with factors 1 and 2 of PCA. (left) and Projection of sites in the plane defined by factors 1 and 2.

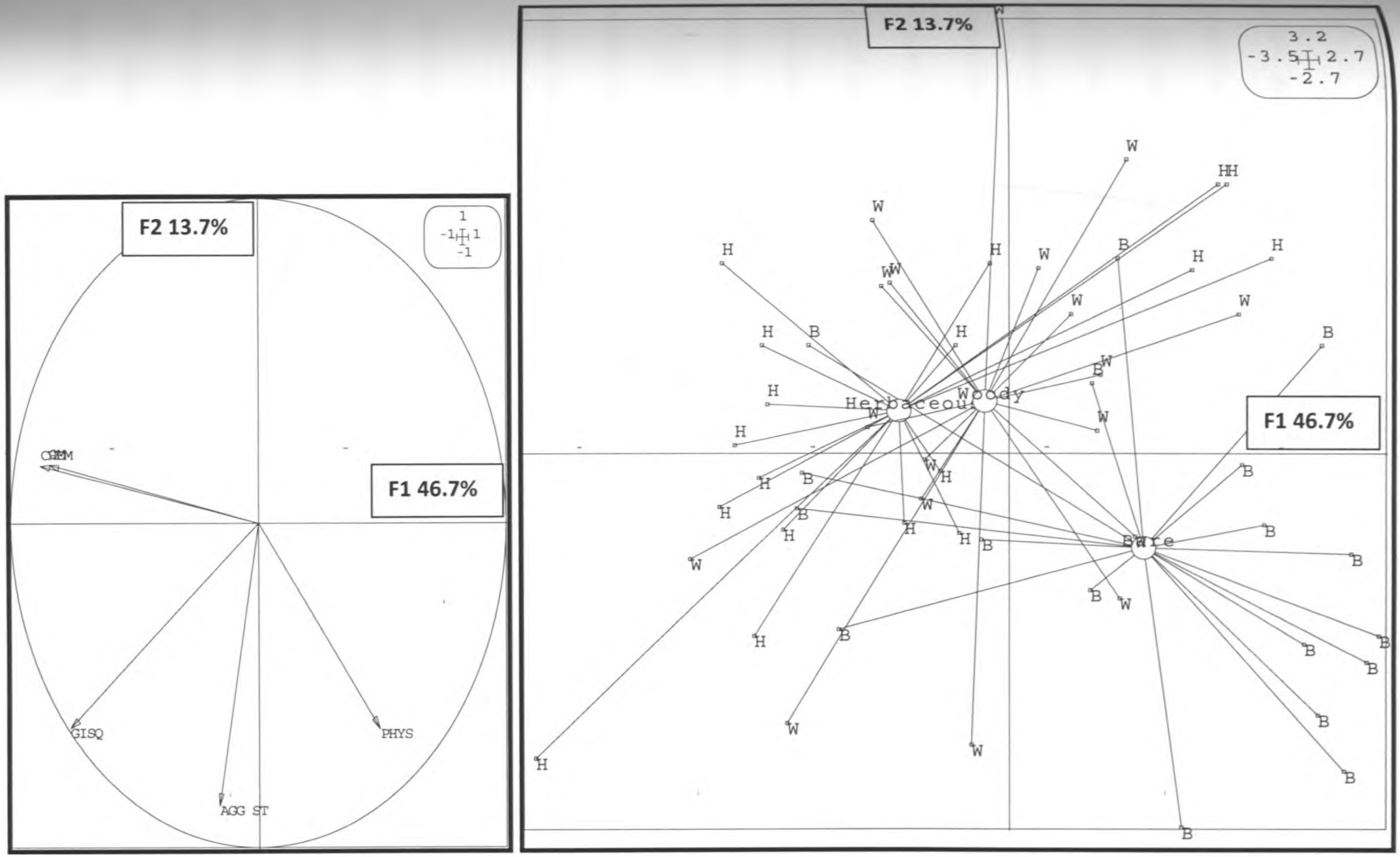

Figure 5. 7: Correlations between GISQ, soil properties and factors 1 & 2 (left) and the Barry-centers of different vegetation covers (right)

5.4 Discussion

Earlier descriptions of the soils and land uses of Uganda described the soils of Nakasongola District as being sandy loam with sand having the highest percentage in the top soil and grasses as the dominant vegetation (Radwanski, 1960). This explains why soils under herbaceous cover were poor in physical properties and aggregate stability because high levels of sand are associated with weak soil structure and low stability (Brady, 1990). However, soils under herbaceous cover are rich in chemical and organic matter properties because they are less exposed to soil erosion as compared to soils under bare and woody vegetation where high levels of soil erosion occurred. Because the bare and woody cover are derived from former grass dominated ecosystems due to degradation, most of the top soil layer (fertile soils) has been eroded hence leading to lower levels of nutrients and organic matter. Because clay particles are very fine, they normally percolate and occupy pore spaces in subsurface soil layers. As soil erosion takes place, the top layers of soil are washed away exposing the subsoil layers that are high in clay.

Irrespective of the land use and cover types, the soils in the rangelands of Nakasongola have limited levels of nutrients to support plant growth. This shows that the amount of nutrients extracted through grazing and soil erosion are greater than the rates of replacement through litter decomposition and manure deposition. However, the land use system subjected to soils under a given cover type are more responsible for driving major changes in the soil physical, chemical and organic properties of the soil hence affecting the GISQ. Any slight decline in soil properties caused by exhaustive land use types creates a great distinction from other soils. This explains why there were significant differences in GISQ between land use types (production systems) with the semi-settled having a highest GISQ.

Because of the high numbers of grazing animals that were once kept in non-settled production systems and lack of grazing control as a result of the tragedy of the commons in these areas. There was repeated grazing in a few areas leading to the creation of highly grazed patches which nitiated rangeland degradation in terms of increased bare patches hence leading to lower levels of GISQ in non-settled production systems.

The lower GISQ values in settled production systems are attributed to the fact that the ntroduction of specialized production systems (land use systems) such as sedentarization of pastoralists, fencing and implementation of rotational grazing under settled production systems ead to overstocking of land as managers devise mechanisms to obtain more profits due to high evels of investments in fencing and water development. The overstocking had negative impact on soils due to compaction and high rates of nutrient harvesting that led to lower GISQ. Under ettled systems, the area is divided into several grazing paddocks that are grazed under a otational system. Calculation of the carrying capacity is often based on the total grazing area of he ranch/farm, but because of the paddocking, all animals are allowed into one particular paddock at a time. This therefore means that stock density in paddocks is higher than the carrying capacity of the land. Land under settled systems is therefore exposed to high stocking ates and over grazing.

Several studies have also indicated that specialized grazing systems such as rotational grazing are only useful in achieving a more uniform utilization of forage due to reduced selectivity in grazing animals but livestock productivity and ecosystem sustainability may be greatly reduced in such systems compared to continuous grazing as practiced in semi-settled production systems (Heitschmidt and Walker, 1996; McCollum *et al.*, 1999; Briske et al., 2008).

5.5 Conclusion

Chemical and organic matter fractions are the most important factors that determine the general quality of soils. Therefore, management interventions intended to improve soil quality and productivity should strongly focus on improving the chemical and organic matter properties of soil. Conversion of rangelands from grass dominated to bare and woody domination as well as changes in production practices from pastoral to sedenterized production systems result in a reduction of soil quality and the overall sustainability of the ecosystem. Because of the high GISQ values, herbaceous cover and semi-settled production systems are the best land cover and land use systems identified for sustainable production in the rangelands of Nakasongola District. Overall, the soils are generally low in chemical fertility and organic matter, have a poor structure and therefore require interventions that would improve their production potential.

Chapter 6

Determining the effect of land use and cover change on soil nutrient status and pasture productivity in semi-arid rangelands of Nakasongola District

Abstract

The current pace of rangeland degradation imparted by uncontrolled land use and management systems is greatly limiting the potential of the soil resource to support pasture production. The study area was stratified into three production systems and three land cover systems from which six pasture and soil samples were collected following a Modified-Whittaker sampling method for determination of biomass yield and effects of land use and cover change on pasture production. Pasture biomass yield was significantly different between cover types ($p < 0.0001$), with high biomass in herbaceous (2019 kg/ha) and least in bare land. Production systems also had significantly different ($p < 0.013$) biomass yield, highest in settled 1266 kg/ha and least in semi-settled (953 kg/ha). Biomass yield was more associated with high levels of OM ($r = 0.91$), Ca ($r = 0.91$), Mg (0.83), N ($r = 0.77$) and base saturation ($r = 0.88$) and were therefore identified as the most critical soil nutrients limiting pasture production. The soils in Nakasongola are generally very strongly acidic (average pH = 4.5) and therefore improving soil pH and addition of organic matter are major soil management practices that should be undertaken to increase pasture biomass yield in the degraded rangeland ecosystems. Encroachment of grasslands by bare and woody vegetation has led to a decline in pasture biomass yield and therefore has strong implications on the sustainability of pastoral livelihoods in the semi-arid rangelands of Nakasongola.

6.1 Introduction

Rangelands are generally known to be overgrazed throughout the world and their potential to produce edible forage for livestock feeding has greatly declined (Wilson and Macleod, 1991). There exist copious pressures that pose risks to rangelands, with some arising from livestock – pasture interactions (Mitchell *et al.*, 1999). The most important product provided by rangelands is the rich diversity of forages, especially the herbaceous vegetation that is extensively grazed by animals. However, the increasing population pressure imposes a great threat to sustainability of natural vegetation through settlements and increased cultivation in grasslands which reduces the area available for grazing (Kristjanson *et al.*, 2002).

The transformation of land cover and land use system in pastoral rangeland communities is believed to have significant impacts on the productivity of the herbaceous layer which needs detailed understanding if sustainable rangeland management practices are to be developed. Of the three major drivers of vegetation structure and composition in rangeland ecosystems; fire, herbivory and climate (Noy-Meir, 1993; Hudak and Wessman, 2001; Lechmere-Oertel, 2003; Azardi *et al.*, 2009), the impact of herbivory has been identified by many authors as a critical force in semi-arid rangelands (Archer, 1994; Brown and Archer, 1999; van Auken, 2000; Higgins *et al.*, 2000; Jeltsch *et al.*, 2000). As such, many traditional rangeland management practices were considered unsustainable and hence the proposition to devise better rangeland management practices.

The alienation of traditional practices in most parts of the world was done with limited scientific evidence and is thus also believed to have contributed to accelerated land cover changes in the rangelands (Briske *et al*., 2008). Increased loss of vegetation cover, soil erosion, loss of organic matter and essential soil nutrients are among the consequences of changes in land use and cover types in the semi-arid rangeland ecosystem with major striking effects being the decline in herbaceous vegetation upon which pastoral livelihoods are anchored.

Decline in pasture production is of global concern to all rangeland managers. Woody encroachment, creation of bare patches of soil and cultivation are major factors deterring the available land for grazing, reduces pasture production as well as the quality of primary production. Keeping large livestock numbers, in a bid to increase profits in privately owned lands or increase resource use in communally owned lands (the tragedy of the commons) and the expansion of cultivation in grazing areas are major areas of concern for reduced herbaceous cover and production. With increased stock density, the soils become compacted, infiltration reduces and runoff increases which leads to the washing away of all major soil nutrients and organic matter. This reduces the growth potential of pastures (shallow feeders) and thus reduces competition with deep rooted woody species leading to an increase in woody cover at the expense of grasses.

Rangeland management for sustainable production is not a new phenomenon. Traditionally, pastoralists used to reserve dry season grazing areas and only grazed livestock in such common pool resource areas when an intense drought strikes. Elsewhere, animals could graze the rangeland continuously to levels perceived to be recuperative and moved to other places for grazing. However, the breakdown of traditional rangeland management practices, changes in land ownership and the lifestyles of pastoralists through individualization and sedentarization, the influx of people with a different way of life style from high potential areas (cultivators) led to the collapse of the ecological and production sustainability of Uganda's rangeland systems. Currently, rangelands are under different production systems (land use) that involve permanently settled systems that practice rotational grazing (individualized and sedentarization), semi-settled systems where continuous grazing is practiced, there is regulation of stock numbers and involves movement to better places in dry seasons and the non-settled systems where many people own small herds which graze everywhere. These three land use practices subject the rangeland to grazing intensities that lead to overgrazing and degradation resulting into ecosystems that can no onger maintain their stability, function and structure due to subsequent changes in land cover.

The extensive degradation of rangelands is making life harsh for livestock herders in Nakasongola District. Overstocking in open range undermined the economic welfare of local livestock keepers who faced high levels of stock mortality especially in dry seasons (the tragedy of the commons). However, transformation of rangeland use from open access to individual and sedentarization of pastoralists which were thought to provide a solution to licentious problems of communal grazing are now faced with almost the same challenges of reduced pasture production. Individualization of former communally owned resources involves increased investment for fencing and water development. As such, rangeland owners are known to overstock in order to increase the returns to investment. Although heavy stocking is known to result into greater economic return in the short-term, it often results to degradation of the soil and pasture resource and potentially affects sustainable production in the long term.

The system of production applied on a land resource affects the ecosystem, vegetation cover, soil and socio-economic factors of the communities inhabiting a given area. Appropriate rangeland use systems that involves resting of land rehabilitates degraded areas, increases biodiversity in favour of desirable plant species, increases vegetation cover through colonization of formerly bare patches and has significant influence on the soil component through reduced runoff, increased infiltration and increased organic matter and soil nutrients (Ekaya and Kinyamario, 2003; Gilad *et al*., 2004; Mengistu *et al*., 2005; Mureithi, 2006; Mureithi *et al*., 2010). However, the ability of resting to rehabilitate depends on whether the ecosystem was not severely degraded past their recuperative capacity. Otherwise, severely degraded rangelands may fail to return to their original states when rested (Westoby *et al*., 1989; O'Connor, 1991) or may be converted to an entirely different state (Kosmas *et al*., 2000). Although the rangelands of Uganda are regarded as severely degraded areas, the extent of degradation is not known and it has not been established whether mere resting of the range can promote pasture production to its original level.

Although traditional livestock management practices in the rangelands of Uganda were believed to have contributed to rangeland degradation, the formulation and recommendation of new livestock management systems (sedentarization of pastoralists, fencing and rotational grazing) was carried out with no scientific evidence. As such, the impacts of the new land use systems and their subsequent cover types on pasture production and sustainability of the rangeland ecosystem are unknown. More so, because of the low input production systems practiced with constraints in soil fertility improvement, the issue of increasing soil fertility for increased pasture production is more of a blanket statement with no major emphasis on critical nutrients affecting pasture production. Therefore, there is a need to establish the impacts of land use and cover change on pasture production if more informed decisions for proper rangeland management are to be formulated and to maintain harmony among sustainable utilization of resources and socio-economic needs. It is also imperative to note that the most productive management system may not necessarily be the most sustainable system since increased production is short-term whereas sustainability is long term. There is therefore an urgent need for scientific evidence to qualify sustainable rangeland management systems.

6.2 Methodology

6.2.1 Description of study area

The study area (refer to Chapter 4) was characterized into three rangeland management systems (settled, semi-settled and non-settled) which were stratified into three land cover types (bare, herbaceous and woody) in which six locations were randomly selected for establishment of the sampling sites. A Modified-Whittaker plot (20 m × 50 m; Figure 4.2, chapter 4) was placed with the long axis parallel to the environmental gradient (Stohlgren *et al*., 1995). In each plot of 1000 m^2 was nested subplots of three different sizes. A 5 m × 20 m (100 m^2) subplot in the center, two 2 m × 5 m (10 m^2) subplots in opposite corners and ten 0.5 m × 2 m (1 m^2) subplots (six arranged systematically inside and adjacent to the 1000 m^2 plot perimeter and four arranged systematically outside and adjacent to the 100 m^2 subplot perimeter).

6.2.1 Pasture sampling

Pasture sampling was done towards the end of the rain reason when most of the plants were at the peak of their phenology and when there was optimum biomass production. All herbaceous plants present in each of the 1 m^2 and 10 m^2 subplots were cut at ground level using a sickle and 1 m^2 at the center of the 100 m^2 subplot. The collected pastures from all sampling points within one Modified-Whittaker plot were then pooled, packed in labeled bags, weighed and recorded. The fresh forage was air dried and then oven dried at 80^0 C for 48 hours and finally re-weighed (Roberts *et al.*, 1993).

6.2.2 Data analysis

Analysis of variance was conducted using XLSTAT package to analyze the difference in biomass yield as affected by production system, land cover type and the interaction between production system and land cover type. The hypothesis tested is that there are no significant differences in pasture biomass yield among production systems and land cover types. Type III sum of squares were used to identify significance levels and mean pasture biomass yield was separated using Least Square means.Fifteen selected physical and chemical soil properties (pH, OC, OM, N, Ca, C:N, Mg, K, Na, CEC, Ksat, BD, available P, base saturation and porosity) were subjected to Principle Component Analysis in order to analyze the correlations between biomass production and soil properties and to identify the most critical soil properties/nutrients limiting biomass yield. Squared Cosines values of variables (soil properties) were used to identify the factors that are more linked with most variables.

6.3 Results

6.3.1 Effect of land use and cover change on pasture biomass yield

Pasture biomass yield ranged between zero and 3116 kg/ha, with a mean of 1107±925.6 kg/ha. Highest biomass yield was under herbaceous cover (2019 kg/ha) followed by woody (1302 kg/ha) and least (none) in bare cover (Figure 6.1). The settled production system had more biomass yield (1266 kg/ha) followed by the non-settled (1102 kg/ha) and least in semi-settled (953 kg/ha) (Figure 6.2).

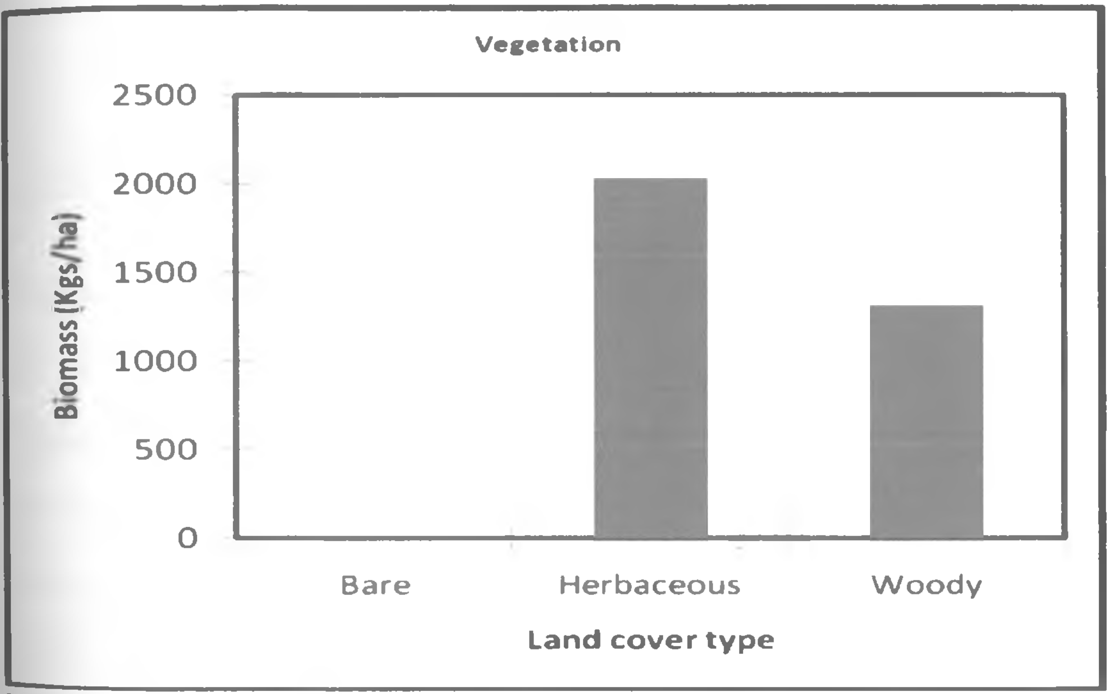

Figure 6. 1: Pasture biomass yield under different land cover types

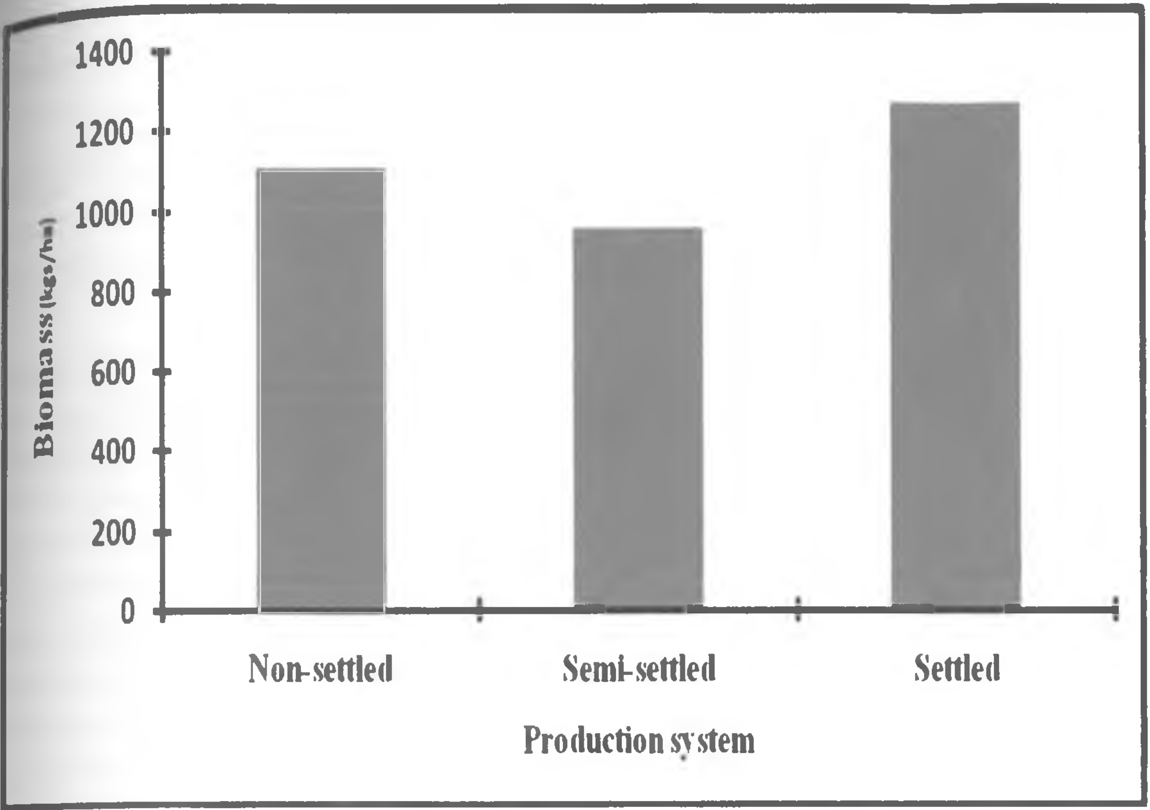

Figure 6. 2: Pasture biomass yield under different pastoral production systems

Pasture biomass yield was significantly different ($p < 0.0001$) across land cover types (Table 6.1) and significantly different ($p < 0.013$) between settled and semi-settled production systems (Table 6.2). The interaction between production systems and cover types showed significant differences between different combinations (Table 6.3). High pasture biomass was recorded under herbaceous vegetation in settled systems while no biomass was recorded in all production systems where bare ground existed.

Table 6. 1: Fishers LSD analysis of differences between land cover types at 95% confidence interval

Contrast	Difference	Pr > Diff
Herbaceous vs Bare	2019.222	< 0.0001
Herbaceous vs Woody	717.417	< 0.0001
Woody vs Bare	1301.806	< 0.0001

Table 6. 2: Fishers LSD analysis of differences between production systems at 95% confidence interval

Contrast	Difference	Pr > Diff
Settled vs Semi-settled	313.028	0.013
Settled vs Non-settled	163.778	0.184
Non-settled vs Semi-settled	149.25	0.226

Table 6. 3: LS means used to differentiate the interactions between production systems and land cover types.

Production system*Vegetation type	Pasture Biomass (kg/ha)
Settled*Herbaceous	2320^{a}
Settled*Woody	1478^{bc}
Settled*Bare	0.000^{d}
Semi-settled*Herbaceous	1643^{b}
Semi-settled*Woody	1216^{c}
Semi-settled*Bare	0.000^{d}
Non-settled*Herbaceous	2095^{a}
Non-settled*Woody	1211^{c}
Non-settled*Bare	0.000^{d}

Means followed by the different superscripts are significantly different at the 0.05 probability level.

6.3.2 Identifying critical soil properties affecting pasture biomass yield

Fifteen factors were obtained (Figure 6.3), with the five factors explaining 77.4% of the total variability. Factors which have the highest cosines values for each variable were selected hence having Factor 1, 2, 3, 4 and 5 as the most important factors explaining differences in biomass (Table 6.4). The first two eigenvalues correspond to a high percentage of the variance (54%) and are thus a good quality projection of the initial multi-dimensional table. Since there are 15 factors out of the 15 variables uploaded for analysis, there is no variable that has a strong negative correlation (r = -1) with others. However, available phosphorus is negatively correlated with all variables except CEC, Ksat and porosity.

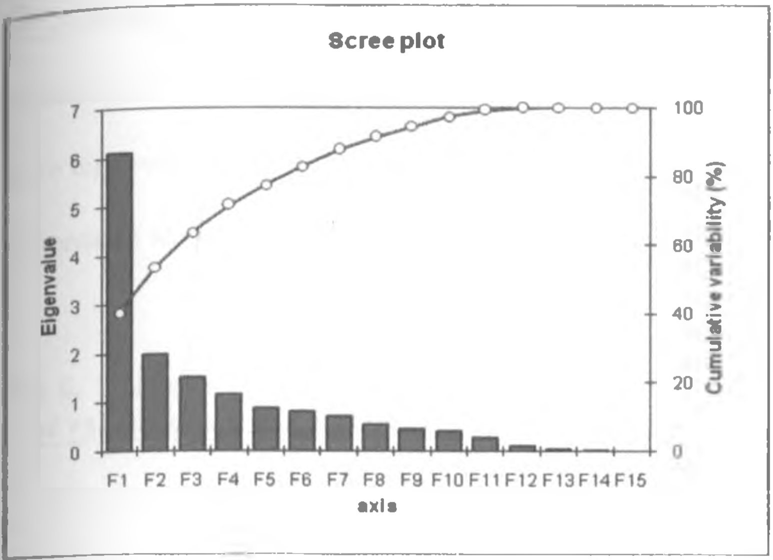

Figure 6. 3: Eigenvalues and cumulative variability explained by the fifteen factors

Table 6. 4: Squared cosines of the variables.

Variable	Factors				
	F1	F2	F3	F4	F5
pH	**0.413**	0.111	0.013	0.036	0.007
OC	**0.823**	0.028	0.018	0.032	0.002
OM	**0.823**	0.028	0.018	0.032	0.002
N	**0.589**	0.023	0.156	0.016	0.005
C:N	**0.330**	0.187	0.099	0.130	0.002
Ca	**0.818**	0.001	0.091	0.012	0.002
Mg	**0.685**	0.001	0.135	0.025	0.005
K	0.165	0.100	0.165	**0.239**	0.007
Na	0.048	0.020	**0.462**	0.033	0.152
CEC	0.361	0.028	0.022	0.002	**0.421**
Ksat	0.095	**0.595**	0.001	0.025	0.005
BD	0.000	0.006	0.113	**0.538**	0.039
Av.P	0.054	**0.488**	0.023	0.014	0.085
Base saturation	**0.770**	0.000	0.072	0.031	0.019
Porosity	0.111	**0.360**	0.127	0.001	0.121

The greater the squared cosine, the greater the link with the corresponding axis. Circled figures represent the highest squared cosines for each variable

Factor 1 and factor 2 had the highest cosines values for most variables compared to other factors with factor 1 having eight variables (pH, OC, OM, N, C:N, Ca, Mg and Base saturation) while factor 2 having three variables (Ksat, Av.P and Porosity). Therefore, the trends in biomass production can be best viewed on factor 1 and factor 2 maps. The first two factors (factor 1 and 2) have eigenvalues of 6.1 and 2.0, respectively (Table 6.5) and correspond to a high percentage of variance of about 54% compared to the variance contributed by the other 13 factors.

Table 6. 5: Eigenvalues and cumulative variability of the first 5 factors where greatest Cosine values for all variables are presented

	Factors				
	F1	F2	F3	F4	F5
Eigenvalue	6.1	2.0	1.5	1.2	0.9
Variability (%)	40.6	13.2	10.1	7.8	5.8
Cumulative %	40.6	53.7	63.8	71.6	77.4

The correlation circle based on factor 1 and 2 (Figure 6.4) show that Factor 1 is correlated with pH (r = 0.64), OC (r = 0.907), OM (r = 0.907), N (r = 0.768), C:N (r = 0.574), Ca (r = 0.905), Mg (r = 0.828), CEC (r = 0.601) and Base saturation (r = 0.878) while Ksat (r = 0.771), Av.P (r = 0.698) and porosity (r = 0.6) are correlated with F2. However BD, Na and K are very close to the center which shows that their variability is more explained by other factors than F1 and F2. Analysis of correlation of variables with factors (Table 6.6) shows that BD is more correlated to factor 4 (r = 0.734 while Na (r = 0.679) is highly correlated to factor 3 and K can be more explained on F1 and F3 axes where its correlation with both factors is similar (r = 0.407).

Table 6. 6: Correlations between variables and factors.

Variable	Factors				
	F1	F2	F3	F4	F5
pH	0.643	0.333	0.112	0.191	-0.086
OC	0.907	-0.168	0.134	0.179	-0.043
OM	0.907	-0.168	0.134	0.179	-0.043
N	0.768	0.152	0.395	-0.125	-0.070
C:N	0.574	-0.432	-0.315	0.361	-0.042
Ca	0.905	0.038	-0.302	-0.109	0.040
Mg	0.828	-0.031	-0.367	-0.159	0.068
K	**0.407**	-0.316	**0.407**	-0.488	-0.083
Na	0.220	-0.142	**0.679**	-0.181	0.390
CEC	0.601	0.166	-0.147	-0.048	0.649
Ksat	0.308	0.771	-0.028	0.157	-0.068
BD	0.010	-0.076	0.336	**0.734**	0.198
Av.P	-0.231	0.698	-0.152	-0.119	0.292
Base saturation	0.878	-0.001	-0.269	-0.176	-0.138
Porosity	0.334	0.600	0.357	0.028	-0.347

Bold text shows high correlation between variables and corresponding factors

High pasture biomass is more associated with high levels of OM, Ca, Mg, N and Base saturation than other variables (Figures 6.4 a & b), while decline in these soil properties is associated with reduction in pasture biomass yield. Substitution of pasture biomass yield with land use/cover types on the observations plot on F1 and F2 axes show that points with high pasture biomass yield correspond with herbaceous vegetation type while those with least pasture biomass yield correspond to bare ground (Figure 6.5 a & b)

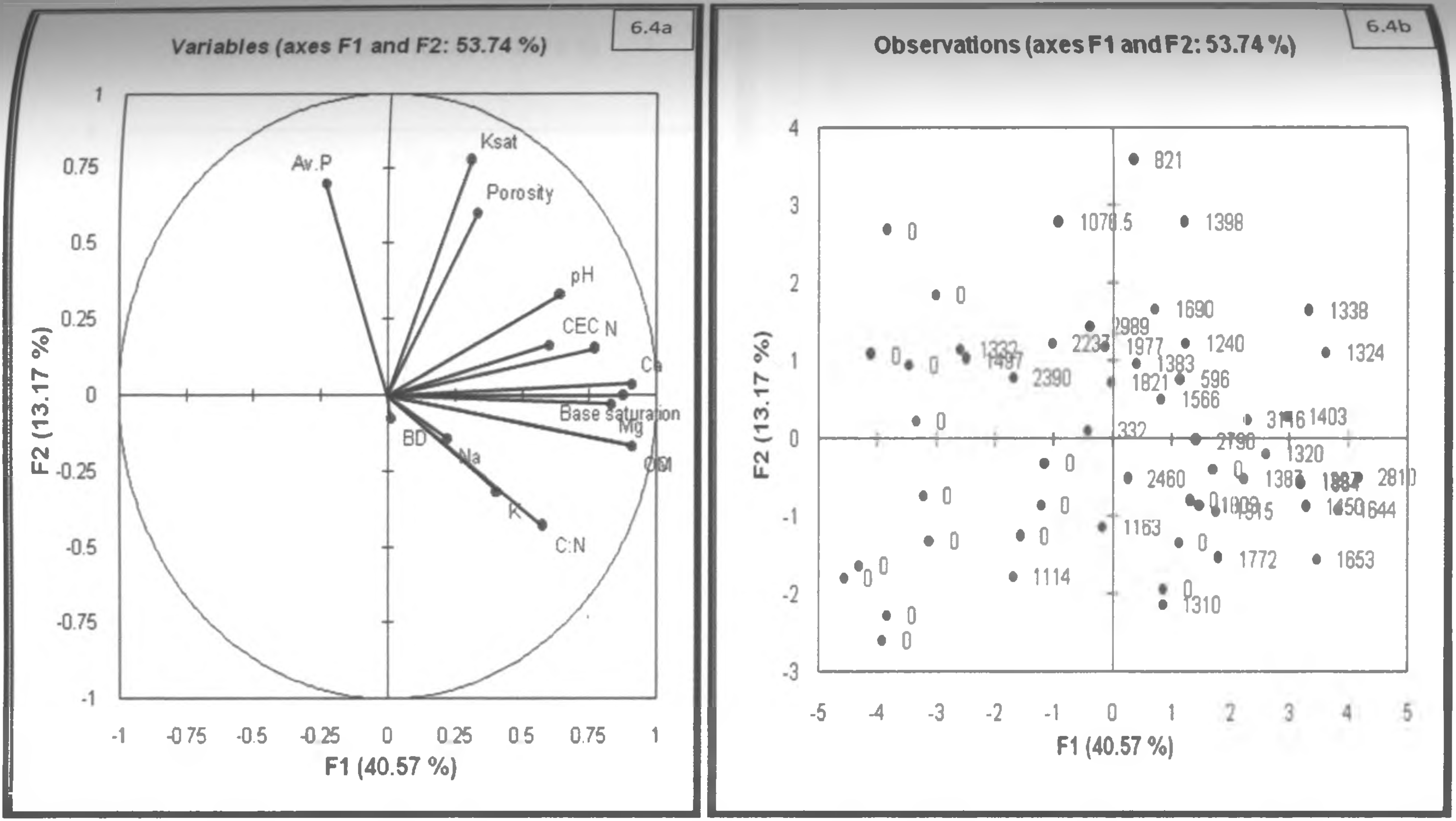

Figure 6. 4: Correlation of variables with factors 1 and 2 (6.4a) and Ordination biplot of soil properties and biomass yield on factor 1 (Horizontal axis) and factor 2 (Vertical axis) which explain 40.57% and 13.17% of the variation (6.4b)

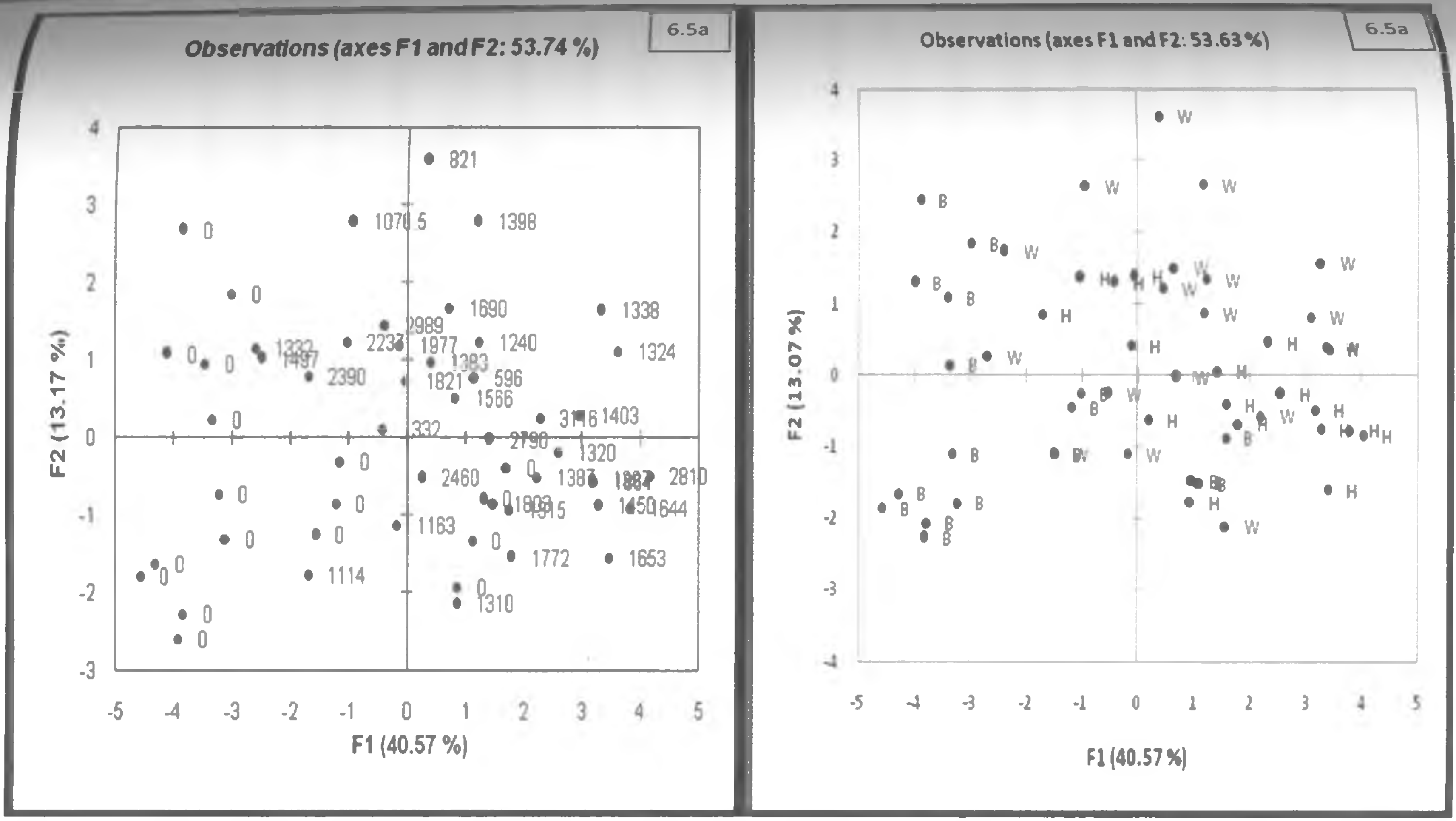

Figure 6. 5: Observations of pasture biomass (6.5 a) and land use/cover types (6.5 b) on F1 and F2 axes. B = Bare, H = Herbaceous, W = Woody

6.4 Discussion

6.4.1 Effect of land use and cover change on pasture biomass yield

The wide variation in mean biomass yield shows that great differences exist in pasture production across production systems and vegetation types. The high biomass yield in herbaceous cover was because of less degradation, high nutrients levels and maximum production due to limited competition for resources with woody species. Because most of the woody vegetation is covering formerly degraded grasslands with remnants of bare ground under the woody canopy, there is limited pasture growth, under woody cover. Also, the increased competition between herbaceous and woody species for nutrients, water and light hinders pasture growth under the woody canopy. Because the settled production system allows ample time for pastures to regenerate after grazing, there is high biomass yield compared to non-settled and semi-settled systems where continuous grazing is practiced with limited resting of land to enable regeneration of pastures. These findings are supported by earlier studies (Biamah, 1986; Kironchi, 1998) who noted that semi-arid rangelands are resilient ecosystems that are capable of regenerating once the drivers of degradation are lifted before the recuperative capacity is surpassed. Therefore, since woody and bare lands are former grasslands that were so much degraded by overstocking, their ability to support pasture production is still low as land was subjected to extensive soil erosion and runoff which depleted most of the organic matter and soil nutrients as reported by Verity and Anderson (1990). Similar results have been reported elsewhere with areas under restricted grazing having high biomass yield compared to freely accessed grazing areas (Makokha *et al.*, 1999; Cleemput *et al.*, 2004; Mureithi *et al.*, 2010).

The relatively low pasture biomass yield under all production systems (maximum of 3000 kg/ha) compared to that earlier reported in the central rangelands of Uganda of 4000 – 5000 kg/ha (Harrington, 1974) is attributed to the fact that regardless of the production system, the available grazing lands had a high stocking density which increased the grazing intensity and limits pasture growth. Bartolome (1993), Derner and Hart (2007) and Schuman *et al.* (2009) also reported similar results where they observed that heavy grazing intensities had detrimental impacts on pasture production. It was also noted that specialized grazing systems aimed at controlling selective grazing are not effective in semi-arid rangelands compared to simpler grazing methods based on controlling grazing intensity (Bartolome, 1993). This explains why non-settled systems light grazing intensity had high biomass yield compared to semi-settled systems with high grazing intensities because seasonal cultivation often reduces grazing land and increases grazing intensity.

6.4.2 Identifying critical soil properties affecting pasture biomass yield

Because of the high temperatures associated with the semi-arid rangelands, the rate of primary net production and decomposition are low. Because of this, organic matter and nitrogen are generally limiting nutrients in the rangeland ecosystem of Nakasongola and are thus among the most critical nutrients affecting pasture biomass yield. Because organic matter influences most soil properties and nutrient availability, the low organic matter fraction translates into lower pH levels and CEC which in turn limits pasture production. Since most of the exchangeable bases that could counteract low pH are extensively lost due to excessive erosion, Ca and Mg become important nutrients required for increased pasture production. The results of this study are supported by the findings of Mugerwa *et al.* (2008) who noted that application of cattle manure on degraded rangelands significantly increased pasture biomass yield. Organic matter has also been identified as a major factor limiting crop and pasture production in many other ecosystems across the globe and increase in organic matter leads to an increase in many other physical and chemical properties of soil and subsequently increases primary production.

6.5 Conclusion

The encroachment of grasslands by bare and woody vegetation has led to a decline in pasture biomass yield and therefore has strong implications on the sustainability of pastoral livelihoods in the semi-arid rangelands of Nakasongola. The low pasture biomass yield in woody understorey implies that most native pasture species in the rangelands of Nakasongola are not shade tolerant and therefore increased woody encroachment will most likely wipe out indigenous nutritive pastures in the rangeland. Organic matter, nitrogen, calcium and magnesium are the most critical nutrients limiting pasture biomass yield. Rangeland management strategies for improving soil quality and pasture production should therefore be strongly focused at increasing the levels of these nutrients.

Chapter 7

7.1 Summary and recommendations

Understanding appropriate management practices for rangeland ecosystems is a challenge to many rangeland resource managers but is still an underlying tenet for developing sustainable production principles. The major impetus for this study therefore stemmed from the perception that science needs to be linked to policy formulation and that appropriate management practices for sustainability of ecosystems and production should be based on scientific evidence. Nakasongola rangelands were chosen for this study because they are typical degraded rangeland ecosystems. The main use of rangelands in Nakasongola District is grazing by domestic animals on natural vegetation which provide the cheapest source of nutrients for ruminants. Therefore alterations that result into rangeland degradation and reduction in grazing lands negatively impact on the production and profitability of livestock production and affect the livelihood of farmers.

The framing of policies for rangeland development in Uganda was based on the assumption that pastoralists overstock rangelands causing degradation and that mobility of pastoralists was a primitive production system associated with spread of pests and diseases as well as endemic conflicts and thus had no supporting scientific evidence. This led to modification and annihilation of traditional pastoral patterns and their eventual replacement by sedentary systems in many areas. However, the sedentarization of pastoralists, individualization of land and introduction of fencing and rotational grazing systems have led to severe rangeland degradation within and in the remnant open access grazing areas and gradually caused a decline in the sustainability of rangelands for continued pasture production. From the findings of this study, the following recommendations were drawn;

Revision or formulation of rangeland management policies with appropriate scientific evidences should be considered a priority if the degraded rangelands are to be rehabilitated and utilized sustainably.

There is a need for intensification and transformation of cropping systems from low input to high input agriculture so as to reduce opening up of new land every season in search for fertile soils. Opening new lands for cultivation is among the most insidious practices devastating the sustainability of rangeland ecosystems.

Where cropping is practiced, there is need for integration of crop residues into livestock feeding systems so as to lift the pressure on land (crop-livestock integration). This should be undertaken with scientific evidence on the most appropriate crops, crop varieties and cropping systems to be undertaken in water scarce rangeland ecosystems.

Rangeland management strategies for improving soil quality and pasture production should strongly focus at increasing the levels of organic matter, nitrogen, calcium and magnesium, which were identified as the most critical nutrients limiting pasture production.

There is an overwhelming need to exploit the potential of different land use and cover types (grasslands, woodlands and pine plantations) for economic benefits such as through Payment for Environmental Services (PES) in order to improve the income resource base of farmers in an environmentally friendly and sustainable manner. PES should compliment but not substitute for farmers' income originally obtained from rangelands through livestock grazing. Otherwise because of the long term benefits from PES, rangelands may become food insecure and this will be translated to a national level since rangelands are the major sources of beef and milk consumed in Uganda.

Further areas of research recommended from this study include the inclusion of more soil properties in the development and validation of the general indicator of soil quality in different areas of the cattle corridor (rangelands of Uganda), determining the appropriate levels of different sources of nutrients on pasture production and identifying indicator species of rangeland degradation so as to develop an effective early warning system for rangeland degradation.

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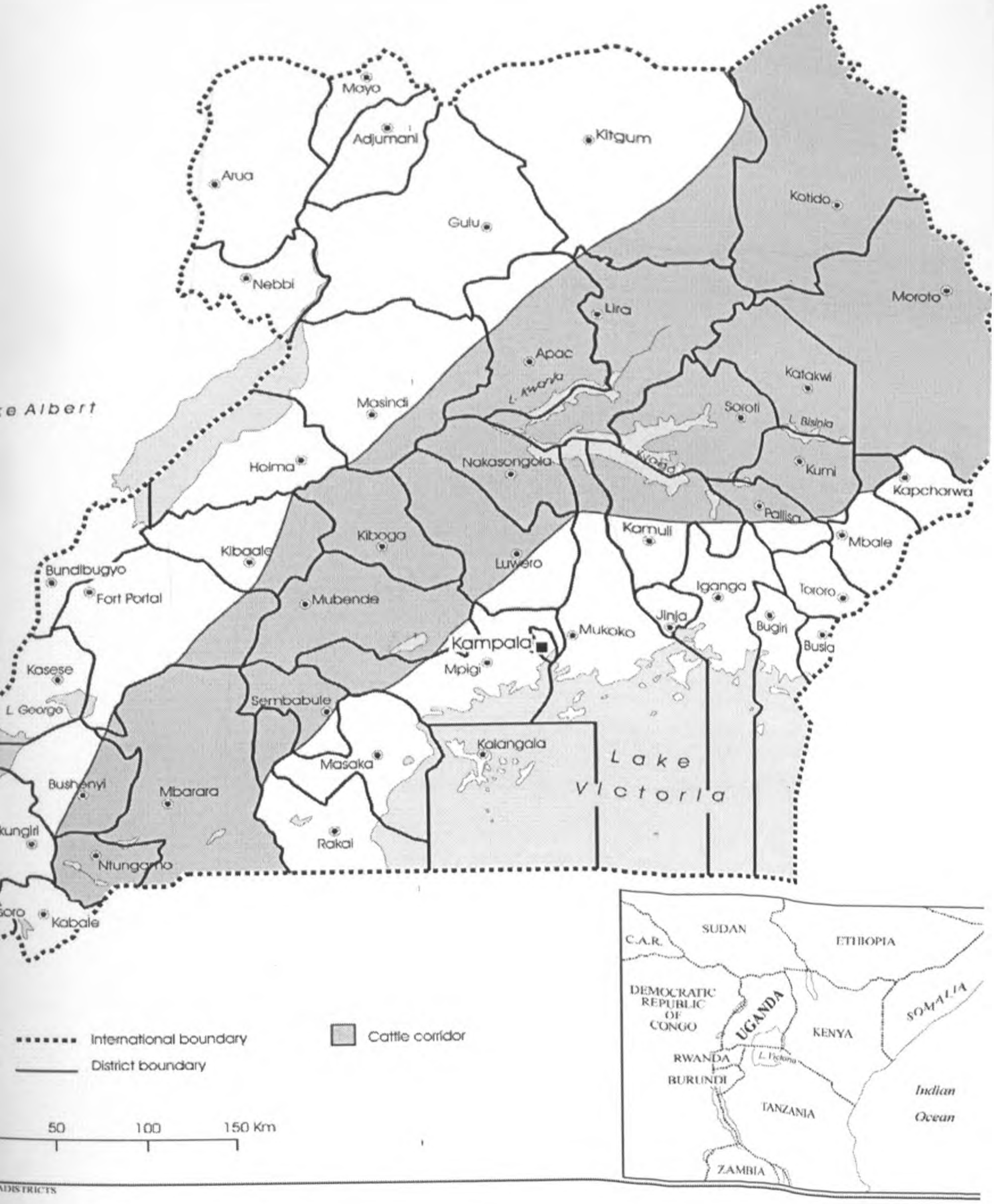
Appendix

dix 1 Map of Uganda showing the cattle corridor (the rangelands of Uganda)



: Zziwa, 2009.