SPATIAL AND SEASONAL DYNAMICS OF RANGELAND HERBAGE: An Integration of Proxy and Direct Monitoring Approaches

BY

Mfitumukiza David (BSc-Mak, MSc- ITC)

A THESIS SUBMITTED IN FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY OF MAKERERE UNIVERSITY

November, 2012
Kampala, Uganda

DECLARATION

I, Mfitumukiza David, hereby declare that this thesis entitled “***spatial and seasonal dynamics of rangeland herbage: proxy and direct monitoring approaches for grazing management***” is my original research work and has never been submitted for any award to any other University. Related studies have been duly acknowledged and what is not indicated is a coincidence of ideas and or is my finding.

CANDIDATE:

Signed: Date:

Mfitumukiza David

This thesis has been submitted with the approval of the following supervisors.

SUPERVISOR 1:

Signed: Date:

Denis Mpairwe, PhD

Senior Lecturer and head, Department of Agricultural Production, Makerere University

SUPERVISOR 2:

Signed: Date:

Makooma Tenywa Moses, PhD

Associate Professor, Department of Agricultural Production, Makerere University

SUPERVISOR 3:

Signed: Date:

Sandy S. Tickodri-Togboa, PhD

Professor, Department of Electrical Engineering, Makerere University

DEDICATION

To my wife Merab K. Mfitumukiza and Children Dara, Davida and Heba

ACKNOWLEDGEMENTS

This research started with an idea that stalled for sometime because there was no funding. Thanks to Professor Kansiime who solicited for funding from Rockefeller Foundation which supported most of the activities of this study. I would like to thank Rockefeller Foundation and former Makerere University Institute of Environment and Natural Resources (MUIENR) for the financial support made available through Grant # 2006 AR 016. I'm equally grateful to The International Foundation for Science and Rufford Small Grants Foundation that provided additional funding which was mainly used for the last part of field and laboratory work.

During this PhD research process I was so fortunate to learn from many, but more specifically from my supervisors Dr. Mpairwe Denis, Professor Tenywa Moses and Professor Sandy Tickodri-Togboa to whom I'm so greatly indebted. I thank them for having spent their time and effort to tassel with enriching my reading, writing and other research skills. I greatly appreciate the inputs and positive criticisms from the other doctoral committee members, Associate Professor Majaliwa Mwanjalolo, Professor Kansiime and Professor Sabiiti that shaped the processes and outputs of this study. Through my mentorship relationship with you, I have not remained the same in all spheres of life. Dr. Larsen, thank you for your inputs into this study especially on remote sensing aspects. Thank you indeed for the hospitality during my stay at you house in Wisconsin. I would also like to express my gratitude to the Department of Geography and Geology for the warm environment and support they rendered to me during my visit to the University of Wisconsin Stevens Point, USA.

Executing the activities of this study was quite challenging especially at the start, but I'm grateful for the support I got from former MUIENR staff which was incredibly rejuvenating. I particularly thank Mr. Erima, Dr. Kateyo, Prof. Tabuti, Prof. Pomeroy, Mr. Kissa, and Mrs. Biganja for supporting me all the way. The regular personal follow-ups on my progress by Dr. Muwanika were absolutely encouraging and memorable. Fieldwork was always wearing but because of an enduring and supportive fieldwork team, data collection was unstoppable. I'm so grateful to Sarah, Gershome, Collins, Peter, and Moses for having laboured to ensure that all the target data were collected and well managed. Dr. Namaganda, thank you for teaching us how to collect and identify plant species. Without the commitment of the rain gauge attendants who recorded rainfall data for over two years, achieving the objectives of this study would have been extremely difficult. Thank you for this huge contribution. Rain gauges were obtained with the help of Mr. Magezi S.K, Mr. Nkalubo, Mr. Waiswa and Mr. Tenywa from the Department of Meteorology. I thank you all and the Department at large. I wish to thank Mr. Katongole the chief technician and the entire staff of the nutrition Laboratory of the Department of Agricultural Production, Makerere University for their assistance during the chemical analysis of herbage samples. My gratitude also goes to Dr. Lwanga, Mr. Kato, Mr. Ddumba of Makerere University Biological Field Station (MUBFS) and all the staff members of the station for having supported me during the time I was compiling this thesis.

I want to thank Mr. Charles Saturday Ngabirano for introducing me to the study area and the wonderful people of Nyakashashara and Kacheera sub-counties. I will never forget the night we had to sleep in the jungles of Rurambira when our car got stuck in deep mud and you had to stay away from your family and comfort of your home for 24 hours because of this study. I appreciate your kindness and love. I certainly am glad we crossed each other’s path and have been able to secure friendship with you and your dear family. Without the generosity and support of the communities and leaders especially the sub-county chiefs that you introduced to me, everything would have resulted in undesired outcomes. I’m so thankful to all the community members who offered their land for experimental setup which was core to the objectives of this study. And indeed I’m grateful to the support accorded to me by the sub-county authorities at different levels.

I received various forms of support from all my social circles including my relatives, church, Together in Development Association (TIDA) to which I’m so grateful. Kanyangabos, Dan Munyaneza, Lydia Tusingwire, Joshua, Okwares, Mugishas, Habyaras among others, thanks for supporting my family especially the times I would be away pursuing the objectives of this research. I may not be able to exhaust the list the way I would want to, but just in case you don’t see your name here, know that it is not because of lack of appreciation but brain scattering. Merab Mfitumukiza, without your courage and consideration to put on my shoes all the times I would be away from home, persisting through this study period would have been very difficult. I thank you for being the encouraging and admirable woman that Solomon talks about in Proverbs 31.

Above all, I thank the Almighty God for being gracious to me through it all. It has been another reason and experience to believe and depend on HIS dependable promises. His name has been, is and will always be my strong tower.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS

ANOVA	Analysis of Variance
ANPP	Annual Aboveground Net Primary Production
AOAC	Association of Official Analytical Chemists
ASTER	Advanced Spaceborne Thermal Emission and Reflection
AVHRR	Advanced Very High Resolution Radiometer
CL	Clay Loam
CP	Crude Protein
DM	Dry Matter
ESRI	Environmental Systems Research Insitute
ETM+	Landsat Enhanced Thematic Mapper
FAO	Food and Agricultural Organization
GIS	Geographical Information Systems
GP	Grassland Patches
GPS	Global Positioning System
IRS	Indian Remote Sensing
LS	Loam Soil
LSD	Least Significant Differences
ML	Maximum-Likelihood
MODIS	Moderate Resolution Imaging Spectroradiometer
MoLHUD	Ministry of Lands, Housing and Urban Development
MUBFS	Makerere University Biological Field Station
MUIENR	Makerere University Institute of Environment and Natural Resources
NBS	National Biomass Study
NDF	Neutral Detergent Fibre
NDVI	Normalized Difference Vegetation Indices
NEMA	National Environment Management Authority
NFA	National Forestry Organization
NOAA	National Oceanic and Atmospheric Administration
OM	Organic Matter
OMD	Organic Matter Digestibility
PPT	Precipitation
PUE	Precipitation use Efficiency

RC	Rangeland Condition
RS	Remote Sensing
SIC	Satellite Imaging Corporation
SL	Sandy Loam
SPOT	Système Pour l'Observation de la Terre
SRTM	Shuttle Radar Topographic Mission
TIDA	Together in Development Association
UNEP	United Nations Environment Programme
USA	United States of America
USGS	United States Geological Surveys
UTM	Universal Transverse Mercator
UWA	Uganda Wildlife Authority
WP	Woodland Patches
m	Meters
cm	Centimetres
mm	Millimetres

SUMMARY

Rangeland forage quantity and quality are subject to spatial and temporal variability mainly due to the inherent variations in rainfall and landscape characteristics. Consequently, regular forage condition assessment and monitoring to provide reliable information for grazing management are vital. Studies on herbage assessment and monitoring have mainly focused on quadrat based harvesting approaches which are limited to small areas and often based on a few samples. Remote Sensing (RS) and Geographic Information Systems (GIS) have been proved to be very useful technologies for rangeland forage monitoring. This study was designed to contribute to the development of an integrated spatial and temporal grazing management information system for assessing, monitoring and predicting rangeland forage quantity and quality by taking advantage of RS and GIS. In particular, the study investigated the spatial and seasonal patterns of herbage quantity and quality in relation to grazing, vegetation cover and soil type by integrating both RS and field data using GIS.

Two approaches were used to assess, monitor and predict herbage quantity and quality: Proxy and direct harvest methods. Proxy methods of assessing quantity included extraction of vegetation physiognomic cover classification from satellite images and measurement of herbage cover and height in different vegetation types, which served as a basis for predicting herbage mass. Analysis of species composition was used as an indirect way of assessing quality in different vegetation strata. The direct methods included clipping, drying at 60^{o}C, weighing and analysis of neutral detergent fibre, digestibility and crude protein content of herbage from 1x1m sample plots using standard methods. The effect of season, vegetation cover types, grazing, soil types and their interactions on herbage mass, nutritive value, species cover and height were analysed using Analysis of Variance (ANOVA).

Herbage species cover significantly differed ($p<0.05$) across seasons with the highest herbage cover (77%) occurring during March-May wet season and the lowest (27%) during September-November wet season. Herbage species height ranged from 11 to 15 and 16 to 23 cm during the dry and rainy seasons respectively. Vegetation cover, soil type and grazing explained 85% of herbage dry matter yield, 77% of crude protein, 67% organic matter digestibility, and 64% neutral detergent fibre variations. Spatial variation of herbage was mainly influenced by grazing and vegetation cover. Ungrazed sites were 42% lower than grazed sites. Herbage yield on grassland patches was 21% higher than the yield from woodland. Results of vegetation classification from both Landsat and IKONOS images showed that grassland patches were classified more accurately compared to woodland patches. Grouping detailed vegetation classes to a definition level that creates a favourable relationship between sensor resolution and vegetation patchiness increased herbage mapping accuracy for both classifier and imagery type. This study demonstrated that herbage cover is an important proxy measurement of spatial and seasonal patterns of herbage mass. Results showed that vegetation cover type and grazing were the key factors in determining herbage species composition and quality.

Use of fuzzy classifiers improved mapping accuracy in comparison to maximum likelihood classifiers. In the quest to further improve rangeland herbage mapping, there is need to investigate other classifiers. . It has been demonstrated that herbage quantity and quality can in reality be monitored based on cover and species composition measurements to avoid or at least minimise the cost, destruction and information timeliness implications that are known to be associated with harvesting methods. Results from this study also showed that grazing and vegetation cover management are essential for rangeland productivity and biodiversity conservation. The substantial changes in temporal patterns of herbage composition resonate the need for regular monitoring and provision of information for sustainable rangeland ecosystem management.

CHAPTER ONE

1.0 General Introduction

1.1 Background

Wildlife and livestock in sub-Saharan Africa rangelands like elsewhere in the world are continuously confronted with forage quantity and quality deficiencies, particularly during dry seasons and droughts (Li et al., 2009; Putfarken et al., 2008). The conditions in these rangelands are primarily arid and semi-arid where other land uses, such as crop agriculture, may not be economically feasible (Herlocker, 1999). The indigenous vegetation is predominantly grass, grass-like plants, forbs or shrubs that are grazed or have potential to be grazed, and which is used as a natural ecosystem for the production of grazing herds of wild or domestic ungulates (Allen et al., 2011). In East Africa, rangelands are mainly characterised by natural or semi-natural vegetation (Pratt and Gwynne, 1977). Primarily, the spatial and temporal patterns of forage quantity and quality are directly influenced by rainfall, biophysical factors (Turner et al., 2005) and indirectly by human population related pressure (Gordon, 2009). The key biophysical factors are soil types, topographic conditions and vegetation cover types (de Ridder and Breman, 1993; Hodgson, 1990).

The peculiarly erratic and poorly distributed rainfall in rangelands causes annual and inter-annual variations in pastureland productivity (Ellis, 1995). Some of the variations are associated with droughts in which large stocks of animals die due to highly reduced forage as well as surface and ground water levels (de Ridder and Breman, 1993; NEMA, 2002). Such variations and their effects however, are dynamic with remarkable disparities in spatial and temporal patterns due to differences in biophysical characteristics (Kassahun and Afsaw, 2008). Forage shortages during droughts, usually cause herdsmen and their animals to move long distances in search for forage and water whose locations are usually not predetermined and predicted. Large wild herbivores also usually follow the same movement patterns into privately owned land. During these movements quite a number of them are killed by poachers. Other deaths occur due to conflicts resulting from crop raiding or competition with livestock for forage and water. This trend of movements changes with seasons and creates a divide of wet and dry season grazing concentration sites (Olupot et al., 2010). As a consequence, animal numbers and rangeland productivity tend to become uncoupled in some grazing lands especially during droughts. This carries the risk of ecological change and reduced forage quantity and quality for both domestic and wild animal production (Cowling, 2000).

On the other hand, biophysical characteristics influence both run-off coefficient and storage capacity, which in turn determine the amount of water stored in the soil and hence available for forage production (de Leeuw and Tothill, 1993). Forage composition is therefore a consequence of variations in topographic characteristics and their interactions with amount of rainfall and distribution (Bernués et al., 2005). For example, loss of a few centimetres of topsoil through sheet or wind erosion can greatly reduce soil fertility and its ability to store water, thereby reducing water availability for plant growth resulting into poor quantity and quality of forage. Such changes ultimately lower pastureland productivity (Herlocker, 1995).

Due to increasing spread of cultivation and settlements, wildlife and livestock are continuously being squeezed into increasingly smaller areas. As a result, competition among people, livestock and wildlife for forage and water which are the primary resources in rangelands is also increasing (UNEP, 2006). Wildlife is being extirpated as a consequence of habitat change or direct persecution. This is in turn restricts wildlife populations into smaller habitats and eventually may even mean that the only refuge for wildlife will be national parks (Gordon, 2009). Among the outcomes of such a pattern of processes and events are overgrazed rangeland sites, reduced herbage production, loss of herbage species that are vulnerable to grazing and general rangeland degradation (McNeely et al., 1995). This calls for efforts to conserve the remnant rangelands as a means of maintaining biodiversity. Conservation requires availability of information to promote knowledge and skills for rangeland management (Mohammed and Bekele, 2009).

Sustainable development and equitable rangeland resources management is not only important for improved human wellbeing, but equally for maintaining biodiversity (UNEP, 2006), although balancing these two aspects is still a big challenge world over. There is need for optimizing rangeland production to support livelihoods and biodiversity conservation. While doing this, emphasis should be on integrating agricultural production and biodiversity conservation interests for the sustainable utilization of rangelands (Mohammed and Bekele, 2009). Rangeland ecosystem sustainability requires monitoring and prediction information for understanding spatial and temporal variations of rangeland resources. With such information, the likely responses to these variations such as opportunistic exploitation of forage by animals can easily be explored. Prediction and monitoring of forage are important for sound management of rangeland ecosystems. This in turn allows for sustained development and thorough understanding of the patterns of herbivore requirements in relation to ecosystem dynamics (de Ridder and Breman, 1993).

It is apparent that, for each herbivore species or group of species on a given pastureland, there must be optimal stocking rate to enable it obtain maximum intake of nutrients for minimum expenditure of energy (Woolley et al., 2009). In determining and monitoring the optimum forage requirements, considerations must be taken of the spacing of the preferred forage components, their weight per unit area and their degree of interspersion with other components in the same landscape (Pratt and Gwynne, 1977). Hence, providing information and tools for predicting and describing spatial and temporal patterns of forage is a prerequisite for the management of its interactions with grazers. Studies of pastoral systems reveal that spatial and temporal variation in forage quantity and quality is of crucial importance in regulating grazers (Ellis, 1995).

Whereas the spatial and temporal dynamic nature of rangeland ecosystems dictates the need for reliable spatial and temporal information for effective management, there are still many challenges especially methodological and information quality ones, to realising this need. Martin et al. (2005) highlight the challenges of identifying tools that would be reliable in a variety of field conditions and the difficulty of finding an accurate, consistent method of monitoring and predicting herbage patterns. These challenges include differences in sampling dates that affect accuracy, differences in instrument calibrations for different harvest occasions, inconsistencies in results, and rigorous and expensive data collection procedures. Remote Sensing and Geographic Information Systems have become vital monitoring tools (Olsvig-Whittaker et al., 1992) since they address some of the above challenges. Their application in rangeland vegetation resource monitoring is now well recognised (Beeri et al., 2007; Li Jianlong, 1998; Liang and Chen, 1999; Moreau, 2003)

Tools for monitoring herbage should reveal and integrate the influence of various biophysical factors that determine its quantity and quality at a given site and time. The suitability of RS and GIS for herbage monitoring essentially arises from their ability to offer such integrating possibility (Turner, 2003). Experience in using in remotely sensed imagery has shown that there are positive relationships between forage cover and spectral signatures (Curran, 1983; Price et al., 2002). Furthermore, Remote sensing allows for a quick, cost effective and systematic way of obtaining accurate, uniform, consistent and up-to-date information about natural resources (Beeri et al., 2007; Moreau, 2003), hence providing a good potential for improving the existing monitoring techniques in Uganda.

Remote sensing data does not only offer a possibility of extrapolating forage measurements to larger areas, but also help to overcome accessibility and financial constraints (Kassahun and Afsaw, 2008). Traditionally, quantifying rangeland herbage has been done using quadrat sampling and harvesting method. In this method, a quadrat is defined as a square plot (Brower et al., 1997). Use of quadrats to characterise herbage at a given time involves clipping the above-ground herbage tissue in a specified unit size of the quadrat, drying them and weighing the dried material for quantity and quality evaluation. The results are expressed in g/unit area (Kent and Coker, 1994). Quadrat sampling and harvesting method of herbage mass and quality assessment is limited to small areas controlled by a few samples and infrequent measurements, is time consuming and costly (Li Jianlong, 1998; Martin et al., 2005). Timely information for resource management requires fast data acquisition and processing approaches and this requirement has put the previous approaches in Uganda at a disadvantage compared to RS and GIS. In addition, use of RS addresses the problems associated with spatial and temporal bias as well as the generalizations that are usually associated with environmental monitoring (Turner, 2003).

There have been attempts to assess and quantify forage dynamics using Remote Sensing at continental and regional scales (Moreau, 2003 & Reeves, et al., 2006). The first attempt in Uganda is linked to the National Biomass Study (NBS 1992) which used remote sensing to estimate woody biomass in some selected districts. However, the assessment information is lacking in terms of cartographic scale. Therefore there is need to develop more accurate guidelines based on localized and detailed estimations upon which reliable management decisions can be made. Another limitation of the study is that it does not reflect the relationship of woody biomass with other vegetation cover types (NBS, 1992). In another attempt, Moreau et al. (2003) investigated the possibility of assessing the biomass dynamics of high-protein wetland herbage using National Oceanic and Atmospheric Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR) derived indices. However, the information obtained using such low resolution imagery can be misleading when used for localised decision making processes. It is for this reason that the study, recommended use of narrow and optimum spectral bands for studying vegetation for better results.

1.2 Problem Analysis and Statement

Rangelands in Uganda are characterised by seasonal fluctuations in the amount and distribution of rainfall and thus it is not easy to predict the conditions of a given rangeland over a long period of time. Periodic assessments, monitoring and prediction are therefore necessary to ensure that management strategies are in line with the characteristic rangeland spatial and seasonal dynamics. Developing strategies for rangeland management is made even more complex with the current and potential effects of climate change and variability. Hence, monitoring and prediction of herbage mass and quality, especially during dry seasons when there is limited water and herbage is essential for rangeland sustainable utilisation. To some limited extent, knowledge on rangeland ecology especially from autoecological studies exists in tropical countries like Uganda, but there is very limited focus on spatial and temporal patterns from a synecological perspective.

On the other hand, spatial and temporal rangeland information obtained using well advanced techniques of monitoring exist in other regions such as Northern America. However, the variations in biophysical factors (and their interactions) that exist between these regions and tropical regions make it inappropriate to directly apply these techniques in tropical rangeland ecosystems. Some of the variations exist in land cover types, seasonal amount, distribution and type of rainfall as well as forage species composition. In Africa, there have been attempts to respond to drought triggered crises by developing finer early warning systems. Nevertheless, information from such warning systems falls short of the ability to predict micro level variations in the impacts of seasonal changes in rainfall amount and distribution because of their generalised nature. The need for ecosystem and site level monitoring and prediction information has been left to be provided by entirely using rudimentary and destructive techniques such as the quadrat sampling and harvesting method. These techniques have been proven to be difficult to repeat for reliable monitoring results and decision making. Failure to provide reliable and objective information through improving spatial and temporal accuracies in existing information systems in the management of rangelands is likely to hamper efforts towards improving livestock dependent livelihood and enhancing biodiversity conservation in rangeland ecosystems.

1.3 Contribution of the Study

In view of the aforementioned gaps in spatial and temporal rangeland forage assessment and monitoring techniques, it can be urged that further research in the understanding of rangeland herbage dynamics is of paramount importance in the area of rangeland ecology and management. For that reason, this study was centred on understanding the dynamic nature of herbage by taking advantages of GIS and RS capabilities in providing monitoring information. In this thesis, the cause-and-effect of rainfall seasons and landscape characteristics on rangeland herbage productivity in Uganda are investigated and documented. Specifically, the contributions of this study include:

a) Quantifying and understanding of the spatial and seasonal patterns of rangeland herbage quantity and quality in south western Uganda
b) Updating a species composition and diversity list for rangelands of Uganda
c) A model for Estimating, monitoring and predicting rangeland herbage mass by utilising remote sensing data. This had not been previously attempted on Ugandan rangelands
d) Widening the scope of rangeland forage assessment, monitoring and prediction comparisons; and
e) Documenting methodological issues regarding herbage productivity assessment and monitoring in Uganda.

1.4 Conceptual Framework

In this study, soil texture, vegetation cover type, grazing and rainfall seasons are considered as independent variables while the dependent variables considered are herbage mass for herbage quantity, organic matter digestibility, crude protein and neutral detergent fibre for herbage quality. The relationship among these variables is influenced by factors like topographic conditions, fires, land use history, among others. Rainfall amounts and distribution interact differently with the various biophysical characteristics resulting in spatial and temporal variations in rangeland productivity. These variations deem it necessary to periodically quantify and monitor the relationships among these variables so as to ensure appropriate decision making regarding grazing management. Lack of efficient and reliable monitoring tools and information leads to spatial and temporal inaccuracies in decision making and hence uncertainty. For example, use of the standard quadrat method is limited by its failure to perform accurate point based repetitions. It is also very expensive for large area coverage. Together, these limitations lead to increased incidences of inaccurate information and consequently inaccurate decision making. Improving spatial and temporal information accuracy by using fast and efficient methods will lead to reliable decision making processes, in rangeland management. Such processes are most likely to lead to improved animal production and biodiversity conservation, hence healthy rangeland ecosystems. The conceptual model for the framework of this study is graphically shown in Figure 1.1.

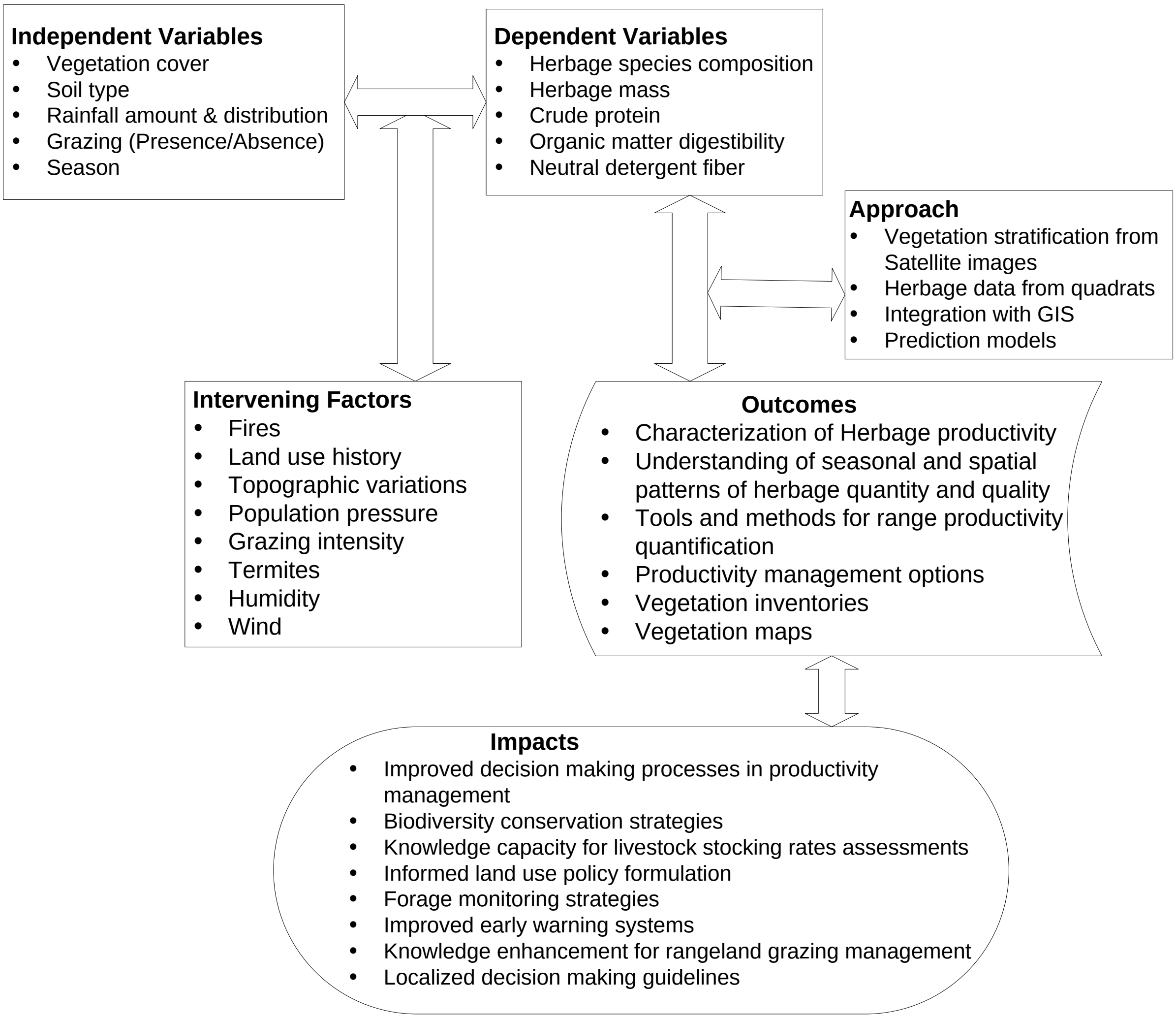


Figure 1.1: Conceptual model for the study

The conceptualization reflected in Figure 1.1 is that measurements and monitoring of spatial and temporal variations in the herbage variables, resulting from differences in rainfall and biophysical characteristics can be enhanced using RS and GIS capabilities. The viewpoint in this study is that RS based rangeland herbage monitoring and prediction can improve the effectiveness of planning and decision making for grazing management. Use of remote sensing allows for site specific, easy to repeat observations and measurements, cheaper data collection process, coverage of a wide range of scales and area coupled with high temporal resolution. Exploiting these advantages over other previously used quadrat sampling based methods is expected to generate more reliable spatial and seasonal information on herbage quantity and quality variations in space and time. This in turn will lead to reliably informed decision making processes and consequently predictable impacts of decisions made in grazing management.

1.5 Justification

Quantification and understanding of the dynamic patterns of rangeland forage is important for determining the numbers of animals that can be sustained on a given rangeland management unit. It is also a basis for prediction of seasons of abundance and deficiency, so that utilization strategies and mitigation measures can be designed to fit in the right place and time. Adoption of remote sensing based approaches developed in this study will allow for the acquisition of information for large areas using and re-using the same or similar sensors and hence presenting an easier and cheaper way of observing and monitoring spatial and temporal change patterns in herbage.

This study also provides a basis for developing a knowledge-based or scientifically sound decision support system that livestock owners, extension workers, wildlife managers and others, can effectively and efficiently use for sustainable utilization of rangeland resources. One of the outputs of the study is a series of step-by-step guidelines which can be translated into a manual for estimating, monitoring and prediction of seasonal and spatial variations in rangeland herbage. With the information on seasonal and spatial variations of herbage mass and quality, livestock and wildlife management options can be derived for including, but not limited to; keeping animal populations that are proportional to a given pastureland capacity and potential during a given season.

This study supports and is in line with the National Land Use Policy (MoLHUD, 2007) for Uganda (MoLHUD, 2007) which highlights the need to:

a) make available on regular basis, land use/cover data which are of sufficient detail and efficiently disaggregated;

b) make available a land resource inventory and any other necessary information on which appropriate decisions can be made on land use for agriculture;
c) make available an updated resource inventory and present the data in form of a map, with map units that are as disaggregated as possible to be used for detailed land use planning purposes;
d) avail information for grazing management to reduce soil erosion hazard and enhance soil productivity;
e) provide information for supporting management of marginal lands and fragile ecosystems like rangelands; and
f) support knowledge improvement for promoting practices and strategies that minimize the impact of climate variability and change.

1.5 Objectives of the study

1.5.1 General Objective

To contribute to the development of an integrated spatial and temporal grazing management information system for Characterising, assessing, monitoring and predicting rangeland forage quantity and quality.

1.5.2 Specific Objectives

The specific objectives were to:

I. Characterise vegetation composition and establish the feasible mapping levels of physiognomic vegetation cover types
II. Assess the spatial and seasonal variations in herbage species composition, biomass yield and nutritive value.
III. Test GIS and RS technologies as tools for estimating and predicting spatial and seasonal herbage mass in relation to herbage cover, rainfall and soil physical properties

1.5.3 Research Questions

The research questions addressed for each specific objective were:

Objective I

i. What is the current vegetation physiognomic and species composition for rangelands in Uganda?
ii. To what extent can the rangeland vegetation physiognomic classification as documented by Pratt and Gwynne (1977) be effectively discriminated using Landsat and IKONOS satellite images?
iii. To what extent does Landsat imagery compare with IKONOS for spectral discrimination of rangeland vegetation physiognomic classes?
iv. How does fuzzy classifier compare to Maximum Likelihood for rangeland vegetation physiognomic classification?

Objective II

i. Do changes in season and vegetation physiognomic vegetation cover types significantly affect herbage species composition?
ii. What are the spatial and seasonal patterns of herbage in south western Uganda?
iii. How are the seasonal patterns of herbage mass and nutritive value affected by vegetation cover, soil type and grazing?

Objective III

i. Are herbage quantity measurements from quadrat harvesting method significantly different from predictions based on herbage cover visual estimations?

CHAPTER TWO

2. Literature and Theory

2.1 Introduction

This chapter presents some key aspects on rangeland vegetation patterns; factors for rangeland plant growth; effect of grazing on vegetation communities; rangeland plant-animal interactions; sustainable grazing; vegetation, soil and climate interactions; vegetation temporal patterns; rangeland resource assessment and monitoring; forage species patterns and composition; and use of geo-information. The context of the rangeland used here is land carrying natural or semi-natural vegetation which provides a habitat suitable for herds of wild or domestic ungulates (Pratt and Gwynne, 1977). Grazing is the key land-use of focus with specific attention to herbage as the major feed resource for livestock and wild animals.

2.2 Rangeland Vegetation Patterns

In order to devise management programs in a rangeland, there is need to understand factors underlying changes in vegetation through time, in terms of structure and composition. The relative extents of woody and herbaceous cover are determined by complex interactions of fire, grazing, browsing, among other factors when the effect of climate is kept constant (Mueller-Dombos and Ellenberg, 1974). For example, fire in combination with elephants can be devastating to woody vegetation. Nonetheless, grazing and browsing regimes, and human activities can change the frequency and intensity of fires and the ability of woody vegetation in particular to withstand it (Olupot et al., 2010). Despite the dynamic nature of the vegetation cover patterns in rangelands due to the aforementioned factors, no or limited work has been done to establish how such changes affect forage quality and quantity at large cartographic scales (Trodd and Dougill, 1998).

Vegetation in rangeland landscapes continuously change and reflect site-specific dynamics. A better understanding of these dynamics is a pre-requisite for their sustainable utilisation (Bloesch, 2002). Rangeland ecologists have been debating the validity of two current paradigms (the continuous and reversible vegetation dynamics; and the discontinuous and non-reversible vegetation change) for the assessment of vegetation dynamics on rangelands. Equilibrium and non-equilibrium ecosystems are not distinguishable on the basis of unique processes or functions, but rather by the evaluation of system dynamics at various temporal and spatial scales. Although both equilibrium and non-equilibrium dynamics occur in numerous ecosystems, the empirical evidence is frequently confounded by (i) uncertainty regarding the appropriate evidence necessary to distinguish between paradigms; (ii) disproportionate responses among vegetation attributes to climate and grazing; (iii) comparisons among systems with varying degrees of managerial involvement; and (iv) the evaluation of vegetation dynamics at various spatial and temporal scales (Briske et al., 2003).

Changes in vegetation from one area to another or even from one place to another are either as a result of inherent differences like soil variations, or disturbances of some nature (Bothma, 1996; Brower et al., 1997; Dale, 2000; Herlocker, 1999). Disturbed areas are inclined to return to a state of equilibrium with the prevailing environmental factors. This may lead to successive types of vegetation, where each type is characteristic of a specific phase of recovery or deterioration (Brower et al., 1997). Fluctuations are essential and integral part of a rangeland ecosystem without which the ecosystem could not remain viable. Stability is the tendency to resist change, while resilience is the measure of systems ability to recover after disturbance. Stable systems often have a low resilience while unstable ones are usually relatively resilient. With an increase in stability, ecosystems lose their resilience. However, resilience has a definite lower limit of recovery. If the ecosystem is forced to exceed this lower limit, then a new and usually irreversible balance is reached which is of lower productivity than before (Bothma, 1996). Therefore rangeland management should always aim at increasing resilience of the ecosystem by means of healthy forage management which periodically allows various levels of grazing pressure without causing irreparable damage to the ecosystem. With information on spatial seasonal patterns it is envisaged that from this study, knowledge for enhancing ecological processes through which vegetation changes take place for purposes of proper use of grazing resources (Bernués et al., 2005) will be realised.

Rangelands world over are associated with seasonal variations in forage production and species composition as well as limitations of water or nutrients which vary from place to place (de Ridder and Breman, 1993; Fujita et al., 2009). Forage production potentials vary according to climate, soil and other conditions. The trends in such rangeland condition are always assessed almost accurately from a series of inspections which should consider agents of spatial and temporal dynamics related to human activities and/or natural phenomena like climatic changes (Hodgson, 1990; Pratt and Gwynne, 1977). The kinds and amounts of plants associated with rangelands are influenced greatly by the forms, amounts, and seasonal variations of precipitation (de Ridder and Breman, 1993; Herlocker, 1995; Tueller, 1993). Strictly speaking, rangeland vegetation should be considered to be part of the climate system on all time scales (Zeng and Neelin, 2000). Precise understanding of the patterns of climatic influence on forage patterns is however limited by lack of reliable data that is common in African countries. Lack of accurate information on seasonal changes in rainfall ultimately leads to limited understanding of forage characteristics such as species composition and consequently spatial and seasonal differences in quality and quality (Bernués et al., 2005).

The microclimate of any particular locality is basically a fixed resource which depends on geographic location, although it is still generally beyond human capacity to manipulate. Knowledge of the microclimate immediately surrounding a plant is important for the understanding of its behaviour (Skerman et al., 1988). Soil moisture is the major limiting factor for livestock production in rangelands. Attempts including new technologies such as cloud seeding have so far failed to improve the quantity and predictability of precipitation. Actual water use and loss varies depending on factors such as the seasonal pattern of annual rainfall, individual storm intensity and duration, type and condition of the rangeland site. During rainfall, water may enter the soil surface (infiltration) and move through the soil profile (percolation) or run off the soil surface to be lost from that specific site. Most livestock owners desire to minimize rainfall runoff in order to maximize rainfall effectiveness for plant growth and hence livestock production (McGinty et al., 1991). Such desires are in most cases limited by lack of reliable information to support the decision processes involved.

Management cannot be used to improve the amount or predictability of rainfall received at a given location. However, management can improve rainfall effectiveness by increasing rainfall infiltration rates, reducing evaporation from the soil and plant surface, controlling soil erosion, reducing noxious/toxic plant densities and improving forage harvest efficiencies (McGinty et al., 1991). Annual rainfall on rangelands is both variable in amount and erratic in occurrence, so annual totals must be used with care in interpreting the probable forage growth response. Knowledge of annual amount and seasonal dominance is, however, a useful guide to understanding rangeland productivity (de Ridder and Breman, 1993; Skerman et al., 1988). In rangelands, rainfall often limits forage availability due to its high variability and, hence, herbivore populations (Behnke and Scoones, 1993).

Non local terrain attributes that determine the transfer of water show a less pronounced influence on the ground grass cover spatial distribution than local terrain attributes (slope angle, elevation, or slope aspect). This can be explained by the scarce runoff characterizing such areas, where runoff is discontinuous and strongly non-uniform. Runoff flow concentration may be a source of extra-water and increase erosion risk, especially in highly erodible landscapes. To understand the heterogeneous spatial distribution of forage, the influence of topography on ground herbage cover patterns must be analyzed, because topography constitutes a main control in most landscapes. Given the importance of the spatial distribution of ground herbaceous vegetation cover on the water balance in these systems, the capacity to predict the ground cover from terrain attributes based on the topographical control of the latter over the former, will provide prime information for the management of rangelands (Canton et al., 2003).

In their study, Santos et al (2003) found out that slope of a given site affects the overall soil infiltration, runoff and sediment loss and hence forage production at a given location. Studies also reveal that grazing intensity is key in determining seasonal and spatial variations in forage production.

According to Bousquet et al. (1999) the management of rangeland vegetation patterns is a collective learning problem. They point out that models may be used to focus discussions on cause and effect connections between behavioural and interaction rules and rangeland dynamics. The goal of models according to them is to assist and inform adaptive management and policy decision-making in complex systems, rather than to prescribe and direct a supposedly optimal solution.

2.2.1 Factors for Rangeland Forage Growth

The individual plant is the foundation of a rangeland ecosystem. Animals in a rangeland are a product of plant growth. Whereas several habitat factors control plant growth, it is worth noting that growth results directly from food or energy supply (Kent and Coker, 1992). Reduction of leaf surface by grazing also reduces the growth and productivity of the plant (Olupot et al., 2010). Therefore, the objectives of rangeland management should be able to ensure near optimum plant growth conditions for livestock and wildlife production. Good rangeland management plans should be built on individual plant as a unit. As a plant thrives, so does the rangeland. Disuse is not normal for vegetation. Vegetation has always provided for animal life of all kinds. Nevertheless, abnormal use has in many cases resulted in widespread destruction. Unwise grazing has for many occasions accounted for much of vegetation loss (Xie et al., 2007). However, normal use will not cause it to undue injury. It is important, then, to know how grazing influences the functions of the plant and just how they may be disturbed without permanent injury (Pratt and Gwynne, 1977). Plants are living organisms growing, breathing, digesting, and dying. If too many demands are made upon them, premature death occurs. They require definite conditions for proper development (Stoddart and Smith, 1955). Any grazing use which prevents such development constitutes misuse of the rangeland in question and may lead to decline in forage production (Han et al., 2008).

Rangeland plants especially in East Africa are subject to three important controlling factors of drought, fire and defoliation. Various physiological and anatomical adaptations have been developed to enable plants to survive these influences (Herlocker, 1999). Drought effect is mainly evidenced in annuals which complete their whole life cycle during a brief period of water supply and pass the dry periods of the year in seed form (Osborne, 2000). To some extent, plants can also evade drought by a combination of small size, slow growth and wide spacing, which reduce water demand relative to supply. Perennials on the other hand, incorporate more positive features which enable them to overcome periods of drought, either by conserving water or withstanding desiccation (Boelman et al., 2005). However, under extreme stress, even perennials that are adapted to drought are usually forced to take evasive action, either by dropping their leaves and becoming more or less quiescent or by adopting an annual habit (Pratt and Gwynne, 1977). Therefore, there is need for monitoring such seasonal and annual patterns for purposes of establishing their effects on herbage mass and quality.

Herbaceous and woody plants co-exist in a delicate state of balance controlled by competition for water, minerals and other essentials of life (Mueller-Dombos and Ellenberg, 1974; Pihlgren and Lennartsson, 2008). Any change which encourages herbaceous vigour discourages the spread of woody plants. On the other hand, anything that weakens herbaceous vegetation speeds the invasion by shrubs and trees. The two factors which most closely determine the direction in which the balance swings are fire and grazing. The reaction of a plant to fire depends on the intensity of the fire and the condition of plant (Archibald, 2008; Kassahun and Afsaw, 2008). Fire intensity is the reflection of the nature and quantity of combustible material, weather conditions and the way in which the fire spreads. Plant condition depends on external morphology, surface anatomy, age and vigour. Most plants can tolerate one fire or infrequent burning but vary their response to repeated burning, depending on the number, character and frequency of fires (Pratt and Gwynne, 1977).

Grazing is especially detrimental when excessively wet soil results in trampling damage (Bernués et al., 2005); in seasons when root reserves are low or when plants are not able to replace leafage because of dry conditions (Lin et al., 2010); and when continued at frequency or intensity which does not allow adequate photosynthetic tissue to remain on plant (Herlocker, 1999). However, the effect of these factors upon forage may differ greatly with different species. A plant grows at a rapid rate when appropriate temperature and abundant soil moisture permit. Such growth is usually initiated by use of stored food reserves in the plant, generally in the root. Heavy food demand is made upon the newly manufactured food reserves as fruits and seeds are being formed. These grow rapidly and they are concentrated storage organs; hence their growth requires large food supplies. Following this period of active growth and seed production, there is a period during which the plant stores reserve food. This storage may occur after the forage may seemingly become inactive. The reserve food in the perennial plant provides it with material which will initiate growth the following growing season. Therefore, knowledge of minimum food storage seasons is important, for, when feed supply is low, forage plants are most subject to damage by grazing, hence affecting its quality and quantity.

More important than the total forage yield is the actual digestible nutrient yield from the rangeland (Pratt and Gwynne, 1977). Grazing intensity is one of the major factors that cause differences in chemical composition and digestibility of forage (Turner et al., 2005). Frequent harvesting may be followed by a regrowth of forage of high protein content and relatively low fibre. Even though herbage yield declines with frequent grazing, the total protein yield may increase because of increased percentage of leaf surface. Regrowth from frequently grazed herbage is more leafy and generally more palatable to animals because it is more tender, high in moisture content, and contains less yellowed and dried material (Olupot et al., 2010). Therefore, moderate to heavy grazing during the growing season is desirable to the limit of the capacity of the plants. Nevertheless, it does not mean that heavy rangeland use necessarily improves forage quality. In most cases, the higher the grazing intensity on a rangeland, the poorer the quality of forage they receive, unless conditions are favourable for rapid regrowth (Stoddart and Smith, 1955).

Any grazing, whether moderate or heavy or whether early or late, has a measurable influence upon the metabolism of a plant (Pratt and Gwynne, 1977). Reduction in photosynthetic tissue is followed by reduction in carbohydrates and nitrogen reserves and decreased rate of root and forage production. Provided that grazing is neither too frequent nor too close, it is quite possible that the total forage value may not decrease greatly. Though lesser volume is produced, it is sometimes better quality because grazing may stimulate leafy regrowth (Olupot et al., 2010). Vital to the rangeland forage also is the influence of grazing upon the volume and depth of the root system. A reduction of food reserves slows the growth of the whole plant including the roots. This is the most crucial effects of overgrazing. Water must be drawn to the root from the soil through a complicated and slow process of absorption and osmosis. Where transpiration is rapid, wilting may occur, even with a relative abundance of soil moisture because of the slow movement. It thus requires a widespread plant root system to obtain sufficient water to maintain turgidity of plant cells during periods of stress. When surface soil becomes dry, absorption in the upper soil layers becomes very difficult or impossible. No amount of surface roots will enable the plant to live in these dry soils. Deep soil layers are usually moist and if the plant can tap this source of water, its chance of survival is higher. Plants that have been heavily grazed are injured more easily by drought partly because of their inability to reach deep moisture (Han et al., 2008).

Grazing animals have an influence upon the soil, tending to compact it sometimes to surprising depths during wet seasons. Compact soils are not only poor absorbers of precipitation, but also prohibit normal root development (Facelli and Springbett, 2009). Compaction is greater near the surface and is of considerable influence in hardening the soil (Lin et al., 2010), hence making it unfit for seedlings establishment. On the other hand, when the soil is not wet, animals are believed to be beneficial in loosening the soil surface and covering seeds that have accumulated on the surface. The mechanical action of animals in loosening seed, carrying seeds in their hair, distribution of hard-coated seeds through the faeces, and in loosening bulbs, corms, and bits of rhizomes, among others also plays a big role in rangeland vegetation growth and composition. There are incidences in which total protection of rangeland from animals has failed to result in the expected revival of vegetation, most apparently because of animal action in aiding reproduction. In dry rangeland sites, it is quite possible that grazing induces better moisture relations through reduction of forage cover and hence reducing the transpiring surface which may enable plants to withstand more drought (Stoddart and Smith, 1955). The influence of grazing animals in adding fertilizer to the soil is probably not of material value since the animal removes rather than adds fertility. But of course, digestion of organic materials makes the materials immediately more available to plants.

2.2.2 Effect of Grazing on Vegetation Community Patterns

The underlying factors for grazing patterns and consequently its effect on pastureland productivity include rainfall seasons, location of watering points, availability of forage and their palatability and slope (Pickup, 1994). Whereas studies concur on most of the several factors that determine animal grazing patterns, their relationships are not easily understood mainly because their interactions do vary from place to place (Tate et al., 2003; Turner, 2003). Crist et al. (1992) established that inter-site comparisons involving taxonomically similar vegetation structure systems suggest that the mosaic context of patches at various spatial scales can be important determinants of animal grazing patterns in heterogeneous landscapes. Depending on prevailing grazing conditions, some grazing sites may frequently be preferred by animals leading to overgrazing at times. Overgrazing results in variation in organic matter (Han et al., 2008) and contributes to nutrient depletion and redistribution. Grazing effect can decrease organic matter that could function as the major stock for many primary nutrients such as nitrogen and phosphorus and consequently affect forage quantity and species composition (Bernués et al., 2005; Mligo, 2009). Several other factors determine how grazing intensity and distribution influence forage biomass productivity (Cid et al., 2008; Lin et al., 2010). These include water availability (Skarpe et al., 2004), land tenure, cropping patterns, availability of forage, authority to enforce movement restrictions, herd size and production goals of livestock owners among other factors (Baker and Hoffman, 2006).

A great number of actions may disturb the climax plant cover and bring about retrogression which leads away from the climax community (Brower et al., 1997; Xie et al., 2007). By far the most important of the factors that bring about retrogression is improper grazing (Fujita et al., 2009; Herlocker, 1999). Retrogression of plant cover under grazing does not follow in the reverse order to the succession that gave rise to it because retrogression is usually of vegetation not of soil. Since the climax of soil is less easily damaged, it is more permanent than the vegetation and its retrogression lags behind. The stages of grazing retrogression in vegetation are not determined by climate or soil, but by the introduced biotic factor and, livestock (Fujita et al., 2009; Lanta et al., 2009). Continued weakening of the soil-protecting vegetation by grazing may result in soil deterioration as well (Facelli and Springbett, 2009;

Olupot et al., 2010). Water or wind may move away the developed surface soil to the point that the exposed subsoil is not able to continue supporting climax plants. Development of a new soil mantle may take very many years especially in dry areas where soil formation is a slow process. Soil retrogression caused by erosion and trampling may progress so far that vegetation may be held in a sub-climax stage even after grazing has ceased entirely (Brower et al., 1997).

Retrogression of vegetation under grazing may follow a multitude of courses depending on vegetation and type of grazing (Facelli and Springbett, 2009). Grazing in some seasons may harm some species and others may benefit because of reduced competition (Olupot et al., 2010). If a short grazing season results in the use of certain species during a critical growth stage, that species may disappear. Another species that is fully palatable may thrive or even increase in numbers because grazing does not occur in its critical growth period. Preference differences among different animals may cause certain forage species to increase, decrease or disappear (Facelli and Springbett, 2009). Too intensive grazing is marked by disappearance of some preferred forage species or of those physiologically less resistant to grazing (Herlocker, 1999). Retrogression therefore involves plant competition. The removal of climax plants by abuse beyond their endurance leaves space for other plants. Less preferred or more resistant plants may survive and replace the removed plants. These plant species are sometimes referred to as increasers, because they increase under heavy grazing. Continued grazing will cause an influx of often annual invader species which are not a part of the climax (Ao et al., 2008). Based on reports that several rangeland sites in Uganda are overgrazed and degraded due to overstocking and overgrazing, it is envisaged that information on spatial and temporal patterns of herbage in relation to grazing will be important for strategic management, such as the timing and intensity of grazing (Belesky et al., 2007)

Some stages of retrogression following improper grazing are easily recognised and are characteristic of most retrogression. Stoddart and Smith (1955) classify these stages into four categories; physiological disturbance of climax plants, composition changes of climax cover, invasion of new species, disappearance of invasion plants, and decreased density of invaders. The most preferred climax plants under stress of grazing lose vigour as evidenced by reduction in annual growth; and reduction or complete absence of reproduction activity. When physiological disturbance of preferred species continues, it results in their death. Death and disappearance may result from starvation following reduced photosynthesis, competition from other plants less weakened from grazing, natural old age accompanied by lack of reproduction, or drought made more serious by a weakened root system. Composition change on rangeland is usually gradual, marked with decrease in; most preferred species, and species that are physiologically and anatomically most susceptible to grazing damage. This trend of retrogression causes animals to change their diet because of increasing shortage of desirable species, to those less preferred. Succession therefore continues with better climax plants. Continuous trampling of plants and soils by animals especially on steep slopes creep downwards under the force of gravity or runoffs making soils of such areas shallow and fragile, hence reducing their productivity (Facelli and Springbett, 2009).

The grazing animal is part of the plant's environment and the plant is part of the animal's environment. Hence as long as the two live together, the welfare of each other is dependent upon the other. Forage, livestock and wild animals should be looked at as part of a great and intricately related biological complex (Facelli and Springbett, 2009). The parts of this complex called habitat factors can be classified as climatic, edaphic, biotic, and physiographic. Fire is sometimes included as a separate factor (Herlocker, 1999; Stoddart and Smith, 1955). The principle of ecology assumes that any organism must reach a point of equilibrium between related factors, such as its food supply, predators, diseases, and its physical needs, including temperature, moisture, and protecting cover favourable to such life processes as reproduction (Brower et al., 1997). This does not imply a static relationship since nature is dynamic with constant fluctuations. Whenever there is a change through rangeland management of any factor of this complex habitat, change will be expected else where. For example, introduction of livestock in an area also introduces new changes elsewhere in the habitat (Lanta et al., 2009; Xie et al., 2007).

Just as the plant individual grows, matures, and reproduces, so does the plant community. The occurrence of a certain plant in a given place or the grouping of plants usually does not come about by chance. It is the direct result of long series of developments controlled by climate and to some extent by soil. Soil is in turn a product of vegetation. Since soil is so intimately related to vegetation, knowledge of soil as a habitat factor is important for understanding of rangeland management (Herlocker, 1999; Tibor, 2010).

2.2.3 Vegetation, Soil and Rainfall Interactions

Soil is a product of the action of climate and vegetation upon rock material. The effect of rock material on the end product is variable, but since most rock and mineral mixtures contain all essential elements, the general opinion holds that the parent material has no great influence on the mature soil when compared to climate (Lomolino et al., 2006). However, all the mineral elements are obtained from parent material, not from weathering and plant action (Pratt and Gwynne, 1977). The parent material may also influence the texture of soil since the formation of clay is to a large extent dependant upon the nature of the parent material. Soil goes through a series of developments from original rock and ultimately becomes a climax soil which may be defined as soil that is in a state of relative stability or balance with weathering and plant action (Stoddart and Smith, 1955). On a climax soil erosion is at a minimum; horizontal development has progressed as far as possible under existing climatic conditions and downward movement of soluble materials by leaching is in balance with decay (Mueller-Dombos and Ellenberg, 1974). A biological balance is attained among minute plants and animals which inhabit the soil (Tibor, 2010).

However, soil properties like nutrients, and moisture among others at a given rangeland site are dependent upon other factors such as slope (de Leeuw and Tothill, 1993; Majaliwa et al., 2010) and grazing (Lin et al., 2010). Mligo (2009) pointed out that variation in soil organic carbon is influenced by the topography of a rangeland site. In areas with inclinations, hilltops, plateaus, valleys and low plains, the increase of slopes in combination with effects of grazing pressure contribute to decrease in litter deposition, accumulation of organic matter and consequently increase in runoffs and subsequent erosion on bare lands. The influence of soil properties in a given landscape on forage biomass production is associated with fertility; pH and texture (Tiemann et al., 2009; Turner and Congalton, 1998); nitrogen and phosphorus content (Turner, 1998) and soil moisture (Sánchez-Jardón et al., 2010). However, the way these soil related factors affect forage biomass production is greatly influenced by amount and seasonal distribution of rainfall at a given rangeland site (Turner, 1998).

Each phase of soil development is associated with a specific level of vegetation development, though the flora will differ depending on the prevailing climate (Stoddart and Smith, 1955). Undisturbed climax soil will support climax vegetation, both of which are in condition of approximate stability, at balance with climatic elements especially rainfall. Climax vegetation is undisturbed by man or man's activities—it is a natural vegetation which has completed its development to a condition of relative balance. It fluctuates but no longer following the trend toward a fundamentally different condition. As the climate fluctuates, so does the vegetation and to a lesser extent, the soil. In some parts of East Africa, vegetation is more abundant due to heavy precipitation and hence more organic matter in the soil. Weathering is greater under heavy precipitation. Leaching and organic matter accumulations are the major forces in soil formation. Leaching of the soil removes soluble salts and colloids from the surface layers and carries them to deeper layers, a process which results in the development of distinct horizons (Brower et al., 1997). Differences in soil horizons will ultimately have effects on forage productivity on a given rangeland site. Nonetheless the resulting effects on forage yield and quality will vary in space and time depending on climatic conditions among other factors (DeKeyser et al., 2009; Tibor, 2010; Tiemann et al., 2009)

2.2.4 Forage Temporal Patterns

Long-term Plant temporal patterns involve replacement of species associations by others in a process known as succession (Brower et al., 1997; Mueller-Dombos and Ellenberg, 1974). Such a succession is usually gradual and involves a series of changes which follow a more or less regular course. Succession results from a change in habitat and invasion of new plant species. Change of environment or habitat results in change of the plant cover adapted to the area (Kent and Coker, 1994). The change may sometimes be due to action of plants upon soil and microclimate. Therefore, the plants themselves can set off the change which will ultimately result in their own destruction. The rangeland manager works with plant habitat to direct plant succession toward his desired objective. Studying such vegetation patterns is an important measure of effectiveness of rangeland management (Herlocker, 1999; Stoddart and Smith, 1955), and requires a continuous long term monitoring that is lacking in East Africa

These temporal changes may either be natural or induced. Natural succession takes place until climax conditions are reached (Herlocker, 1999). It results from soil changes in the process of soil succession. Induced succession results from man’s action and hence not a condition imposed by nature. For that matter, it can be modified by man in a much easier way than natural succession. Abnormal vegetation cover may remain for many years especially in instances where soil erosion follows destruction of the climax plants and induces sub-climax soil (Kent and Coker, 1994). Such a condition may easily be confused with a soil-plant complex which has never reached a climax unless a careful study is done. Large plants have a positive advantage in their ability to shade out competing species of lower stature, but they have an inherent disadvantage in that large surface area means large transpiration loss. Succession on dry land changes the habitat from the xeric to the more mesic condition; hence the vegetation changes are from small and drought resistant species to large and less drought-resistant species. Other factors influencing plant competition, such as root spread, reproduction capacity and shade tolerance modify the trend. Succession involves change in species composition and also change in plant abundance. As soil develops and its moisture holding capacity increase, greater plant density results (Brower et al., 1997).

Species composition changes are followed by invasion of new species which may not or have been present in the primary succession which were constituents of the climax cover (Brower et al., 1997). The first invaders are mobile annuals followed by herbaceous or woody perennial of low grazing value. Most invading perennials are not highly preferred by stock and many are valueless. This and other stages are marked more by decreased quality than by decreased quantity. Climax plants may ultimately disappear. Continued heavy grazing forces animals to consume invading species with the most preferred most susceptible being removed first. These are not followed by new invaders but rather the land approaches a barren state, with soil regressing rapidly (Mueller-Dombos and Ellenberg, 1974). Therefore, not all plant species can be considered available for all the rangeland sites in all seasons (Turner, 1998). As a result, species dominance is subject to local variations which may be caused by seasonal changes or variation in landscape characteristics as well (Bernués et al., 2005; Pontes et al., 2007; Turner, 1999).

Secondary succession following improved grazing conditions usually differs from the initial or primary plant succession since good soil conditions may remain (Herlocker, 1999). However, soil retrogression follows plant retrogression because of erosion and trampling. In such cases, secondary succession will be almost as slow as primary succession. When the soil has not deteriorated along with vegetation, succession upon removal of grazing stress may be very rapid, especially when there is high precipitation. If climax plants remain to seed the area succession will even be faster but slower when all climax plants have been removed (Brower et al., 1997).

2.3 Seasonal and Spatial Patterns of Forage

Growth in perennial plants is a cyclic phenomenon related to environmental factors. Generally, in East Africa, growth is rapid just after the onset of the rains and tails off to little or no growth at the height of the dry season. The initial wet season flush produces young green foliage rich in protein and carbohydrates, but as the season advances, more and more fibrous support tissue is laid down and the leafy material becomes tougher. In terms of total dry weight, the protein content of the leaves decreases. These changes are of critical importance to the nutrition of the grazing animals (Pratt and Gwynne, 1977). Moreover, due to the unpredictability inherent to rangeland ecosystems, the forage quality and productivity levels may vary seasonally and inter-annually (Li et al., 2009; Putfarken et al., 2008; Turner et al., 2005) in response to variations in rainfall and nutrient availability (Han et al., 2008). Hence the need to continuously monitor the forage quality and quantity supply and demand conditions (Bernués et al., 2005). Monitoring is essential for understanding spatial and temporal variations of rangeland resources. With such understanding, the likely responses to these variations such as opportunistic exploitation of forage by animals can easily be explored. Monitoring and prediction are important for sound management of forage in rangeland ecosystems (de Ridder and Breman, 1993; Herlocker, 1999). .

Forage cover is an important measure of plant quantity and distribution (Mueller-Dombos and Ellenberg, 1974). It has a large influence on light intensity, temperature, soil moisture, and habitat space for rangeland animals (Brower et al., 1997). Improper grazing results in an increase in less desirable plant cover which is often less dense and short lived (Ao et al., 2008). Reduction in yield is very crucial because it increases the energy the animal expends in obtaining forage. Plants that invade with overgrazing are not prominent in the climax cover because they can't withstand competition. A closed plant community is fully occupied by plants that new ones cannot easily invade. In such a community, soil and moisture resources are fully used and there is no room for additional plants. Nonetheless, that does not mean that the forage is dense, since even dry areas may be fully occupied and still display bare surface soil which will be filled underground by roots. Bare ground should not be considered as an indicator of unoccupied area or an ecologically open community. Annual plants may stage severe competition to perennials for short periods of time despite the fact that they are generally regarded as poor competitors. They sometimes form dense stands and fully occupy land during favourable moisture periods. Perennials find such areas difficult to occupy. But the deep-rooted native perennials under good management may ultimately compete successfully for the area during seasons that are unfavourable for annuals. Once established, they form closed communities invulnerable to the invasion by annuals (Stoddart and Smith, 1955).

Clear understanding of plant competition and its temporal patterns is important in rangeland management. The best adapted plant species can compete best because it can make most efficient and full use of the resources offered by the environment. Trees compete best because they are tall and can shade out smaller species, but the very size of trees prevents its growth in dry areas because of its very large transpiring area. Usually the largest plant which thrives under existing soil moisture will dominate. These will be perennial so that they can guard their ground throughout the year (Herlocker, 1999).

2.4 Sustainable Grazing on Rangelands

Sustainable grazing management is a key issue of concern in most rangelands. The removal of forage from rangelands in a manner sustainable for productivity and stability requires an understanding of the vegetation community dynamics. However, such an understanding is difficult given the vagaries of rangeland productivity and basic changes in understanding of temporal dynamics (McArthur et al., 2000). Ecologists have been reassessing the appropriate paradigm to interpret and manage vegetation dynamics on rangeland for purposes of identifying and solving problems related to suitable utilization of rangelands (Briske et al., 2003).

A number of studies have recognised the importance of ensuring sustainable productivity of rangelands (Baars, 1996; Behnke & Scoones, 1993; de Leeuw & Tothill, 1993; Vallentine, 1989; van Wijngaarden, 1985). In these studies, emphasis has been on catering for sustainable herbage production by suggesting the proportions of the total forage production that must be left by the end of a dry season. This is estimated to be the amount of protective herbage cover left after a long dry season as a basis of sound rangeland resource and animal production. It is also from this fraction that it is assumed that some herbage would disappear due to trampling, insects' damage, rodents, desiccation and decay. van Wijngaarden (1985) illustrated that large herbivores can apparently consume approximately 45 percent of the standing crop at the beginning of a dry season without doing any damage to the perennial herbage. The fraction however is not yet an established figure and the accuracy of the estimate is still uncertain (Bartels, 1993).

Sustainability of rangelands requires constant adaptation to change, not only utilizing the opportunities, but also using resources at a sustainable rate, so that they remain available year after year (Behnke and Scoones, 1993). Ideally, for stocking rates to achieve maximum profitability, they should also be sustainable. Where profit maximization is not the objective, it will be more difficult to achieve sustainability. It is possible to have more than twice as many animals that can be kept at maintenance level, than the number of animals required to achieve maximum profitability. At this high stocking rate, feed availability is markedly lower than at stocking rate required for higher animal production (Umrani, 1998).

2.5 Forage Biomass Inventories and Monitoring

One of the key requirements in sound development of land resources is carrying out inventories of the existing resource base (Brower et al., 1997; Pratt and Gwynne, 1977). In pastureland development and livestock production, inventories are essential for planning and implementation of rangeland development programs (Skerman et al., 1988). Considering the dynamics in rangeland ecosystems, it is vital that there is a regular assessment of rangeland resources (Asner and Lobell, 2000; Buchanan and Davies, 1995), so as to ensure that management interventions are based on reliable and up-to-date information. In Uganda, the spatial and temporal dynamics of rangeland herbage are mainly influenced by anthropogenic, grazing, vegetation cover type and climatic variables through their interaction with local topography and soils, which in Uganda often have high contents of sand and clay. Annual rainfall ranges between 450 – 800 mm and drought is a common recurrent phenomenon. These conditions in Ugandan rangelands are usually characterized by low biological productivity. Rangeland vegetation does not only directly or indirectly provide rangeland animals with food but also to a large extent, physical environment in which their activities take place. These services provided by a rangeland ecosystem have continuously raised the awareness of the importance of evaluating and quantifying habitat complexity or structure including vegetation monitoring for sustainable use (Dale, 2000). Sustainable management of a rangeland ecosystem requires the gathering and analysis of information regarding the resource base, especially the distribution of vegetation types. (Cingolani et al., 2004; Herlocker, 1999; Schmidt and Skidmore, 2002).

To provide reliable information on how healthy a rangeland is, some key components of different sites should be regularly monitored. These include rainfall, soil structure and nutrients, permanent natural surface water, vegetation structure, cover and composition among others depending on management objectives.

Monitoring of seasonal patterns of herbage is important when managing rangelands for sustainable animal production (Pontes et al., 2007). The frequency of monitoring will of course depend on the rate of ecological changes which are being measured and size of the area in question (Bothma, 1996; Herlocker, 1999). A broad reconnaissance or survey of the geology, geomorphology (landform), soils, vegetation, water resources and existing land use can be made by aerial inspection and strategic land traverses (Skerman et al., 1988). Knowledge of soils is necessary for forage scientists, extension workers and farmers to effectively understand plant performance (Skerman et al., 1988). However, site specific information on the magnitude of such spatial and temporal patterns in relation to herbage composition is in most cases lacking (Bernués et al., 2005).

2.5.1 Herbage Mass

Rangeland herbage mass is an important characteristic of rangeland vegetation since it supports either directly or indirectly, all grazer groups. It is also a measure of dominance among plant communities in high herbage mass, usually indicating abundance of herbaceous vegetation cover. For primary production, it can also be referred to as a quantitative expression of herbaceous matter (e.g. harvestable yield) which can be produced (e.g. in tones) by the natural environment at a location per unit area over a given period of time, e.g. in a season or a year (Pratt and Gwynne, 1977). Herbage mass may also be used as the quantitative measure of the production level of a rangeland site for a specified management objective. The concept of herbage mass is particularly useful and objective in assessing intrinsic environmental production capability and in comparing the environmental resource potential of one location with others (Schulze, 1997). Herbage mass varies with both changes in available plant moisture and nutrients (Ellis, 1995). Herbage mass production in a rangeland is one of the key measures of carrying capacities to support animal populations. For extensive grazing systems, it is a normal practice to use dry matter weight as the measure of standing crop (Baars, 1996).

Herbage mass estimation techniques can be classified into two broad categories, i.e. direct harvest methods and indirect harvest methods. Direct methods mainly involve sampling and measuring the target herbage mass component using a plot of desired shape and size and then estimating the total mass for the total area of interest. On the other hand, indirect methods of herbage mass assessment involve measurement of a variable which is closely related to herbage weight and relatively easy to measure and relating this variable to herbage weight by a chosen method e.g. regression analysis. Thereafter, only the related variable would be measured (Tueller, 1993).

Tueller (1993), highlights the following examples of indirect techniques of herbage mass estimation:

i) Capacitance meters based on the differences in dielectric constants between air and vegetation;

ii) Beta attenuation technique which involves emitting *β*-particles on one side of a plot and then counting the particles which emerge on the other side of the plot; and

iii) Cover which is based on the logical relationship between vegetation cover and herbage mass weight.

Another example of indirect method is dimension analysis which involves measurements of some easily measured parameter of a plant like crown basal diameter, twig length or diameter and relating these measurements to herbage. Many methods have been devised to estimate plant herbage mass, but all have some limitations. Estimation techniques, either by plot or plant, often involve a double sampling procedure to improve on estimates. One of the outstanding observations about direct harvesting methods is that they involve destructive sampling procedures (Moisey et al., 2005).

The most accurate method to estimate herbage mass is to clip the herbage from quadrat and determine the dry matter weight, but this is time consuming and destructive (Martin et al., 2005). Direct harvest techniques have also been found to be insufficient in presenting spatial extent of herbage (Roy and Ravan, 1996). Researchers have investigated alternative methods for the purposes of improving efficiency in terms of time and resources (Li Jianlong, 1998; Martin et al., 2005; Vermeire and Gillen, 2001).

Diaz-Solis, Kothmann et al (2003) simulated forage production as a function of precipitation and soil characteristics; and range condition as a function of grazing efficiency. In their study, they related annual aboveground net primary production (Kg dry matter ha^{-1} year^{-1}) to annual precipitation (PPT, mm year^{-1}). They applied the concept of precipitation use efficiency (PUE, kg aboveground dry matter (DM) produced ha^{-1} mm^{-1} of precipitation-year $^{-1}$) in which soil characteristics were used to modify annual above ground net primary production (ANPP). Estimates of the potential productivity of a specific site and rangeland condition were based on the proportion of ANPP that could be classified as forage. The equation used is:

$$\mathrm{ANPP} = \mathrm{PPT} \times \mathrm{PUE} \times \mathrm{RC}$$

Where:

ANPP = Annual Aboveground Net Primary Production
PPT = Annual Precipitation
PUE = Precipitation use Efficiency
RC = Rangeland Condition

Other studies have attempted to use RS imagery and GIS to discriminate rangeland vegetation and herbage yields (Li Jianlong, 1998; Liang & Chen, 1999; Moreau, 2003; Price, et al., 2002; Reeves, et al., 2006). Reports from such studies indicate that integration of RS data and ground data using GIS can be used for estimating herbage yields over a large area. It is has been realised that RS and GIS technologies are proving to be efficient tools that enable decision makers to address problems of environment and development in pastoral areas. The future of rangeland resources development and management is dependent upon increased scientific capability. RS, along with GIS, can contribute information for a variety of rangeland resources management and estimation applications. Annual or inter-annual maps of herbage can help in guiding decision makers to understand how rangelands vary spatially and temporally (Beeri et al., 2007; Li Jianlong, 1998; Liang and Chen, 1999; Moreau, 2003; Price et al., 2002; Reeves et al., 2006).

Normalized Difference Vegetation Indices (NDVI) derived from satellite images have been suggested to be very useful for estimating and monitoring changes of above ground forage mass for terrestrial ecosystems like rangelands (Boelman et al., 2005; Li Jianlong, 1998; Liang and Chen, 1999; Moreau, 2003; Price et al., 2002; Reeves et al., 2006). NDVI is the ratio of the difference between and the sum of the reflectance values in near infrared and visible red regions of electromagnetic spectrum respectively (Carlson and Ripley, 1997). It is important to have knowledge of which vegetation communities are present in the area of interest and in what proportions (either via field based ground truthing, or more efficiently, via spectral unmixing analysis), since NDVI-forage mass relationships are community specific. Use of NDVI is usually lacking due failure to consider these factors and this usually results in inaccurate interpretation of NDVI data collected at plot-level and at global scales (Boelman et al., 2005).

Studies such as Price et al. (2002); Roy and Ravan (1996) reveal that there is a relationship between satellite measured spectral responses and forage biomass. However, most studies have extensively been centred on low resolution satellite sensor data especially NOAA-AVHRR and the Moderate Resolution Imaging Spectroradiometer (MODIS). High resolution satellite sensors like Landsat, ASTER, SPOT, IKONOS, Geoeye, Quickbird and IRS (Indian Remote Sensing Satellite) which provide larger scale spatial information are not yet fully exploited for purposes of understanding rangeland herbage mass dynamics (Reeves et al., 2001). Even for the work done using these low spatial resolution sensors, much of the work covers areas in Australia and Northern America (Beeri et al., 2007; Boelman et al., 2005; Curran, 1983; Moreau, 2003; Price et al., 2002). Most of the work done in (or for) Africa is based on global public domain data sets, whose resolution does not reflect landscape differences in radiation use efficiency, which can vary significantly across landscapes and between rangeland sites. Hence, productivity estimates over areas with variable weather and climatic conditions and landscape characteristics may be subject to error. On the other hand they are advantageous when it comes to temporal resolution (Reeves et al., 2001).

Beeri et al. (2007) highlight the need for research that integrates remote sensing based forage mass estimates with the large herbivores. In their study, they conclude that remote sensing-based observations will facilitate large-scale hypothesis testing necessary for scaling up our understanding of rangeland condition from field plots to eco-regions. They also recommend that experiments that integrate remote sensing with forage biomass availability should be conducted.

Current ground-based inventory methods are not suitable for regional assessments of vegetation seasonality. Point-based sampling schemes are conducted with frequencies too low to effectively capture temporal variability and therefore provide poor representation of heterogeneous landscapes through time. Conversely, satellite-derived short-time productivity information indicates the spatial extent of vegetation response consistently and instantly over even the most inaccessible rangeland. Monitoring forage growth and temporal changes of rangeland plant communities over time permits the identification of essential herbage quality and quantity stages. Temporal and spatial resolutions of different satellite imagery products permit monitoring of variability in vegetation production and development. Such information may provide a valuable planning tool to estimate turnout dates and for other grazing management decisions (Reeves et al., 2006).

2.5.2 Herbage Species Patterns and Composition

The natural world is a patchy place where sometimes the patchiness has some level of predictability that can be quantified in a particular spatial pattern. Studying this spatial pattern in rangeland plant communities enables one to describe, quantify and understand their characteristics, both spatial and temporal, and then relate these characteristics to underlying processes such as establishment, growth, competition, reproduction, senescence, and mortality (Brower et al., 1997). Spatial pattern is a crucial aspect in natural vegetation because it affects future processes, both of the plants themselves and of a range of other organisms with which they interact (Dale, 2000).

Recording of botanical change is necessary for monitoring progress in grazing schemes or status of grazing areas (Dumont et al., 2009; Lanta et al., 2009). These inventories usually pose two main challenges; whether to fix permanent recording sites or to collect data at random, and how to obtain representative data from a limited sample area especially in expansive grazing areas. Rather than random sampling, the better solution is to stratify permanent recording sites in representative areas (Pratt and Gwynne, 1977). The choice of these 'representative' areas (strata) should always be based on preliminary survey of ecological land units and rangeland condition. When recording plant composition, it is usually sufficient to take note of the species available in each quadrat, without counting the number of plants. In addition to easing the task of recording, the use of specific frequency serves to free the records of the haphazard seasonal fluctuations in plant numbers (Brower et al., 1997), especially the annuals, which may otherwise mask the longer term changes in flora which are the main subject of interest (Pratt and Gwynne, 1977). Estimates of ground cover can conveniently and usefully accompany the analysis of the flora (Bartolome et al., 2007). The estimate is made by eye observation and should differentiate between the cover of different plant groups (Kent and Coker, 1994).

Botanical composition is a good index for rangeland condition assessment, but sometimes the tools available to a rangeland manager for vegetation analysis are so limited that it is so difficult to detect minor changes (Herlocker, 1999; Pratt and Gwynne, 1977). Succession induced by heavy grazing and that resulting from recovery may follow different species composition paths depending upon climatic, edaphic and perhaps other factors. Moreover, botanical composition changes may occur within a rangeland even when its condition remains the same. The use of botanical composition involves ecological analysis of the climax and successions leading to and away from the climax. This must be done for each climatic entity and for each soil type and physiographic unit (Stoddart and Smith, 1955). Key composition aspects that need to be considered when using this assessment criterion include vigour, percentage cover, litter formation and ability to burn (Pratt and Gwynne, 1977).

2.5.3 Herbage Quality

Herbage quality varies in space and time (Pontes et al., 2007; Tiemann et al., 2009). The variations may be according to differences in species composition (Sánchez-Jardón et al., 2010; Zarovali et al., 2007), soil characteristics (Hiernaux and Turner, 1996), season of the year (Turner, 1998), among other factors including grazing intensity (Li et al., 2009; Stoddart and Smith, 1955). As seasons change, the herbivores diet also changes (Bothma, 1996). High quality forage is more desirable than low quality one—in terms of palatability and/or nutrient content. High quality herbage species are also more productive in support of grazing animals. The main challenge of herbivores therefore is to keep pace with these variations in terms of obtaining sufficient energy and nutrients from the available plant stock at a given time and location (Woolley et al., 2009). Plants have entrenched themselves in the ecosystem by reducing their nutritional value with structural carbohydrates which are not palatable to herbivores. Plants have also developed defence mechanisms which are aimed at preventing them from being eaten. Anatomical characteristics of plants such as thorns, hairs, toughness, stickiness and texture influence the palatability thereof. It has been indicated that plants which cattle find more palatable have higher contents of soluble sugars and unsaturated fats than the more unpalatable plants. Phosphates and potassium are also usually present in higher concentrations in tastier plants. There is also a possible relationship between the amount of tannin and the digestibility of those leaves. This is linked to the ability of tannins to react with the microbial fermentation enzymes in the rumen, since these enzymes are also proteins. This results in enzymatic action being inhibited, hence general decrease in digestion (Bothma, 1996).

The most important function of herbage as a source food for animals is the production of energy for body processes. This includes the storage of energy. Since all organic foods serve this purpose, the energy value of the food provides the basis for the expression of nutritional values. Different nutritional substances (carbohydrates, fats, and proteins) and especially proteins have specific and unique functions in an animal body (Stoddart and Smith, 1955). Nevertheless, these substances collectively play an important role as sources of energy. Thus, determination of the intake and loss of energy provides an important measure to determine whether an animal is well nourished with the available forage. This is also a gauge for establishing the relative values of the various types of forage. In addition the energy balance provides a specific basis for predicting the gross chemical changes in the body as a result of specific diet or treatment. The energy balance also provides a gauge for determining nutritional deficiencies in the animal body (Pratt and Gwynne, 1977).

In addition to protein and starch or carbohydrates, animals also require minerals and vitamins for skeletal development and to form various body fluids. Although required in small quantities, they are essential for life and forage production for example phosphorus (Jones, 1990; Winks, 1990). In tropics, phosphorus and nitrogen are the two major limiting factors in the production of forage. All of the desired quantities of the nutrients must be present within the amount of food that an animal can consume a day, which may present difficulties when only low value forage is available. Consequently, to compile a ration or to assess the requirements of a grazing animal, it is necessary to know, not only the requirements of energy and protein for maintenance of the required production, but also the quantities that the animal is likely to consume (Pratt and Gwynne, 1977). The value of forage therefore depends on the quantity eaten and the extent to which the food consumed supplies the animal with energy, protein, minerals and vitamins (Skerman et al., 1988).

In order to assess the value of forage at a given time, it is necessary to know the chemical composition of its cover and nutritive value; the use to which animals will make of the available forage, allowing for selective grazing; and the bulk available at various times of the years (Pitman et al., 1992). From various laboratory analyses, it has been established that there is a consistent pattern of change associated within different times of seasons and between different seasons (Belesky et al., 2007). When there is sufficient forage available, energy values very rarely drop below the maintenance level ('tMannetje, 1990). However, some seasons may be associated with acute shortage of digestible protein (Peake et al., 1990), especially in *Themeda* sp, or *Hyperthelia* sp dominated grasslands. In Uganda, drier or overgrazed areas where short annual herbage dominates, deterioration in nutritive value is often arrested by drought. In such areas the major problem is lack of bulk rather than poor nutritive value (Pratt and Gwynne, 1977).

In rangeland forage quality monitoring, it is sometimes important to assess the proportions of poisonous plants. However, classifying rangeland forage plants into poisonous and non-poisonous groups is not a straight forward assessment procedure. Probably thousands of plants would be poisonous if eaten in sufficiently large quantity. Some of these are excellent for forage when not eaten too abundantly. With a few exceptions, a normal range is safe for grazing animals. Animal poisoning is a sign of an unhealthy rangeland condition. Many plants classified as poisonous are definitely eaten daily by animals with no ill effect because they are taken in small amounts and the poison is eliminated by the animal as rapidly as it is consumed. Generally, animals do not graze highly poisonous plants from choice and are rarely poisoned when they have an abundance of good forage. The exceptions here are the habit-forming species for which the animals acquire a desire. The preference which an animal displays for a plant is not an accurate index to its value for grazing. Animals can be forced to eat almost any plant, and some of the less-liked species are as nutritious as are the preferred. Animals sometimes do as well on the so called low-value plants as on the more preferred. A slight decrease in palatability of the plant cover after excessive grazing may in itself, not necessarily be an indication of reduced value (Stoddart and Smith, 1955). Nonetheless, invasion of less-preferred species is accompanied by marked reduction in grazing capacity, independent of the volume yield. Scarcity of forage may cause animals to consume plant species ordinarily ignored or eaten in small amounts (Olupot et al., 2010; Pratt and Gwynne, 1977).

2.6 Remote Sensing and GIS Tools in Resource Assessment

Remote Sensing (RS) and Geographic Information Systems (GIS) are among the most recommended methods of pattern analysis in plant ecology (Booth & Tueller, 2003; Dale, 2000; Phillips, Beeri, Scholljegerdes, Bjergaard, & Hendrickson, 2009). Studies have demonstrated the ability of GIS and RS in mapping the distribution and status of plant and resources in rangeland ecosystems (Booth and Tueller, 2003; Tsegaye et al., 2004; Turner, 2003). Due to the extensive nature of rangelands and the recognized need to manage them at low cost, remote sensing is considered to have significant promise for the future of rangeland assessment and monitoring. This requires developing an understanding of the ecology of the landscapes and of the vegetation-landform-soil relationships as a basis for image interpretation. Remote sensing interpreters can study certain features directly and other features by inference or association. On the other hand, GIS offers a powerful tool for integrating and analyzing data derived from remotely sensed image interpretations, soil surveys, vegetation maps, land ownership, water resources, geology, and many other potential themes that can be presented spatially (Tueller, 1989). These geographically referenced data sets are spatially registered so that multiple themes of data can be quickly compared and analyzed together. Many other such themes can be looked at individually, or collectively to aid the rangeland manager to place data of all conflicting land use types quickly and efficiently into a proper perspective for rapid and efficient interpretation, evaluation and action (Li Jianlong, 1998).

Satellite remote sensing from space offers the best approach for regularly updating maps of the rangeland vegetation resource (Chopping, et al., 2006) since it allows for a quick, cost effective and systematic way of obtaining uniform and up-to-date information (Beeri et al., 2007; Booth and Tueller, 2003; Moreau, 2003). Studies have revealed that the use of remote sensing has improved environmental analysis by providing a means to expand their temporal and spatial scales (Booth and Tueller, 2003; Turner, 2003). Despite the significant role that vegetation cover information plays in monitoring, no or limited work has been done in mapping rangeland vegetation especially in Africa. Attempts in vegetation mapping projects have been conducted using mid-resolution satellite imagery especially Landsat (Trodd and Dougill, 1998). Moreover these mapping efforts have been centred on general land cover mapping (NBS, 1992; Otukei and Blaschke, 2010).

Remote sensing and GIS provide spatial (geographic) information which can be integrated with other types of information for the routine management of resources. This integration process is associated with challenges for the whole routine in natural resource management in general and rangeland management in particular. The challenges include: the mix and value placed on the different items of information; how management structures adapt to the advantages of the opportunities that arise from the use of the new mix of information; how the resources are managed; and how the resource manager relates the wider community that has identified its investment in the maintenance of environmental resources. GIS provide the technology that can allow resource managers to acquire resource information and to partition that information into different areas for the analysis of the various rangeland management issues (McCloy, 1995).

Mapping vegetation community types accurately is one of the main challenges for monitoring vegetation with RS (Schmidt and Skidmore, 2002; Su et al., 2006). Three major problems are faced when mapping natural vegetation using mid-resolution satellite images with conventional supervised techniques: defining the adequate hierarchical level for mapping; defining vegetation units discernable by the satellite; and selecting representative training sites (Cingolani et al., 2004). In addition to technical mapping problems, the issue of imagery data costs is also a challenge. The challenges of vegetation classification may be methodological (Cingolani et al., 2004; Price et al., 2002; Turner, 2003), landscape character associated (Herlocker, 1999; Turner and Congalton, 1998; Vicente-Serrano et al., 2008) and/or data related (Schmidt and Skidmore, 2002; Su et al., 2006; Turner, 2003). However the challenges encountered seem to be different from one geographic area to another as evidenced by differences in reported accuracy levels using similar sensors and classification procedures.

2.6.1 Satellite Image Data acquisition

A satellite image is composed of a two dimensional array of discrete picture elements, or pixels. The intensity of each pixel corresponds to the average brightness, or radiance measured electronically over the ground area corresponding to each pixel. This average radiance measured in each pixel is called a digital number (DN). These values are simply positive integers that result in quantizing the original signal from the sensor using a process called analog-to-digital signal conversion. Typically, the DNs constituting a digital image are recorded over such numerical ranges as 0 to 255, 0 to 511, 0 to 1023, or higher. These ranges represent the set of integers that can be recorded using 8-, 9-, and 10-bit binary computer recording scales, respectively. In such numerical formats, the image data can be readily analysed with the aid of a computer (Lillesand et al., 2004).

2.6.2 Image Resolution

Different remote sensing systems have different spatial, spectral, temporal and radiometric resolution characteristics. Resolution is a measure of the ability of an optical system to distinguish between signals that are spatially near or spectrally similar (Jensen, 1996). Spatial resolution refers to the fitness of detail visible in an image. In digital remote sensing, the term spatial resolution corresponds to ground pixel size. Spectral resolution refers to the width across the electromagnetic spectrum that RS instrument is detecting. Landsat Thematic Mapper has better spectral resolution than IKONOS for vegetation mapping because many vegetation types can be delineated using spectral differences. Radiometric resolution is the ability of a remote sensing system to record many values. For example, Landsat MSS data were recorded in grid cell values ranging from 0 to 63 and therefore have lower radiometric resolution when compared to Landsat Thematic Mapper data which are records in a range from 0 to 255. On the other hand, temporal resolution is the imaging revisit interval. IKONOS has a higher temporal resolution compared to Landsat since the orbit cycle for IKONOS is 4 days while the orbit cycle for Landsat is 16 days. Each satellite system has advantages and disadvantages. The most appropriate satellite imagery depends on the objectives of the natural resource manager (Verbyla, 1995). The comparison basis of IKONOS and Landsat in this study was entirely centred on spatial resolution differences.

2.6.3 Image Analysis and Thematic Information Extraction

Image analysis involves processing of image data to extract information. It also involves classification which is the process of partitioning the m-dimensional response domain into discrete number of class sub-domains. These sub-domains may match the range of response values that would be expected from the different land-cover and land use classes (McCloy, 1995). The use of computer-assisted analysis techniques permits the spectral patterns in remote sensing data to be more fully examined. It also permits the data analysis process to be largely automated, providing advantages over visual interpretation techniques (Lillesand et al., 2004). Multispectral classification is one of the most often used methods of information extraction. The procedure assumes that imagery of a specific geographic area is collected in multiple regions of the electromagnetic spectrum and that the images are in good geometric registration. The actual multispectral classification may be performed using a variety of algorithms including: hard classification using supervised or unsupervised approaches; classification using fuzzy logic; and/or hybrid approaches often involving the use of ancillary information (Jensen, 1996).

In supervised classification, the analyst attempts to locate specific sites in the remotely sensed data that represent homogeneous examples of known land-cover types. These are usually referred to as training sites because the spectral characteristics of these known areas are used to train the classification algorithms for the ultimate land-cover mapping of the remainder of the image. Multivariate statistical parameters including means, standard deviations, covariance matrices and correlation matrices are calculated for each of the training sites. Every pixel both with and outside these training sites is then evaluated and assigned to the class to which it has the highest likelihood of being a member. This is often referred to as hard classification because a pixel is assigned to only one class (Jensen, 1996; Lillesand et al., 2004). Hard classification procedures like maximum likelihood have been found to be associated with relatively low classification accuracies (Cingolani et al., 2004; Turner and Congalton, 1998).

Unsupervised classification on the other hand is a process of grouping pixels that have similar spectral values. Each group of similar values is typically called a spectral class. The spectral classes are assumed to correspond to cover type classes such as rangeland type (Verbyla, 1995). The basic premise is that values within a given cover type should be close together in the measurement space, whereas data in different classes should be completely well separated. This is not always true (Su et al., 2006; Turner and Congalton, 1998). Since the resulting spectral classes are entirely based on natural groupings in the image values, the identity of the spectral classes will not be initially known. The analyst must compare the classified data with some reference data to determine the identity and informational value of the spectral classes (Baker et al., 2001).

Hybrid forms of image classification have been developed to either stream-line or improve the accuracy of purely supervised or unsupervised procedures. Hybrid classifiers are particularly useful in analyses where there is complex variability in the spectral response patterns for the individual cover types present. These conditions are quite common in such applications as vegetation mapping. Under these, conditions spectral variability within cover types is usually due to variations in species composition and different site conditions such as, soils, slope, aspect and crown closure (Lillesand et al., 2004). Geo-information, including remotely sensed data is generally imprecise since in most cases the boundaries between different phenomena are fuzzy. Fuzzy theory provides some useful tools when working with imprecise data during image classification (Jensen, 1996).

Fuzzy image classification approaches handle the mixed-pixel image problems by employing the fuzzy set concept, in which a given entity, in this case a pixel may have partial membership in more than one category (Asner and Lobell, 2000; Drake et al., 1999; Jensen, 1996). Instead of “hard” boundaries between classes in the spectral measurement space, fuzzy regions are established. Instead of each unknown measurement vector being assigned solely to a single class, irrespective of how close that measurement may be to a partition in the measurement space, membership grade values are assigned to describe how a pixel measurement is close to the means of all classes. Another approach to fuzzy classification is fuzzy supervised classification. This approach is similar to application of maximum likelihood classification, though in this case fuzzy mean vectors and covariance matrices are developed from statistically weighed trained data (Cingolani et al., 2004; Lillesand et al., 2004).

2.6.4 Image Classification Accuracy Assessment

There are many openings for errors in extracting information from remotely sensed data (Su et al., 2006; Turner and Congalton, 1998). Therefore, one will want to weigh the value of information from a particular image classification process relative to other information, in making decisions (McCloy, 1995). To correctly perform classification accuracy assessment, it is necessary to compare two sources of information: the remote sensing derived classification map; and the reference test information. The relationship between these two is usually summarised in an error matrix. An error matrix is the square array of numbers laid out in rows and columns that express the number of sample units, in this case pixels, assigned to a particular category relative to the actual category as verified in the field (Baker et al., 2001; Jensen, 1996). Various aspects of classification accuracy challenges have been reported by a number of workers (Cingolani et al., 2004; Price et al., 2002; Schmidt and Skidmore, 2002; Su et al., 2006; Turner and Congalton, 1998; Vicente-Serrano et al., 2008). These fall in a number of categories, including methodological, landscape variability, and/or geometric and radiometric data related problems.

2.6.5 Use of Field Data in Image Estimations

Estimation of the values of the physical environment of parameters from remotely sensed data will usually be done for each pixel in turn. The samples used to assess the accuracy and consistency of estimated classes will therefore be related to a single or groups of pixels. They must be located as accurately as possible relative to individual or groups of pixels. Field data will collect information on the parameters within these samples for comparison with the estimates for the sample parameters from the satellite data (McCloy, 1995; Verbyla, 1995). After the field data have been collected from randomly selected sites, it is compared on a pixel-by-pixel basis with the information present in the remote sensing derived classification map. Agreement and disagreement are summarised in the cells of error matrix (Jensen, 1996).

Overall accuracy is computed by dividing the total correct by the total number of pixels in the error matrix. Computing the accuracy of individual categories, is however more complex because the analyst has the choice of dividing the number of correct pixels in the category by the total number of pixels in the corresponding row or column (Jansen and Gregorio, 2002). This statistic indicates the probability of reference pixels being correctly classified and is a measure of omission error. It is also called the producer's accuracy because the producer is interested in how well a certain area can be classified. If the total of correct pixels in a category is divided by the total number of pixels that were actually classified in that category, the result is the measure of commission of error. This measure, called the user's accuracy or reliability is the probability that a pixel classified on a map actually represents the category on the ground (Baker et al., 2001).

CHAPTER THREE

3.0 General Methods

3.1 Study Area Description

The studies in this thesis were carried out in predominantly pastoralist sub-counties of Kacheera and Nyakashashara in Rakai and Kiruhura districts respectively in south western Uganda (30^{o}53΄E and 0^{o}13΄S to 0^{o}41΄S and 31^{o}14΄E). The location map is shown in Figure 3.1. It is an area where there is convergence of wildlife and livestock owned by communities surrounding Lake Mburo National Park. The vegetation cover type and livelihood systems in the study area make it the most representative landscape characteristics of the Ugandan ‘cattle corridor’ range landscape (Pratt and Gwynne, 1977). The study covered part of the Kooki hill series with altitude ranging from 1200 to 1400 meters above sea level. The south eastern parts are characterized by many hills and connecting valleys. The rest of the areas are generally flat.

Vegetation cover is mainly composed of alternations of woodland and grassland patches with varying proportions of herbaceous and woody species. The dominant woody vegetation species included *Acacia* sp., *Rhus natelensis* and *Carisa edulis* (Personal observations). Dominant herbaceous species are *Themeda triandra*, *Cynodon dactylon*, *Panicum maximum*, *Brachiaria decumbens*, *Sporobolus pyramidalis*, *Loudetia kagerensis*, and *Hyparrhenia filipendula* (Okello et al., 2005). The soils are mainly classified as Leptosols; Acric ferrasols; Lixic ferrasols; Gleyic arenosols; Gleysols; and Histosols soil types according to FAO classification (FAO, 1990).

The local climate of the study area can be related to its equatorial location. Rainfall varies considerably in space and time and rather unpredictable (Bloesch, 2002). The rainfall is bimodal with an annual mean (1975-2009) of 948mm. Mean annual temperature is 22.9 ^{o}C. Daily temperatures fluctuate between 12^{o}C and 34^{o}C with negligible seasonal fluctuations. Rainfall occurs in two peaks of March-May and September-November which are usually the growing seasons. June and July are normally very dry. In January and February there is generally little rainfall. The 2009 September-November growing season precipitation of 495 mm during the study period was higher than the long term average (125mm). On the other hand, the June-August dry season in the same year received relatively lower average precipitation (28mm) than the long term average (38mm). In 2010, the March-May growing season received 272 mm of precipitation which was lower than the long term average. The December-February, which is normally considered a mild dry season month received higher precipitation amounts (192 mm) than the March-May season average, which is normally considered a rainy season.

The area is primarily used for grazing of both domestic and wild animals on native vegetation. It is already subjected to variable rainfall, and due to climate change, may experience increased drought incidences, overlaid on the already low biological productivity. The major limiting factor for livelihood systems in the area is inadequate and poorly distributed water for biological production. Other constraints include socio-economic factors and land use conflicts; land degradation; reduced herbage quality and quantity, poor marketing infrastructure among others (NEMA, 2002).

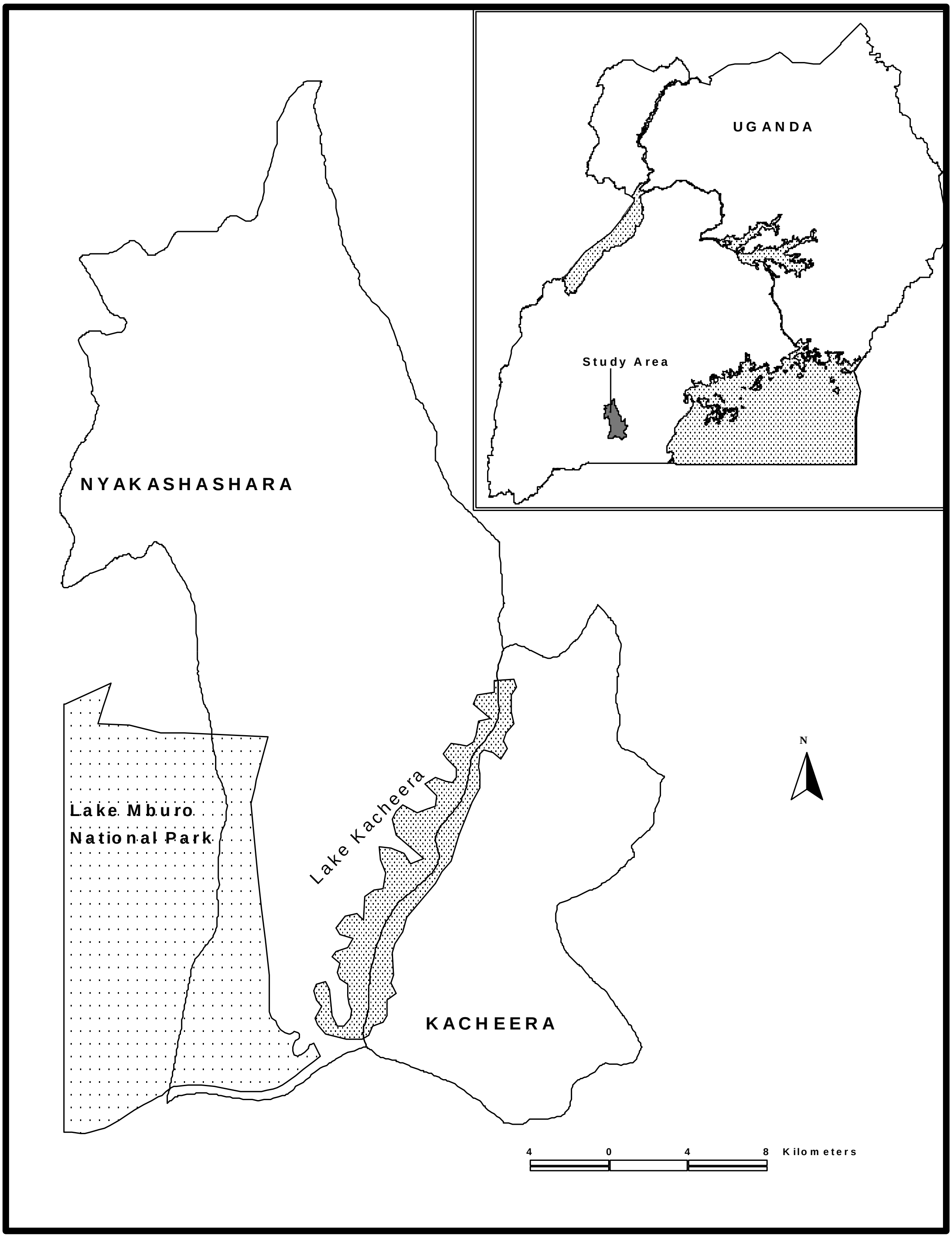


Figure 3.1: The location of the study area in Uganda

3.2 Research Approach

In this study, two approaches were used to assess and monitor rangeland herbage quantity and quality: Indirect estimation and direct harvest methods. Indirect methods of determining herbage quantity involved vegetation cover stratification and measurement of herbaceous vegetation cover in different cover types which served as a basis for estimating herbage mass. Species composition was used as an indirect way of assessing herbage quality. The direct methods involved clipping of herbage from sample plots for herbage quantity and quality assessment.

3.3 General Research Methods

3.3.1 Vegetation Cover Mapping

Sampling for vegetation mapping and proxy herbage mass estimation and monitoring data collection was done using stratified clustered random sampling. The study area was stratified according to different vegetation strata obtained from unsupervised classification of Landsat Enhanced Thematic Mapper (ETM+) image for February 2008 (see figure 3.2). The image characteristics of Landsat TM bands are shown in table 3.1. The unsupervised classes resulted from statistical grouping of Digital Numbers (DNs) of the image. The spectrally grouped classes were verified and modified using vegetation survey data from the field. The verified classes were then used as the vegetation sampling strata.

Sampling locations were selected (clustered) in such way that a maximum number of strata was represented at a given data collection area (cluster) as a way of minimising the time spend on movement to sample different strata (Mueller-Dombos and Ellenberg, 1974). Vegetation height layers in the different strata were identified and the percentage cover for each vegetation layer was estimated and recorded. The dominant vegetation species were identified with guidance from an experienced botanist or well trained research assistants. Those that could not be identified from the field were collected and identified from Makerere University herbarium.

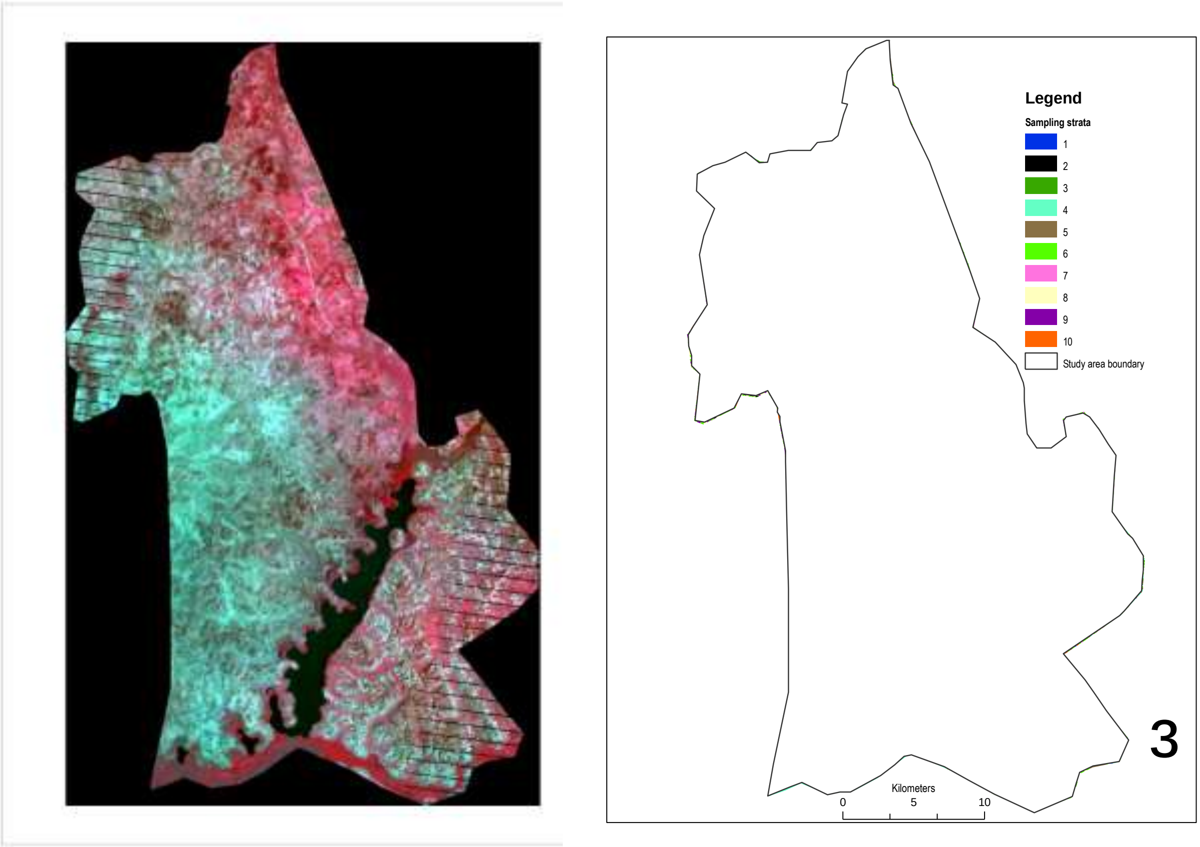


Figure 3.2: Image stratification using unsupervised classification. Left is a Landsat TM image for the study area and Right are the sampling strata

Table 3.1: Landsat Enhanced Thematic Mapper and IKONOS sensor characteristics

Sensor	**Band**	**Wavelength (µm)**	**Resolution (m)**	**Swath width (km)**	**Revisit time (days)**
Landsat Enhanced Thematic Mapper	Band 1 (Visible)	0.45 to 0.52	30	185	16
	Band 2 (Visible)	0.52 to 0.60	30	185	16
	Band 3(Visible)	0.63 to 0.69	30	185	16
	Band 4 (NIR)	0.76 to 0.90	30	185	16
	Band 5 (SWIR)	1.55 to 1.75	30	185	16
	Band 6 (TIR)	10.4 to 12.5	60	185	16
	Band 7(MWIR)	2.08 to 2.35	30	185	16
IKONOS (OSA)	Band 1 (Visible)	0.45 to 0.52	4	11	3
	Band 2 (Visible)	0.52 to 0.6	4	11	3
	Band 3 (Visible)	0.63 to 0.69	4	11	3
	Band 4 (NIR)	0.76 to 0.9	4	11	3

For each vegetation stratum, sample sites were selected considering slope (for hills) and general vegetation structure. With strata represented on a hill, equal number of sites was selected (at the bottom, middle and top). Sampling was only done in units of 60 x 60 meters and above to cater for the minimum classifiable area of 16 pixels according to Townshend

(1983). The minimum area in this case was based on the lowest resolution image used in the study (Landsat Thematic Mapper of 30 x 30 meters). Accessibility was also used as a determining factor for sites to be sampled.

Sampling within strata aimed at establishing the different structural and floristic composition therein was done using square plots. The plot sizes (quadrats) varied with vegetation structure (Kent and Coker, 1992). However, in order to increase the chances of covering species spatial variability, the minimum plot sizes suggested for different vegetation types were accordingly adjusted as recommended for tropical environments (Kent and Coker, 1992) as shown in table 3.2 below. All separately classified strata of the image were sampled equally irrespective of their size. For each sample quadrat (plot) in a stratum, a code identifying the sample according to the unsupervised image classes represented by that sample plot on the image, the geographical coordinates and the altitude were taken from a global positioning system (GPS) and recorded. The datasheet used for data recording is shown in Appendix 3.1.

Table 3.2: Quadrat sizes used for data collection

Vegetation Layer	Height	Kent & Coker size	Adopted size
Grass	Up to 1m high	2x2m	2x2m
Shrub	Up to 3m high	5x5m	15x15m
Shrub	Over 3m	Not given	15x15m
Woodland trees	Over 3m tall	30x30m	30x30m

3.3.2 Herbage species composition data Collection

Data on herbage species composition in the different physiognomic vegetation strata was collected using a 2 x 2 quadrat for different months and seasons. For each vegetation stratum a minimum of twelve sampling locations were established and monitored for a period of 24 months from October 2008 to November 2010. Data collected included species names, species cover and species height.

3.3.3 Direct herbage quantity and quality assessment

Twenty sites were randomly selected based on two vegetation cover classes and three soil textural classes according to FAO (1990) descriptions. The vegetation cover classes used were woodland patches with trees/shrubs shading herbage cover and open grassland patches. The soil textural classes in the area were: clay loam, loam and sandy loam. The 20 sites were a result of all combinations of the two vegetation cover and the three soil types with at least three replicates for each vegetation and soil combinations, namely: clay loam woodland; loam woodland; sandy loam woodland; clay loam grassland; loam grassland; and sandy loam grassland. A portion of each site was enclosed in a 10 x 10 m plot using barbed wire to ensure that no big herbivores enter to graze (see Figure 3.3). A completely randomised design with a split-split plot arrangement was used to determine the effect soil textural classes, vegetation cover types and grazing on herbage quantity and nutritive value.

Figure 3.3: Fenced plots: Left is a fenced patch of woodland nested with grassland patches; and right is a fenced grassland patch

Freshly harvested above ground herbage mass was collected and weighed at each cut after every 30 days for a period of twenty three consecutive months from December 2008 to November 2010. Harvesting was done from 1 x 1m plots both inside and outside the enclosed plots for purposes of capturing the effect of grazing on patterns of herbage yield. For each plot, a sub-sample of the fresh harvested herbage mass was weighed, dried at 60°C to constant weight to determine the dry matter content. Individual herbage species cover and height were recorded before every harvesting.

The nutritive value of harvested herbage was assessed using seasonal composite from monthly samples collected for dry matter yield. These sub-samples were ground and analyzed for neutral detergent fibre (NDF), digestibility and crude protein content from Makerere University Department Agricultural Production.

3.3.4 Herbage Cover data Collection

For every 30 days from November 2008 to November 2010, the herbage percentage cover relative to woody vegetation and bare ground cover in each of the strata was measured on same locations using visual inspections as described by Brower et al. (1997) and Kent and Coker (1994). Navigation to these data collection locations every month was done using a GPS. The changes in herbage cover in different vegetation types and different seasons were used as a proxy measurement for changes in herbage mass. To ensure consistency and minimise errors in cover estimations, training in visual estimations was done using measured block dots shown in appendix 3.2.

3.3.5 Rainfall data collection

Fifteen rain gauge stations were setup in the study area. Recording of rainfall was done every morning at 09:00 hours for a period of two years. The total amount of rainfall for each station was computed for monthly, seasonal and annual totals and averages.

3.3.6 Soil Characterisation

FAO (1990) soil units were used as the sampling strata for soil physical and chemical properties data collection and analysis. The seven FAO units represented in the study area were Acric ferrasol, Leptosols, Acric ferrasols, Lixic ferrasol, Gleyic arenosols, Gleysols, and Listosols. Sampling was based on strata resulting from GIS spatial overlay of the soil units and two slope (%) classes (<8.65 and >8.65). The sources of elevation data for slope classes was a Digital Elevation Model derived from SRTM (Shuttle Radar Topographic Mission). For each of the resulting combination stratum, soil types were characterized in terms of physical and chemical properties.

3.3.7 Data Management and Analysis

Data for all variables were entered and managed using Microsoft access (Microsoft, 2003) relational databases. Use of relational databases allowed for easy retrieval using queries, minimising errors and redundancy (de By, 2001).

Spatial data analyses and integration for spatial and seasonal patterns in herbage were done using ArcGIS (ESRI, 2008) Geographic Information System (GIS). The integration of datasets was done based on grid (raster) maps. Use of grid maps in rangeland assessments has been found to be a relatively rapid and accurate way of appraising rangeland resources (Baars, 1996). Use of maps and GIS was not only important for information on herbage mass patterns in time, but also information on spatial variation of management variables themselves in relation to land attributes and management decisions (Verweij, 1995).

Using the statistical package GenStat (GenStat, 2008), herbage mass, species cover and height data were analysed using Analysis of Variance (ANOVA) to establish the statistical significance of season, vegetation cover types, grazing, soil types and their interactions.

CHAPTER FOUR

Overall Thesis Synthesis

This thesis has been presented in nine chapters. Chapter one presents the introduction with a general background to the study. Chapter two is about existing literature and theory on spatial and temporal dynamics of rangeland forage including remote sensing monitoring and Geographic information techniques. Chapter three is on the general methods of the thesis. This chapter highlights the links among the different manuscripts presented from chapters five to eight. The manuscript chapters present the outcomes of the studies based on research questions derived from objectives as presented in chapter one. Chapter nine is on general discussions, conclusions and recommendations for research in and management of rangeland herbage.

The studies in this thesis which focused on integration of proxy and direct approaches to herbage quality and quantity assessment, monitoring and prediction are presented in four manuscripts. The proxy approach entailed determination of spatial and seasonal patterns of herbage quality and quantity based on satellite image derived strata. Mapping and prediction of vegetation cover types from the satellite images was done to establish herbage assessment and monitoring spatial units. The variables measured for proxy herbage quantity and quality in the different vegetation cover types were percentage herbage cover and species composition respectively. The direct approach to the studies involved use of quadrat harvesting methods to establish the patterns of herbage quantity and quality. Harvesting was done from selected sites based on variables that influence spatial and seasonal patterns of herbage. The variables used to select harvesting sites were soil type, grazing and vegetation cover type. Dry matter yield of harvested samples was used as measure of direct herbage quantity. Herbage quality was measured based on neutral detergent fibre (NDF), organic matter digestibility and the percentage of crude protein content (CP).

In order to establish herbage assessment and monitoring units, vegetation stratification and mapping were done using Landsat ETM+ and IKONOS satellite images in a manuscript presented in Chapter 5. The stratification and mapping involved characterisation of vegetation physiognomic composition and assessment of Landsat and IKONOS Sensors spectral discrimination effectiveness for mapping vegetation physiognomic cover types. Maximum (ML) likelihood and fuzzy classifiers were used to predict vegetation cover types from the images. Plot vegetation species growth form, cover and height data were collected from sampling sites based on eight spectral strata generated using unsupervised image classification. Field data were grouped at four levels of seven, six, three and two vegetation physiognomic classes which were subjected to both ML and fuzzy classification using both Landsat and IKONOS satellite images. Classification of vegetation plot data resulted in seven physiognomic classes (bush grassland, bushland thicket, bushland, grassland, shrubland, woodland and wooded grassland). Only two broad classes of physiognomic vegetation cover types (woodland and grassland) were accurately mapped using fuzzy and ML from Landsat and IKONOS images. Overall, the findings of this study indicated that IKONOS reflectance spectra discriminate rangeland physiognomic vegetation classes better than Landsat imagery. It was also shown that fuzzy classification resulted in higher discrimination ability of the physiognomic vegetation types than maximum likelihood. The vegetation strata and maps in chapter five were used in herbage assessment and monitoring procedures in chapters six, seven and eight of this thesis.

In chapter six, soil characterisation for herbage productivity and its interactive effect with vegetation cover types and grazing on herbage species composition and herbage production are presented. The vegetation cover types used were as a result of the mapping and stratification from chapter five. The manuscript addresses the question: How do vegetation cover, soil type and grazing affect site specific herbage species composition and herbage yield? A completely randomised experimental design with a split-split plot arrangement was used to determine the effect soil textural classes, vegetation cover types and grazing on herbage species composition and herbage production. Soil and herbage data were analysed using analysis of variance (ANOVA). In the manuscript grass species cover and species composition with respect to vegetation cover types, soil types and grazing were documented. The study revealed that vegetation cover type and grazing were key factors in determining herbage species composition and production.

Using the baseline information on vegetation cover types, soil characteristics and herbage productivity presented in chapters five and six, monitoring of spatial and seasonal patterns of herbage species composition, mass and nutritive value was undertaken and presented in chapter seven Proxy monitoring of seasonal patterns in herbage botanical composition was based on seven vegetation strata derived from the Landsat image in chapter five. Direct monitoring of herbage mass and nutritive value was based on the same experiment used in chapter six. Monthly data were collected on species composition, cover and height for two years and analysed based on seasonal patterns of daily rainfall data collected during the period of study. Herbage was analysed for dry matter (DM) yield, crude protein (CP) concentration, *in vitro* organic matter digestibility (OMD) and neutral-detergent fibre (NDF). Results showed that bush grasslands recorded the highest number of species (43) and Woodlands with the lowest (32). The most dominant species were *Brachiaria decumbens, Cynodon dactylon, Loudetia kagerensis* and *Sporobolus pyramidalis.* The variables considered explained 85% of DM yield, 77% of CP, 67% OMD, and 64% NDF variations. Grazing significantly affected DM yield and accounted for 0.35 of total variance. Seasonal DM yield ranged between 252 and 347 gDMm-2 with the highest recorded in March-May and the lowest in September-November seasons. Vegetation type explained most of variations in herbage nutritive value. A comparison of herbage cover as a proxy measure with direct harvesting dry matter yield measurements was done. Seasonal patterns of herbage cover were similar with those for herbage yield from harvesting experiments. In order to establish usability of species composition as a measure of herbage quality, seasonal species patterns were compared with those of nutritive value. Results showed that herbage quality could be predicted from species composition. Seasons of higher nutritive value were dominated by *Brachiaria decumbens* which is a palatable herbage species. Lower nutritive values were recorded when the herbage was dominated by *Sporobolus pyramidalis* known to be a non-palatable species. Substantial differences in seasonal patterns of herbage quantity due to erratic nature of rainfall were revealed. Herbage quality was predominantly controlled by rainfall seasons and therefore its improvement may not be well within the control of rangeland users and managers especially under the current management systems.

Information on vegetation strata (chapter 5) soil characteristics (chapter 6), herbage cover and rainfall (chapter seven), was used for herbage quantity estimation and prediction (Chapter 8). Herbage spatial and seasonal patterns were estimated from the functional relationship among herbage cover, rainfall and soil physical properties related to rainfall effectiveness. Dry matter (DM) measurements from quadrat harvesting method were used to validate the resulting herbage estimations in chapter 8. A multi-linear regression was performed to determine the relationship between DM, herbage cover, rainfall effectiveness, and drainage. Results showed a strong relationship between the above variables. Herbage cover was found to be the important variable for DM estimation. A correlation analysis of estimated and harvested DM resulted in a strong positive relationship. DM was highest in March-May and the lowest in September-November. It was demonstrated that herbage cover is an important proxy measurement of spatial and seasonal patterns of rangeland herbage mass. The results provided useful insights on the importance of vegetation cover as a major indicator of rangeland health and productivity. It was recommended that rangeland herbage monitoring approaches should be centred on cover measurements to avoid or at least minimise the cost, destruction and information timeliness implications that are known to be associated with harvesting methods.

All in all results presented in the manuscripts showed that herbage patterns were a product of the interactions among soil types, rainfall, vegetation cover type and anthropogenic factors such as land use and land cover changes. Results of herbage quantity from the direct approach exhibited a similar seasonal pattern with those from predictions based on proxy measurements in different vegetation strata derived from Landsat satellite image. Herbage quantity peak was during March to May wet season for both approaches and lowest in September-November wet season.

The studies revealed that spatial and seasonal patterns of herbage quantity and quality can be monitored using herbage species cover and composition of vegetation strata derived from Landsat images. The model developed based on vegetation strata derived from Landsat images can accurately estimate and predict herbage yield and its spatial distribution in the rangelands of south western Uganda. Reliable methods for information needed to assess and monitor herbage productivity are available and hence protocols and manuals for rangeland assessment and monitoring in Uganda can developed. From the studies it is shown that there is need to develop a classification scheme for systematically defining rangeland vegetation classes that can realistically be discriminated from medium and high resolution satellite images. The proxy estimation model should be validated and up-scaled for wide application in herbage mass estimations in rangelands. There is evidence that vegetation cover has changed in south western Uganda, therefore there is need to upscale the procedures documented in this thesis and produce current vegetation cover maps for the rangelands in Uganda.

References

Allen, V. G., Batello, C., Berretta, E. J., Hodgson, J., Kothmann, M., Li, X., et al. (2011). An international terminology for grazing lands and grazing animals. *Grass and Forage Science, 66*(1), 2-28.

Ao, M., Ito, M., Ito, K., Yun, J. F., Miura, R., & Tominaga, T. (2008). Floristic compositions of Inner Mongolian grasslands under different land-use conditions. *Grassland Science, 54*(4), 173-178.

Archibald, S. (2008). African grazing lawns—How fire, rainfall, and grazer numbers interact to affect grass community states. *Wildlife Management, 72*(2), 492 - 501.

Asner, G. P., & Lobell, D. B. (2000). A Biogeophysical Approach for Automated SWIR Unmixing of Soils and Vegetation. *Remote Sensing of Environment, 74*(1), 99-112.

Baars, R. M. T. (1996). *Condition and management of the rangelands in the western province of Zambia*. Unpublished PhD thesis, Wageningen Agricultural University; The Netherlands.

Baker, L. E., & Hoffman, M. T. (2006). Managing variability: Herding strategies in communal rangelands of semiarid Namaqualand, South Africa. *Human Ecol, 34,* 765 - 784.

Baker, W. H., Janssen, L. L. F., Reeves, C. V., Gorte, B. G. H., Pohl, C., Weir, M. J. C., et al. (2001). *Principles of Remote Sensing* (Second ed.). Enschede: International Institute for Aerospace Survey and Earth sciences (ITC).

Bartels, G. B., Norton, B.E., Perrier, G.K. (1993). An examination of carrying capacity concept. In J. R. H. Behnke, I. Scoones & C. Kerven (Eds.), *Range ecology at disequilibrium : new models of natural variability and pastoral adaptation in African Savannas* (pp. 89-103). London: Overseas Development institute (ODI).

Bartolome, J. W., Jackson, R. D., Betts, A. D. K., Connor, J. M., Nader, G. A., & Tate, K. W. (2007). Effects of residual dry matter on net primary production and plant functional groups in Californian annual grasslands. *Grass and Forage Science, 62*(4), 445-452.

Beeri, O., Phillips, R., Hendrickson, J., Frank, A. B., & Kronberg, S. (2007). Estimating forage quantity and quality using aerial hyperspectral imagery for northern mixed-grass prairie. *Remote Sensing of Environment, 110*(2), 216 - 225.

Behnke, J. R. H., & Scoones, I. (1993). Range ecology at disequilibrium : new models of natural variability and pastoral adaptation in African Savannas. London: Overseas Development Institute (ODI).

Belesky, D. P., Ruckle, J. M., & Abaye, A. O. (2007). Seasonal distribution of herbage mass and nutritive value of Prairie grass. *Grass and Forage Science*, *62*(3), 301-311.

Bernués, A., Riedel, J. L., Asensio, M. A., Blanco, M., Sanz, A., Revilla, R., et al. (2005). An integrated approach to studying the role of grazing livestock systems in conservation of rangelands in protected natural park (Sierra de Guara, Spain). *Livestock Production Science, 96*, 75 - 85.

Bloesch, U. (2002). *The dynamics of thicket clumps in the Kagera savanna landscape, East Africa*. Zurich.

Boelman, N. T., Stieglitz, M., Griffin, K. L., & Shaver, G. R. (2005). Inter-annual variability of NDVI in response to long-term warming and fertilization in wet sedge and tussock tundra. *Oecologia, 143,* 588 - 597.

Booth, D. T., & Tueller, P. T. (2003). Rangeland monitoring using remote sensing. *Arid Land Research and Management, 17,* 455 - 467.

Bothma, J. d. P. (Ed.). (1996). *Game ranch management*. Pretoria: J.L. van Schaik Publishers.

Bousquet, F., d'Aquino, P., Rouchier, J., RequierDesjardins, M., Bah, A., Canal, R., et al. (1999). *Rangeland herd and herder mobility in dry intertropical zones: multi-agent* *systems and adaptation.* Paper presented at the International Rangeland Congress, Townsville.

Briske, D. D., Fuhlendorf, S. D., & Smeins, F. E. (2003). Vegetation dynamics on rangelands: a critique of the current paradigms. [Essay Review]. *Applied Ecology, 40*, 601 - 614.

Brower, J. E., Zar, J. H., & von Ende, C. N. (1997). *Field and laboratory methods for general ecology* (4th ed.): Michael D. Lange.

Buchanan, M., & Davies, S. (1995). *Famine early warning systems and response - The missing link*. London: Intermediate technology publications.

Canton, Y., Del Barrio, G., Sole-Benet, A., & Lazaro, R. (2003). Topographic controls on the spatial distribution of ground cover in the Tabernas badlands of SE Spain. *CATENA, 55*, 341 - 365.

Carlson, T. N., & Ripley, D. A. (1997). On the relation between NDVI, fractional vegetation cover, and leaf area index. *Remote Sensing of Environment, 62*(3), 241-252.

Chopping, M. J., Su, L., Rango, A., Martonchik, J. V., Peters, D. P. C., & Laliberte, A. (2006). Remote sensing of woody shrub cover in desert grasslands using MISR with a geometric-optical canopy reflectance model. *Remote Sensing of Environment, 112*, 19 - 34.

Cid, M. S., Ferri, C. M., Brizuela, M. A., & Sala, O. (2008). Structural heterogeneity and productivity of a tall fescue pasture grazed rotationally by cattle at four stocking densities. *Grassland Science, 54*(1), 9-16.

Cingolani, A. M., Renison, D., Zak, M. R., & Cabido, M. R. (2004). Mapping vegetation in a heterogeneous mountain rangeland using landsat data: an alternative method to define and classify land-cover units. *Remote Sensing of Environment, 92*(1), 84-97.

Cowling, R. M. (2000). Challenges to the 'new' rangeland science. *TREE, 15*, 303 - 304.

Crist, T. O., Guertin, D. S., Wiens, J. A., & Milne, B. T. (1992). Animal Movement in heterogeneous landscapes: an experiment with Eleodes beetles in short grass prairie. *Functional Ecology, 6*, 536 - 544.

Curran, P. J. (1983). *Problems in the remote sensing of Vegetation canopies for biomass estimation.* Paper presented at the Ecological Mapping from Ground, Air and Space, ITE, Monks Wood Experimental Station, Abbots Ripton, Huntingdon.

Dale, M. R. T. (2000). *Spatial pattern analysis in plant ecology*. Cambridge: Cambridge university press.

de By, R. A. (2001). Principles of geographic information systems.

de Leeuw, P. N., & Tothill, J. C. (1993). The concept of rangeland carrying capacity in sub-Saharan Africa-myth of eality *Range ecology at disequilibrium : new models of natural variability and pastoral adaptation in African Savannas* (pp. 77-88). London: Overseas Development Institute.

de Ridder, N., & Breman, H. (1993). A new approach to evaluating rangeland productivity in Sahelian countries. In J. R. H. Behnke, I. Scoones & C. Kerven (Eds.), *Range ecology at disequilibrium : new models of natural variability and pastoral adaptation in African Savannas* (pp. 104-117). London: Overseas Development.

DeKeyser, S., Clambey, G., Krabbenhoft, K., & Ostendorf, J. (2009). Are Changes in Species Composition on Central North Dakota Rangelands Due to Non-Use Management? *Rangelands, 31*(6), 16-19.

Diaz-Solis, H., Kothmann, M. M., Hamilton, W. T., & Grant, W. E. (2003). A simple ecological sustainability simulator (SESS) for stocking rate management on semi-arid grazinglands. *Agricultural Systems, 76*(2), 655-680.

Drake, N. A., Mackin, S., & Settle, J. J. (1999). Mapping Vegetation, Soils, and Geology in Semiarid Shrublands Using Spectral Matching and Mixture Modeling of SWIR AVIRIS Imagery. *Remote Sensing of Environment*, *68*(1), 12-25.

Dumont, B., Farruggia, A., Garel, J. P., Bachelard, P., Boitier, E., & Frain, M. (2009). How does grazing intensity influence the diversity of plants and insects in a species-rich upland grassland on basalt soils? *Grass and Forage Science*, *64*(1), 92-105.

Ellis, J. E. (1995). Climate variability and complex ecosystem dynamics: Implications of for pastoral development. In I. Scones (Ed.), *Living with uncertainity: New directions in pastoral development in Africa* (pp. 37 - 39). London: Intermediate technology publications Ltd.

ESRI. (2008). ArcGIS 9 (Version 9.3). Redlands, USA: Environmental Systems Reserach Institute Inc.

Facelli, J. M., & Springbett, H. (2009). Why do some species in arid lands increase under grazing? Mechanisms that favour increased abundance of *Maireana pyramidata* in overgrazed chenopod shrubs of South Australia. *Austral Ecology, 34*, 588 -597.

FAO. (1990). *Guidelines for soil description*. Rome: FAO.

Fujita, N., Amartuvshin, N., Yamada, Y., Matsui, K., Sakai, S., & Yamamura, N. (2009). Positive and negative effects of livestock grazing on plant diversity of Mongolian nomadic pasturelands along a slope with soil moisture gradient. *Grassland Science, 55*(3), 126-134.

GenStat. (2008). GenStat - Seventh Edition (DE3) (Version 7.2.2.222). Hemel Hempstead, United Kingdom: VSN International.

Gordon, I. J. (2009). What is the Future for Wild, Large Herbivores in Human-Modified Agricultural Landscapes? *Wildlife Biology, 15*(1), 1-9.

Han, G., Hao, X., Zhao, M., Wang, M., Ellert, B. H., & Willms, W. (2008). Effect of grazing intensity on carbon and nitrogen in soil and vegetation in a meadow steppe in Inner Mongolia. *Agriculture, Ecosystems & Environment, 125*, 21-32.

Herlocker, D. J. (1995). *Range management handbook of Kenya : Vol. III,10, range resource monitoring : field and office guidelines*. Nairobi: Ministry of Livestock Development (MOLD).

Herlocker, D. J. (1999). *Rangeland ecology and resource development in eastern Africa*. Nairobi: German Agency for Technical Co-operation.

Hiernaux, P., & Turner, M. D. (1996). The effect of clipping on growth and nutrient uptake of sahelian annual rangelands. *Journal of Applied Ecology 33*, 387-399.

Hodgson, J. (1990). *Grazing management: Science into practice*. Essex, England: Longman Group UK Limited.

Jansen, L. J. M., & Gregorio, A. D. (2002). Parametric land cover and land-use classifications as tools for environmental change detection. *Agriculture, Ecosystems & Environment, 91*(1-3), 89-100.

Jensen, J. R. (1996). *Introduction to digital image processing* (2nd ed.). New Jersey: Prentice-Hall, Inc.

Jones, R. J. (1990). Phosphorus and beef production in northern Australia. 1. Phosphorus and pasture productivity

Tropical Grasslands, 24, 131 - 139.

Kassahun, D., & Afsaw, S. (2008). Variability and management patterns of range resources in the Baro River plain, Ethiopia. *Area, 40*(1), 108-116.

Kent, M., & Coker, P. (1992). *Vegetaion description and analysis: A practical approach*. London: Belhaven Press.

Kent, M., & Coker, P. (1994). *Vegetaion description and analysis: A practical approach*. London: Belhaven Press.

Lanta, V., Dole, J., Lantová, P., Kelí, J., & Mudrák, O. (2009). Effects of pasture management and fertilizer regimes on botanical changes in species-rich mountain calcareous grassland in Central Europe. *Grass and Forage Science, 64*(4), 443-453.

Li, C., Hao, X., Willms, W. D., Zhao, M., & Han, G. (2009). Seasonal response of herbage production and its nutrient and mineral contents to long-term cattle grazing on a Rough Fescue grassland. *Agriculture, Ecosystems & Environment, 132*(1-2), 32-38.

Li Jianlong, T., L., Quangong, C. (1998). Estimating grassland yields using remote sensing and GIS technologies in China. *New Zealand Journal of Agricultural Research, 41*, 31 - 38.

Liang, T., & Chen, Q. (1999, 19-21 June). *Applications of GIS and remote sensing technologies on grassland monitoring and management in China.* Paper presented at the Geoinformatics, Berkeley.

Lillesand, T. M., Kiefer, R. W., & Chipman, J. W. (2004). *Remote sensing and image interpretation*. New York: John Wiley & Sons Inc.

Lin, Y., Hong, M., Han, G., Zhao, M., Bai, Y., & Chang, S. X. (2010). Grazing intensity affected spatial patterns of vegetation and soil fertility in a desert steppe. *Agriculture, Ecosystems & Environment, 138*(3-4), 282-292.

Lomolino, M. V., Riddle, B. R., & Brown, J. H. (2006). *Biogeography*. Sunderland: Sinauer Associates, Inc.

Majaliwa, J. G. M., Twongyirwe, R., Nyenje, R., Oluka, M., Ongom, B., Sirike, J., et al. (2010). The Effect of Land Cover Change on Soil Properties around Kibale National Park in South Western Uganda. *Applied and Environmental Soil Science, 2010,* 7 pages.

Martin, R. C., Astatkie, J. M., & Fredeen, A. H. (2005). A comparison of methods used to determine biomass on naturalized swards. *Journal of Agronomy and crop science, 191*, 152-160.

McArthur, E. D., Kitchen, S. G., Uresk, D. W., & Mitchell, J. E. (2000). Applicability of Montreal Process Criterion 2 - productive capacity of rangeland sustainability. *Int. J. Sustain. Dev. World Ecol., 7,* 97 - 106.

McCloy, K. R. (1995). *Resource management information systems; process and practice*. London: Taylor & Francis.

McGinty, A., Thurow, T. L., & Taylor, C. A. (1991). Improving rainfall effectiveness on rangeland. *Texas Agricultural Extension Bulletin, L-5029,* 6 pages.

McNeely, J. A., Gadgil, M., Leveque, C., Padoch, C., & Redford, K. (1995). Human influence on biodiversity. In V. H. Heywood (Ed.), *Global biodiversity assessment* (pp. 715 - 802). Cambridge: United Nations Environment Programme (UNEP).

Microsoft. (2003). Microsoft office access 2003 (11.5614.8117). Washington, USA: Microsoft corporation.

Mligo, C. (2009). Determination of the soil organic carbon, nitrogen, available phosphorus and the combined aboveground plant materials in the semi-arid Mbulu District, Tanzania. *African Journal of Ecology, 47*(3), 352-359.

Mohammed, A. S., & Bekele, T. (2009). Forage production and plant diversity in two managed rangelands in the Main Ethiopian Rift. *African Journal of Ecology, 48*(1), 13-20.

Moisey, D. M., Bork, E. W., & Willms, W. D. (2005). Non-destructive Assessment of cattle forage selection: A test of skim grazing in fescue grassland. *Appl. Anim. Behav., 94,* 205 - 222.

MoLHUD. (2007). *The national land use policy.*

Moreau, S., Bosseno, R., GU, X. F., Baret, F. (2003). Assessing the biomass of Andean bofedal and totora high-protein wetland grasses from NOA/AVHRR. *Remote sensing of Environment, 85*, 516-529.

Mueller-Dombos, D., & Ellenberg, H. (1974). *Aims and methods of vegetation Ecology*: John Wiley & Sons, Inc.

NBS. (1992). *Technical report, National Biomass Study, Phase I*. Kampala, Uganda: Forest department.

NEMA. (2002). *State of Environment report for Uganda*. Kampala, Uganda: National Environment Authority (NEMA).

Okello, S., Sabiiti, E. N., & Schwartz, H. (2005). Factors affecting *in sacco* dietary degradation by Ankole cattle grazing natural range pastures in Uganda. *African Journal of Range and Forage Science, 22*(3), 157 - 165.

Olsvig-Whittaker, L. S., Naveh, Z., Giskin, M., & Nevo, E. (1992). Microsite Differentiation in a Mediterranean Oak Savanna. *Journal of Vegetation Science, 3*(2), 209-216.

Olupot, W., Parry, L., Gunnes, M., & Plumptre, A. J. (2010). *Conservation research in Uganda's savannas*. New York: Nova Science Publishers, Inc.

Osborne, P. L. (2000). *Tropical ecosystems and ecological concepts*. Cambridge: Cambridge University Press.

Otukei, J. R., & Blaschke, T. (2010). Land cover changes assessment using decision trees, support vector machines and maximum likelihood classification algorithms. *International Journal of Applied Earth Observation and Geoinformation, 12S*, S27 - S31.

Peake, D. C. I., Myers, R. J. K., & Henzelle, E. F. (1990). Soown pasture production in relation to nitrogen fertilizer and rainfall in southern Queensland. *Tropical Grasslands, 24*, 291 - 298.

Phillips, R., Beeri, O., Scholljegerdes, E., Bjergaard, D., & Hendrickson, J. (2009). Integration of geospatial and cattle nutrition information to estimate paddock grazing capacity in Northern US Prairie. *Agric. Syst., 100*, 71 - 79.

Pickup, G. (1994). Modelling patterns of defoliation by grazing animals in rangelands. *Applied Ecology, 31*(2), 231 - 246.

Pihlgren, A., & Lennartsson, T. (2008). Shrub effects on herbs and grasses in sem-natural grassland: positive, negative or neutral relationships? *Grass and Forage Science, 63*, 9-21.

Pitman, W. D., Portier, K. M., Chambliss, C. G., & Kretschmer, A. E. (1992). Performance of yearling steers grazing bahia grass pastures with summer annual legumes or nitrogen fertiliser in subtropical Florida. *Tropical Grasslands, 26*, 206 - 211.

Pontes, L. S., Carrère, P., Andueza, D., Louault, F., & Soussana, J. F. (2007). Seasonal productivity and nutritive value of temperate grasses found in semi-natural pastures in Europe: responses to cutting frequency and N supply. *Grass and Forage Science, 62*(4), 485-496.

Pratt, D. J., & Gwynne, M. D. (1977). *Rangeland management and ecology in East Africa*. Huntington, New York: Robert E. Krieger Publishing Co., Inc.

Price, K. P., Guo, X., & Stiles, J. M. (2002). Optimal Landsat TM band combinations and vegetation indices for discrimination of six grassland types in eastern Kansas. *International Journal of Remote sensing, 23*(11), 5031 - 5042.

Putfarken, D., Dengler, J., Lehmann, S., & Härdtle, W. (2008). Site use of grazing cattle and sheep in a large scale pasture landscape: A GPS/GIS assessment. *Applied Animal Behaviour Science, 111*, 54-67.

Reeves, M. C., Winslow, J. C., & Running, S. W. (2001). Mapping weekly Rangeland Vegation Productivity using MODIS Algorithms. *J. Range Manage, 54*, A90 - A105.

Reeves, M. C., Zhao, M., Running, S.W. (2006). Applying improved estimates of MODIS productivity to characterise grassland vegetation dynamics. *Journal of rangeland ecology and management*, *59*(1), 1-10.

Roy, P. S., & Ravan, S. A. (1996). Biomass estimation using satellite remote sensing data—An investigation on the possible approaches for natural forest. *J. Biosci, 21*(4), 535 - 561.

Sánchez-Jardón, L., Acosta, B., del Pozo, A., Casado, M. A., Ovalle, C., Elizalde, H. F., et al. (2010). Grassland productivity and diversity on a tree cover gradient in Nothofagus pumilio in NW Patagonia. *Agriculture, Ecosystems & Environment, 137*(1-2), 213-218.

Santos, F. L., Reis, J. L., Martins, O. C., Castanheira, N. L., & Serralheiro, R. P. (2003). Comparative Assessment of Infiltration, Runoff and Erosion of Sprinkler Irrigated Soils. *Biosystems Engineering*, *86*(3), 355-364.

Schmidt, K. S., & Skidmore, A. K. (2002). Spectral discrimination of vegetation types in a coastal wetland. *Remote Sensing of Environment, 85*, 92 - 108.

Schulze, R. E. (1997). Climate. In R. M. Cowling (Ed.), *Vegetation of southern Africa* (pp. 21-41). Cambridge: Cambridge University Press.

Skarpe, C., Aarrestad, P. A., Andreassen, H. P., Dhillion, S. S., Dimakatso, T., du Toit, J. T., et al. (2004). The return of the giants: Ecological effects in an increasing elephant population. *Ambio, 33*(6), 276-282.

Skerman, P. J., Cameron, D. G., & Riveros, F. (1988). *Tropical forage legumes*. Rome: Food and Agriculture Organisation of the United Nations.

Stoddart, L. A., & Smith, A. D. (1955). *Range Management*. New York: McGraw-Hill Book Company, Inc.

Su, L., Chopping, M. J., Rango, A., Martonchik, J. V., & Peters, D. P. C. (2006). Support vector machines for recognition of sem-arid vegetation types using MISR multi-angle imagery. *Remote Sensing of Environment, 107*, 299 - 311.

Tate, K. W., Atwili, E. R., McDougald, N. K., & George, M. R. (2003). Spatial and temporal patterns of cattle feces deposition on rangeland. *Range manage, 56*, 432 - 438.

Tibor, T. (2010). Medium-term vegetation dynamics and their association with edaphic conditions in two Hungarian saline grassland communities. *Grassland Science, 56*(1), 13-18.

Tiemann, T. T., Franco, L. H., Peters, M., Frossard, E., Kreuzer, M., Lascano, C. E., et al. (2009). Effect of season, soil type and fertilizer on the biomass production and chemical composition of five tropical shrub legumes with forage potential. *Grass and Forage Science, 64*(3), 255-265.

'tMannetje, L. (1990). Pasture and animal productivity of buffel grass with siratro, lucerne or nitrogen fertilizer. *Tropical Grasslands, 24*, 269 - 281.

Townshend. (1983). *Effects of spatial resolution on the classification of land cover type.* Paper presented at the Ecological Mapping from Ground, Air and Space, ITE, Monks Wood Experimental Station, Abbots Ripton, Huntingdon.

Trodd, N. M., & Dougill, A. J. (1998). Monitoring vegetation dynamics in semi-arid African rangelands: Use and limitations of Earth observation data to characterize vegetation structure. *Applied Geography, 18*(4), 315-330.

Tsegaye, D., Haile, M., Yifter, F., & L., T. (2004). Assessment of rangeland condition and livestock mobility pattern in Aba'ala Wereda, north Afar Field survey and application of geographic information systems. In M. Haile, D. Tsegaye & T. Teka (Eds.), *Research and development on dryland husbandry in Ethiopia* (pp. 67 - 89). Addis Ababa: Dryland Husbandry Project (DHP).

Tueller, P. T. (1989). Remote sensing technology for rangeland management applications. *j. range manage, 42*(6), 442 - 453.

Tueller, P. T. (1993). *Vegetation science application for rangeland analysis and management* (Vol. 14). Dordrecht.: Kluuwer academic publishers.

Turner, M. D. (1998). Long-term effects of daily grazing orbits on nutrient availability in Sahelian West Africa: 2. Effects of phosphorus gradient on spatial patterns of annual grassland production. *Journal of Biogeography, 25*, 683-694.

Turner, M. D. (1999). Spatial and temporal scaling of grazing impact on the species composition and productivity of Sahelian annual grasslands. *Journal of Arid Environments, 41*, 277 - 297.

Turner, M. D. (2003). Methodological reflections on the use of remote sensing and geographic information science in human ecological research. *Human Ecol, 31*(2), 255-279.

Turner, M. D., & Congalton, R. G. (1998). Classification of multi-temporal SPOT-XS satellite data for mapping rice field on a West African floodplain. *Int. J. Remote Sensing, 19*(1), 21 - 41.

Turner, M. D., Hiernaux, P., & Schlecht, E. (2005). The distribution of grazing pressure in relation to vegetion resources in sem-arid West Africa: The role of herding. *Ecosystems, 7*, 1-14.

Umrani, A. P. (1998). Sustainable approaches for rangeland management and livestock production in arid and sem arid regions of tropical countries. Retrieved 27-8, 2008

UNEP. (2006). *Africa environment outlook*. Nairobi: UNEP.

Vallentine, J. F. (1989). *Rangeland development and improvement*. San Diego, California: Academic press Inc.

van Wijngaarden, W. (1985). *Elephants - Trees - Grass - Grazers; Relationships between climate, soils, vegetation and large herbivores in a sem-arid savanna ecosystem (Tsavo, Kenya)*. Enschede: International institute for aerospace survey and earth sciences (ITC)

Verbyla, D. L. (1995). *Satellite remote sensing of natural resources*. New York: Lewis Publishers.

Vermeire, L. T., & Gillen, R. L. (2001). Estimating herbage standing crop with visual obstruction in tallgrass prairie. *J. Range manage., 54*(1), 57 - 60.

Verweij, P. A. (1995). *Spatial and temporal modelling of vegetation patterns: Burning and grazing in the Paramo of Los Nevados National Park, Colombia.* Unpublished PhD, International institute for aerospace survey and earth sciences (ITC), Enschede.

Vicente-Serrano, S. M., Pérez-Cabello, F., & Lasanta, T. (2008). Assessment of radiometric correction techniques in analyzing vegetation variability and change using time series of Landsat images. *Remote Sensing of Environment, 112*(10), 3916-3934.

Winks, L. (1990). Phosphorus and beef production in northern Australia. 2. Responses to phosphorus by ruminants. *Tropical Grasslands, 24*, 140 - 158.

Woolley, L., Millspaugh, J. J., Woods, R. J., van Rensburg, S. J., Page, B. R., & Slotow, R. (2009). Intraspecific Strategic Responses of African Elephants to Temporal Variation in Forage Quality. *Journal of Wildlife Management, 73*(6), 827-835.

Xie, Y., Becker, U., & Wittig, R. (2007). Vegetation of the Stipa loess steppe in Ningxia (northern China) in relation to grazing intensity. *Grassland Science, 53*, 143 - 154.

Zarovali, M. P., Yiakoulaki, M. D., & Papanastasis, V. P. (2007). Effects of shrub encroachment on herbage production and nutritive value in semi-arid Mediterranean grasslands. *Grass and Forage Science, 62*(3), 355-363.

Zeng, N., & Neelin, J. D. (2000). The role of vegetation -climate interaction and interannual variability in shaping the african savanna. *J. Climate, 13*, 2665 - 2670.

CHAPTER FIVE

5.0 Classification and Mapping of Vegetation Physiognomic Composition

Abstract

Despite the significant role of vegetation maps in understanding and monitoring patterns of rangeland ecosystems, limited work has been done in mapping rangeland vegetation, especially in Africa. In this study, characterisation of vegetation composition and assessment of Landsat and IKONOS Sensors spectral discrimination effectiveness for mapping vegetation physiognomic cover types was done. Maximum (ML) likelihood and fuzzy classifiers were used.. Plot vegetation species growth form, cover and height data were collected from 450 sampling sites based on eight spectral strata generated using unsupervised image classification. Field data were grouped at four levels of seven, six, three and two vegetation physiognomic classes which were subjected to both ML and fuzzy classification using both Landsat and IKONOS satellite images. The most dominant species were found to be *Acacia* spp, *Carisa edulis, Rhus natalensis*, *Sporobolus pyramidalis* and *Brachiaria decumbens.* Results of mapping accuracy assessment showed that IKONOS imagery resulted in higher accuracy than Landsat but the difference was not statistically significant. Fuzzy classification was associated with significantly higher mapping accuracy than ML ($p<0.01$). The highest overall accuracy with ML was 62.8% and 76.2% for Landsat and IKONOS respectively compared to 66.4% and 81% when using fuzzy classification. When compared to previous studies, results showed that vegetation composition is shifting from woody to herbaceous dominant vegetation cover with predominance of stress resistant grass species. Improvement in mapping accuracy results when using fuzzy classifiers as compared to ML, provides useful insights in the limitations of maximum likelihood and the need to investigate other classifiers in order to improve rangeland vegetation mapping and monitoring.

5.1 Introduction

Understanding the distribution of vegetation cover types is important for determining the patterns of variability and change of rangeland forage (Vicente-Serrano et al., 2006). Classification and mapping of variations in vegetation communities is a necessary early element of rangeland inventory. Vegetation maps are used as a basis for planning, implementing and analyzing the results of subsequent rangeland inventory activities and perusal of the maps themselves often provides insights into broad environmental patterns and ecological relationships (Boelman et al., 2005; Herlocker, 1999). Despite the significant role that vegetation cover information plays in monitoring, no or limited work has been done in mapping rangeland vegetation especially in Africa. There is need for up-to-date information on rangeland vegetation cover for grazing management. The characteristic rangeland vegetation dynamics associated with fire (Archibald, 2008), grazing (Mueller-Dombos and Ellenberg, 1974) and the recent changes driven by human population expansion (Gordon, 2009) deem regular rangeland vegetation mapping inevitable.

Satellite remote sensing from space is the best method for regularly updating maps of the rangeland vegetation cover (Chopping, et al., 2006). It allows for a quick, cost effective and systematic way of obtaining uniform and up-to-date information (Beeri et al., 2007; Booth and Tueller, 2003; Moreau, 2003). Studies have revealed that use of remote sensing has improved environmental analysis by providing a means to expand their temporal and spatial scales (Booth and Tueller, 2003; Turner, 2003). Attempts in vegetation mapping projects have been conducted using mid-resolution satellite imagery especially Landsat (Trodd and Dougill, 1998). Moreover these mapping efforts have been centred on general land cover mapping (NBS, 1992; Otukei and Blaschke, 2010) and not vegetation cover structure, which is essential for quantifying pastureland productivity. Low cost vegetation mapping that will detect ecologically important variations in structure and composition over extensive rangelands with acceptable error rates is essential for rangeland management (Booth and Tueller, 2003). There have been no comprehensive rangeland vegetation mapping for Uganda using satellite imagery and as such, there is lack of knowledge regarding the use of spectral discrimination of the vegetation classes unique to Ugandan rangelands.

Whereas the costs of high resolution imagery like IKONOS pose a financial challenge (Booth and Tueller, 2003) especially for the developing world, their advantage over medium resolution of providing high quality imagery needs to be explored for improved vegetation mapping. There is also need to test and establish the best classification techniques for rangeland vegetation mapping. Rangeland vegetation in East Africa is characterised by a recurring pattern of small vegetation patches (Bloesch, 2002; Pratt and Gwynne, 1977) that make it difficult to have entirely homogenous image pixels even with very high resolution imagery. The specific design of fuzzy classification is potentially useful in solving such mapping problems associated with mixed pixels (Jensen, 1996; Lillesand et al., 2004). Therefore there is need to exploit the potential provided by this classifier for obtaining reliable information on rangeland vegetation.

This chapter explores the possibilities of quick, systematic and cost effective rangeland vegetation mapping procedures that maximize physiognomic classification accuracy. The physiognomic classification considered here, consists of description and measurement of the life form and appearance of the vegetation (Brower et al., 1997). The questions addressed in this chapter were: What is the vegetation physiognomic and species composition? Can the rangeland vegetation physiognomic classification as documented by Pratt and Gwynne (1977) be effectively discriminated using Landsat and IKONOS satellite images? How does fuzzy classifier compare to Maximum Likelihood for rangeland physiognomic vegetation classification?

5.2 Data and Methods

5.2.1. Satellite Imagery

IKONOS imagery for June 2009 and Landsat Enhanced Thematic Mapper (ETM+) (Path/Row 185/60) for February 2008 were used. The images were orthorectified and georeferenced to WGS84, UTM Zone 36S. Landsat and IKONOS images were obtained from the archives of United States Geological Surveys (USGS) and Satellite Imaging Corporation (SIC) respectively. Due to cost limitations, a small portion of IKONOS image approximately 75Km^2 of the study area was used and it was not possible to obtain Landsat and IKONOS images for the same season. It was envisaged that use of images for different months would undermine the comparison of classification results. However, since the vegetation and weather conditions in February and June are fairly similar, it was assumed that the effect of the difference on results would not be significant.

5.2.2 Image and Field Sampling

Based on experience from field reconnaissance and visual inspection of different combinations of 5, 4, 3 and 2 bands, a Landsat image for February 2008 was stratified into 10 spectral patterns of cover classes (strata) (Figure 5.1) using unsupervised classification in ERDAS IMAGINE 9.1 software. From eight of the resulting strata, a total of 450 sampling plot locations were selected randomly with at least 50 in each of the strata. Two strata which corresponded with wetlands and water surfaces were not considered for sampling. All other separately classified image strata of 60 x 60 meters (16 pixels) or greater were equally considered for sampling (Townshend, 1983). Equal sampling in the different strata was based on the assumption that since they were derived from spectrally homogenous pixels, the vegetation composition was similarly homogeneous. The location centre coordinates of the 450 randomly selected sites on the classified image were determined and entered into a Garmin 12 handheld Global Positioning System (GPS) for navigation. From the sampling locations in the field, vegetation physiognomic composition (growth form (tree, shrub or herbaceous), cover and height) data were collected following plot size descriptions by Kent and Coker (1994) for different vegetation cover types. Plots of 30 by 30m, 15 by 15m and 2 by 2m were used for tree, shrub and herbaceous cover respectively. To cater for seasonal differences of the image acquisition, data were collected for all the seasons in which the separate images were acquired. To minimise time spent in the field, sampling sites were selected in areas which covered as many strata as possible to reduce travel distance between sampling points (Mueller-Dombos and Ellenberg, 1974). Field sampling focused on cover types that are used for grazing. Information on crop fields and settlement cover which were not considered during data collection was obtained from National Forestry Authority (NFA) and integrated with data from the field.

Sampling locations (Figure 5.1) in the field as randomly selected from the image-derived strata were navigated to using GPS compass direction and distance. Locations which could not be accessed or near to human settlements and crop fields were replaced using the same sampling procedure. Where more than one vegetation cover types occurred, the herbaceous layer plot was nested into shrub plot, and shrub plot into tree plot. For each plot, individual species percentage cover and height were visually estimated and recorded on a datasheet (Appendix 3.1). Plant species identification was done under the guidance of an experienced taxonomist. To ensure consistency in percentage cover estimates, the sampling team was trained together in the field as recommended by Kercher *et al* (2003). The training was done using calculated percentage cover charts (Appendix 3.2) whereby team members independently estimated chart cover values and continuously compared results up to a time when consistent cover estimates were reported by all members. For each plot, location centre coordinates were recorded using hand held Trimble explorer and Garmin 12 GPS.

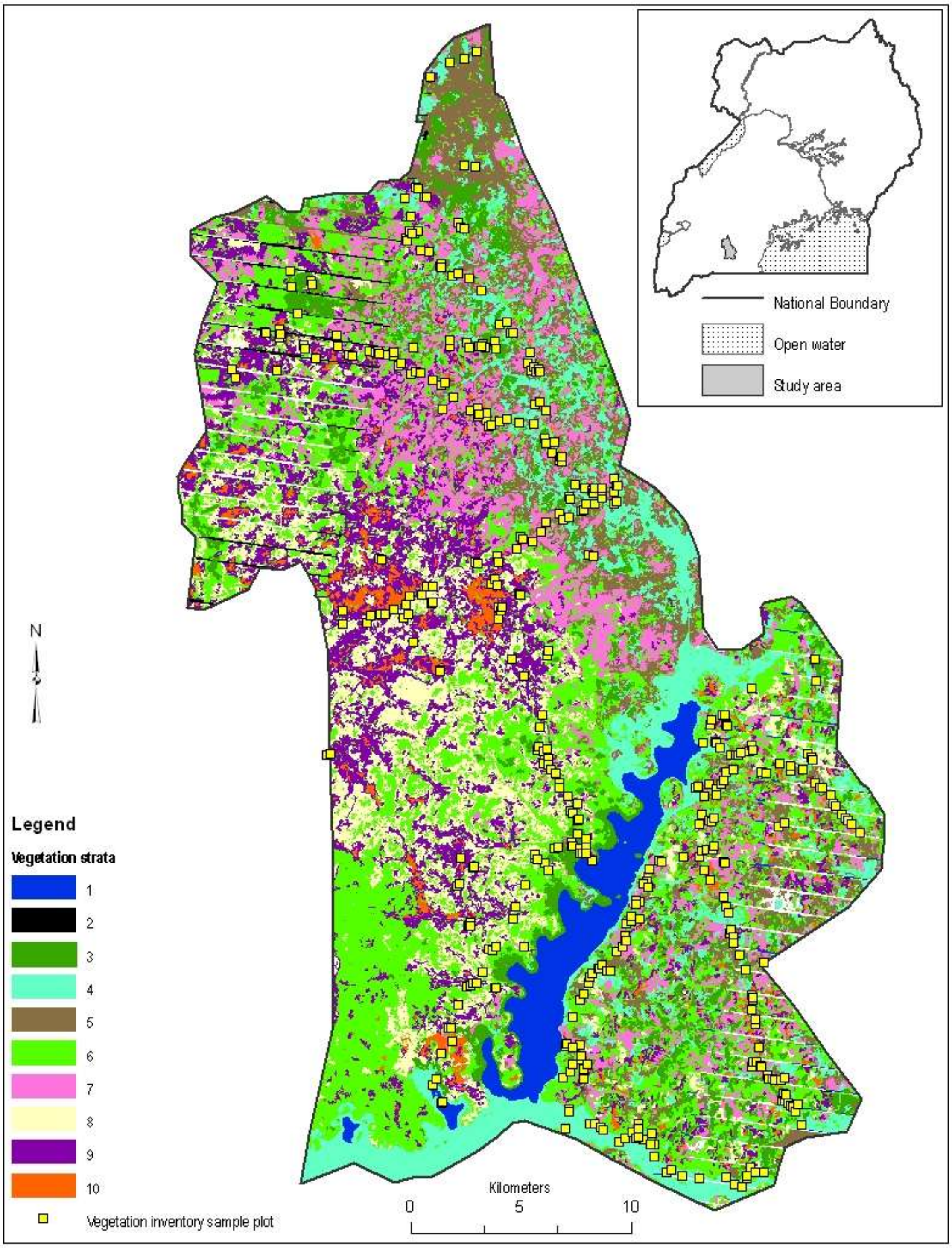


Figure 5.1: Location of sampling sites

5.2.3 Field Data Processing

Using the vegetation physiognomic description (Table 5.1) by Pratt and Gwynne (1977), vegetation growth form, cover and height data from field plots were grouped into physiognomic classes and entered into a Microsoft access relational database. The data were randomly divided into two datasets: one for classification training sample set and the other for accuracy assessment. In order to reflect differences in months of data collection in the two datasets, the random division was done according to the seasons of field data collection. This was also aimed at minimising the effect of the difference seasons of image acquisition on classification results.

Table 5.1: Physiognomic vegetation strata (adopted from Pratt and Gwynne, 1977)

Cover type	Descriptions
Bushland	Assemblage of trees and shrubs; Shrubs are dominant; Trees are conspicuous; Shrubs and tress cover >20%; Height of trees =<10 meters
Bushland thicket	Extreme form of bushland with a closed form of woody plants; Man or larger ungulates can pass with extreme difficulty
Woodland	With an open or continuous but not thickly connected canopy; Grasses dominate the ground cover ; Trees cover up >20%; Height of trees up to 20 meters
Shrubland	Land supporting a stand of shrubs; Poor ground cover; Shrub height =< 6 meters; Shrub cover >20; Trees cover 0 or <10%
Grassland	Dominated by grasses and occasionally other herbs; May have scattered or grouped trees and shrubs; Shrubs and trees cover 0 or <2%
Bush grassland	Grassland with scattered or grouped trees and shrubs—both always conspicuous; Shrub and trees cover <20%
Wooded grassland	With scattered or grouped trees; Trees always conspicuous and determine the classification; Trees cover <20%

5.2.4 Image Classification

Evaluation of mapping results and their accuracies was done using both Maximum-likelihood (ML) and fuzzy classification based on the plot data physiognomic classes. The steps for selection of training sites included assessment of statistical distribution of digital numbers of pixels around a given training point at a given site and comparing them with alternative sets of signatures of other field points with the same vegetation class and the subsequent selection of the best set to perform the classification.

5.2.5 Accuracy Assessment and Classification Improvement

Using the accuracy assessment dataset, validation of the classification results was done. Confusion (error) matrices were constructed for classified vegetation maps and the testing dataset in ERDAS IMAGINE 9.1. Overall, producer's and user's accuracies were obtained using the following formulae:

Overall accuracy = Total correctly classified pixels / Total number of pixels in the matrix

Producer's accuracy = Number of correctly classified pixels of a vegetation class / Total number of reference pixels for that class

User's accuracy = Number of correctly classified pixels of a vegetation class / Total Number of pixels classified to that class

The comparisons of mapping results between Landsat and IKONOS images and between ML and fuzzy classification were tested using a t-test at a confidence interval of 95%.

5.3 Results

5.3.1 Vegetation Physiognomic and Species Composition

Vegetation species cover and height plot data resulted in seven physiognomic classes bush grassland, bushland thicket, bushland, grassland, shrubland, woodland and wooded grassland). The most dominant tree species was *Acacia* sp; shrubs were mainly dominated by *Carisa edulis* and *Rhus Natalensis* species (Table 5.2). *Sporobolus pyramidalis* and *Brachiaria decumbens* dominated herbaceous cover (Figure 5.2). The vegetation cover was mainly constituted of 7.7% trees, 24.4% shrubs and 49.2% grasses. Other herbs were least dominant across all vegetation types with an average cover of 4.6%. The average height for trees was 7.6m, 2m for shrubs and 20 cm for herbaceous layer.

Table 5.2: Vegetation Physiognomic and species composition

	Woody		**Herbaceous**		**Dominant species**	
Vegetation type	Cover (%)	Height (m)	Cover (%)	Height (cm)	Woody	Herbaceous
Bush grassland	22	1 -8	66	3 - 45	*Acacia gerrardii* *Acacia hockii*	*Sporobolus pyramidalis* *Brachiaria decumbens*
Bushland thicket	51	2 -14	33	1-42	*Acacia hockii* *Acacia sieberiana* *Rhus natalensis*	*Sporobolus pyramidalis* *Brachiaria decumbens*
Bushland	31	1-5	54	5-53	*Carrisa edulis* *Acacia hockii* *Acacia gerrardii* *Rhus natalensis*	*Sporobolus pyramidalis* *Brachiaria decumbens*
Grassland	7	1-7	68	5-100	*Lantana camara* *Acacia hockii*	*Cymbopogon nardus* *Brachiaria decumbens* *Loudetia kagerensis*
Shrubland	36	2-6	47	5-45	*Acacia gerrardii* *Rhus natalensis*	*Sporobolus pyramidalis* *Brachiaria decumbens*
Woodland	51	2-8	33	4-23	*Acacia hockii* *Acacia gerrardii* *Rhus natalensis*	*Setaria homonyma* *Brachiaria decumbens*
Wooded grassland	24	3-11	67	4-85	*Acacia hockii* *Acacia gerrardii* *Rhus natalensis*	*Sporobolus pyramidalis* *Brachiaria decumbens*

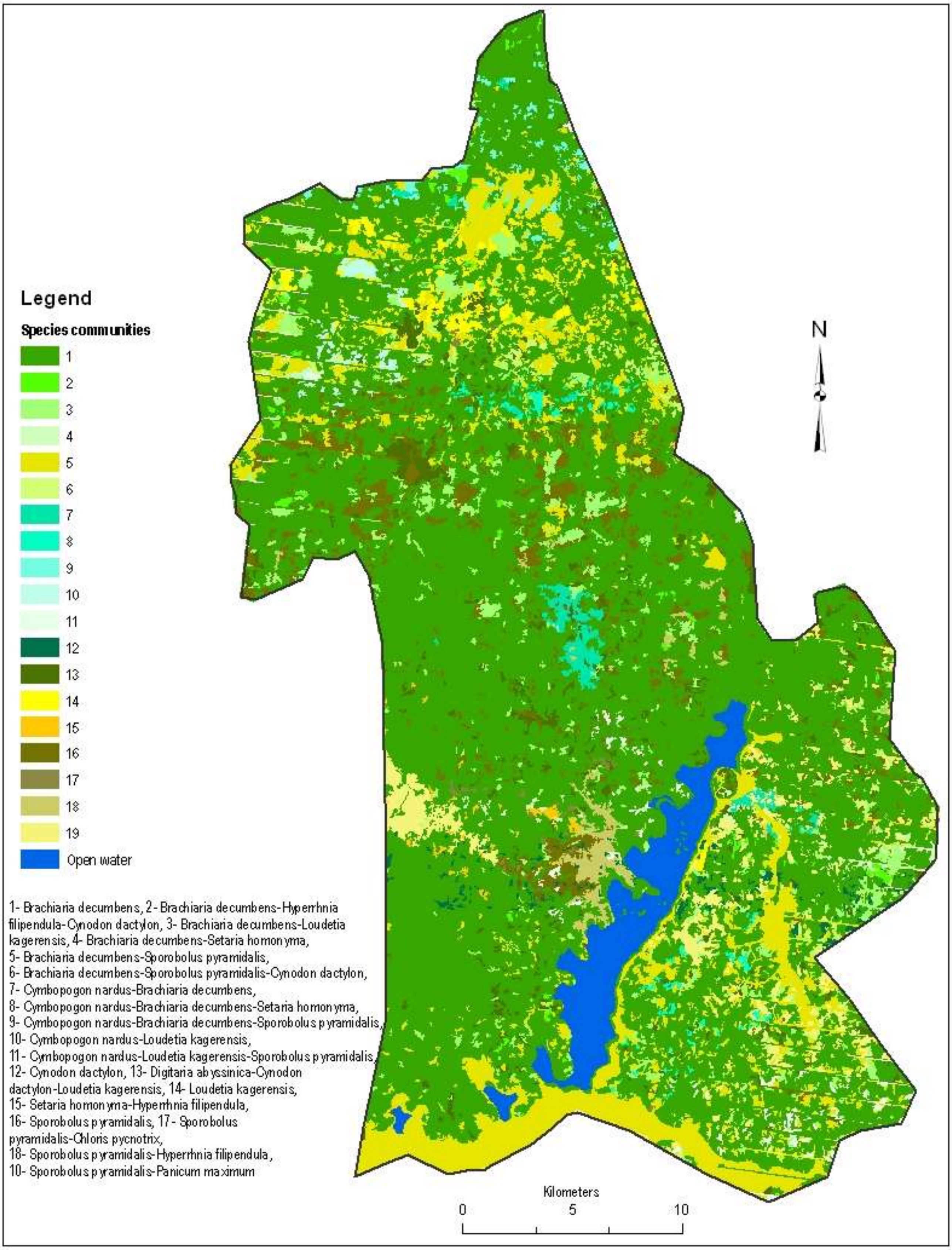


Figure 5.2: The distribution of dominant herbaceous Species in the study area

Image Classification and Accuracy Assessment

Using all the seven physiognomic classes from field vegetation data, the overall accuracy with Landsat was 17.6% and 23% for ML and fuzzy classification respectively. The overall classification accuracy for IKONOS was 23.8% and 33% with ML and fuzzy classification respectively (Appendix 5.3). With such unsatisfactory results, an attempt was made to merge the seven classes at different levels through an iterative classification process to evaluate whether merged classes would result in better accuracy of vegetation mapping. Merging was based on the nature of overlap in the class definitions as reflected in the field data and classification results of the seven classes. The resulting three levels of vegetation class merging were: six classes (Grassland, Bushland, Bushland thicket, Shrubland Wooded grassland, Woodland); three (Grassland, Bushland, Woodland); and two classes Grassland, Woodland) (Table 5.3). Each of these three vegetation physiognomic class grouping levels was subjected to ML and fuzzy classification using both Landsat and IKONOS imagery. The last level (two classes) was as a result of grouping all woody vegetation dominated classes into a woodland class and those dominated by herbaceous cover into a grassland class.

Table 5.3: Summary of the vegetation classes merging levels

Classification Level (Classes)	**Merged Classes (New Name)**	**Classes Used**
Level 1 (All 7 classes)	No merging done	Grassland, Bush grassland, Bushland, Bushland thicket, Shrubland Wooded grassland, Woodland
Level 2 (6 classes)	Grassland + Bush grassland (Grassland)	Grassland, Bushland, Bushland thicket, Shrubland Wooded grassland, Woodland
Level 3 (3 classes)	Grassland + Bush grassland + Wooded grassland (Grassland) Bushland + Shrubland + Bushland thicket (Bushland)	Grassland, Bushland, Woodland
Level 4 (2 classes)	Grassland + Bush grassland + Wooded grassland (Grassland) Bushland + Shrubland + Bushland thicket + Woodland (Woodland)	Grassland, Woodland

Classification Comparisons

Generally, merging classes resulted in improvement of classification accuracy for both ML and Fuzzy classification (Table 5.4). With ML, the first level of merger from seven to six classes resulted in an overall accuracy improvement of 11% and 16.9% for Landsat and

IKONOS respectively. With the same number of classes, accuracy results from fuzzy classification when using IKONOS were marginally higher (41.7%) than for ML (40.7%). On the other hand, fuzzy classification accuracy was higher than for ML when using Landsat. ML classification at the third level of merger to three classes (grassland, shrubland and woodland) resulted in an overall accuracy of 57.1% with Landsat image and 62% for IKONOS. Fuzzy classification with Landsat yielded higher overall accuracy (61.5%) compared to ML. On the contrary, the overall accuracy results of fuzzy and ML were the same for IKONOS image. At this level woodland could not be classified as unique class because of high confusion with shrubland.

The last level of merger with two classes (woodland and grassland) (Figure 5.3) ML classification resulted in an overall accuracy of 62.6% for Landsat and 76.2% for IKONOS (Table 5.4). Fuzzy classification yielded better results than ML for both Landsat and IKONOS. The overall accuracy for fuzzy based classification at this level was 66.4% using Landsat while for IKONOS it was 81%. Classification of IKONOS using ML into these two broader classes resulted in higher producer's accuracy than Landsat for both woodland and grassland (Table 5.5). Similarly, IKONOS registered a higher a user's accuracy for woodlands than Landsat, but the grassland user's accuracy (81.1%) for Landsat was higher than that from IKONOS classification (70%).

All comparisons of ML and Fuzzy within and between IKONOS and Landsat images did not result in any significant differences (Table 5.6). Whereas IKONOS was generally associated with higher classification accuracy, it was not statistically higher than for Landsat (p=0.4). Overall the results of fuzzy classification were significantly better than those from ML algorithm (p=0.005).

Table 5.4: Overall accuracy (%) assessment of Landsat and IKONOS imagery classification using maximum likelihood and fuzzy classifiers

	Landsat		IKONOS	
Number of Classes	ML	Fuzzy	ML	Fuzzy
Seven[a]	17.6	23.1	23.8	33
Six[b]	28.6	33	40.7	41.7
Three[c]	57.1	61.5	61.5	62
Two[d]	62.6	66.4	76.2	81

[a]Grassland, Bush grassland, Bushland, Bushland thicket, Shrubland Wooded grassland, Woodland; [b]Grassland, Bushland, Bushland thicket, Shrubland Wooded grassland, Woodland; [c]Grassland, Bushland, Woodland; [d]Grassland, Woodland

Table 5.5: Maximum likelihood and fuzzy classification user's and producer's accuracy results based on two classes for both Landsat and IKONOS images

	Landsat				IKONOS			
	Producers Accuracy (%)		Users Accuracy (%)		Producers Accuracy (%)		Users Accuracy (%)	
Class Name	ML	Fuzzy	ML	Fuzzy	ML	Fuzzy	ML	Fuzzy
Grassland	62.5	72.6	81.1	84	77.8	67	70	86
Woodland	62.8	78	64.3	73.8	75	92	81	79

Table 5.6: Fuzzy and ML overall classification accuracy comparisons within and between KONOS and Landsat images

Comparison	**p<0.05**
ML and Fuzzy for Landsat	0.776111
ML and Fuzzy for IKONOS	0.813804
ML Landsat and ML IKONOS	0.587859
Fuzzy Landsat Fuzzy IKONOS	0.596954
Over all IKONOS and Landsat	0.405258
Overall ML and Fuzzy	0.004671

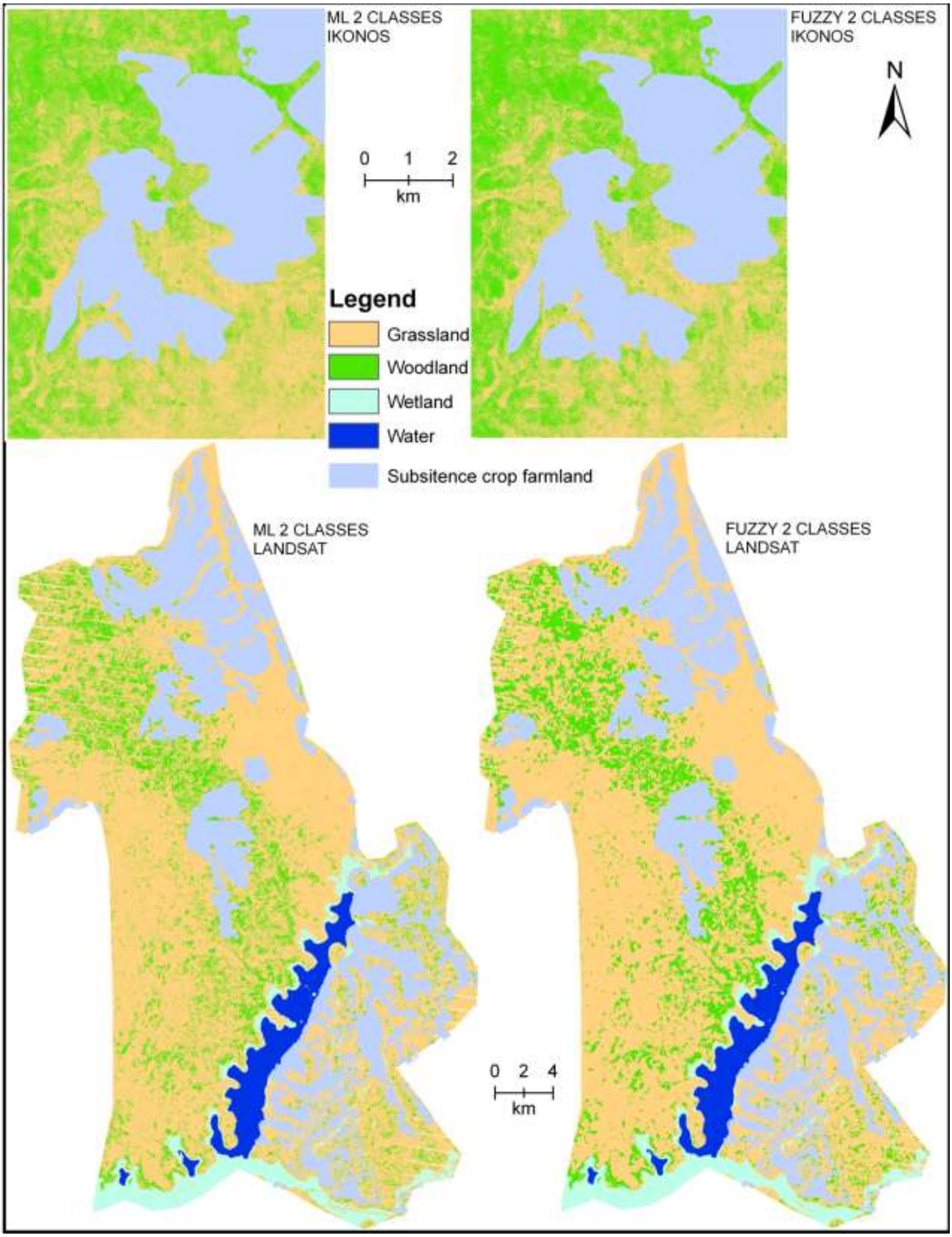


Figure 5.3: Vegetation classification maps from IKONOS and Landsat imagery using maximum likelihood and fuzzy respectively

5.4 Discussion

5.4.1 Vegetation Physiognomic and Species Composition

Results of plant species composition in the study were generally similar to what was reported by Pratt and Gwynne (1977). However, herbage species composition was found to be dominated by *Brachiaria* species and *Sporobolus* species as opposed to the dominance of *Hyperrhenia* species and *Themeda* species that was reported by Langdale-Brown (1970). This change in grass species dominance is most probably due to the effect of increased grazing pressure. *Hyperrhenia* and *Themeda* species have been reported to be less resistant to grazing pressure compared to *Brachiaria* species especially *B. decumbens* which is an aggressive invader by nature because of its creeping habit and underground stolons (Purseglove, 1988). The dominance of *S. pyramidalis* is due to its fibrous nature that is normally detested by grazers. *S. pyramidalis* is also very resilient to disturbances like trampling, seasonal flooding, and excessive drought and burning (Phillips, Namaganda, & Lye, 2003). Increasing grazing pressure and the associated changes in botanical composition in the study area are mainly due to increase in livestock population. Together with other increasing rangeland resource use demands, the rising pressure may lead to accelerated rangeland degradation, if not well managed. Whereas the intensity of fires has decreased in the recent past, annual bushfires in the area might be having a significant contribution to the alterations in species composition (UWA, 2003).

Compared to the vegetation report by Pratt and Gwynne (1977) the current growth form composition has shifted from woody to herbaceous dominated vegetation cover due to several factors. The most important factor that could have contributed to the shift is loss of woody vegetation as a result of cutting trees for charcoal especially *Acacia* sp. Shrub cover has reduced because of land clearing to increase the amount of herbage available for cattle grazing. Loss of woody vegetation cover is also due to the history and ecology of fires in the area (UWA, 2003) which has always been used to stimulate the re-growth of tender and nutritive herbage during dry seasons. Frequent fires keep rangeland vegetation open by suppressing woody vegetation while favouring the growth of herbaceous vegetation (Herlocker, 1999; Osborne, 2000). In addition, the vegetation shifts could be attributed to increase in land under cultivation compared to what was reported by Pratt and Gwynne (1977). Pressure on rangeland for different uses coupled with poor agricultural practices, such as over-stocking and cultivation on steep slopes are leading to soil erosion. There are gross characteristics of the soil surface reflecting soil erosion processes and moisture infiltration impairment which are leading to reduction in productivity (NEMA, 2004).

Averting degradation resulting from excessive human pressure will require regular monitoring of vegetation cover and composition to establish its spatial and temporal capacity for different management objectives (McNeely et al., 1995). Such information should serve as a regular basis for developing rangeland use policies and management plans. In order to ensure sustainability, policies and plans should take into account both environmental and developmental objective with an aim of striking a balance between the two. Given the spatial temporal variability, management decision and policy evaluations should be based on data that are specific to local changes and prevailing factors. There is evidence that generalised policies and management interventions can lead to rangeland misuse and degradation (Homewood, 2004).

5.4.2 Image Classification and Accuracy Assessment

Classification of Landsat imagery resulted in a relatively lower accuracy compared to IKONOS when using seven vegetation physiognomic classes (Grassland, Bush grassland, Bushland, Bushland thicket, Shrubland Wooded grassland, Woodland). With a lower spatial resolution, discrimination of the vegetation classes when using Landsat ought to have been more affected by mixed pixels than IKONOS. This trend is related to the findings by Phinn et al. (1996) in which they reported the importance of using high resolution imagery in improving vegetation biomass mapping accuracy in an environment characterised by spatial heterogeneity. Vegetation cover types in the study area exhibited a recurring pattern of small patches that may hardly be sharply defined within a Landstat pixel of 30 x 30m. Inevitably, this leads to many mixed pixels within vegetation classes. In their findings, Chopping et al. (2008) demonstrated that in cases of favourable relationships between pixel size and vegetation patch size, the use of higher resolution considerably improved classification accuracy. Whereas Landsat TM has been reported to be a good data source for mapping vegetation (Cingolani et al., 2004), the level of detail presented by the physiognomic classes used for classification was most likely higher than could be detected by the sensor as separate units. For example, it would probably be difficult to capture differences in same size canopies of *Acacia* shrubs which go up to six meters in a shrubland and *Acacia* trees in bushland which may range between 1 and 10 meters as described in the classification used here. The accuracy registered by IKONOS when using seven classes was also still very low with an overall improvement of 3.5% only. Therefore the inaccuracies in classification were beyond the spatial resolution limitations of Landsat and advantages of IKONOS. Results from merging of the seven classes at different levels confirmed that the most plausible explanation for this is the inadequate level of definition of the vegetation classes that could not be well discerned by both satellite sensors.

Merging of classes significantly increased mapping accuracy for both Landsat and IKONOS. A related trend in accuracy improvement due to lowering of number of classification strata was reported by Schmidt (2003). However, even mapping at the second level of six vegetation classes (Grassland, Bushland, Bushland thicket, Shrubland Wooded grassland, Woodland) the accuracy was below 50% for both Landsat and IKONOS images. On the other hand, when the six classes were merged to three classes (grassland, shrubland and woodland) the accuracy increased by 28% for Landsat and 20% with IKONOS. Woodland at this level of classification could not be discriminated from the other two classes (grassland and shrubland). This was most probably due to overlapping spectral characteristics especially between woodland and shrubland whose species composition were in both cases dominated by *Acacia* species save for the differences in growth form and height. Moreover at this level, even the grassland class had woody species included from the original classes (bush grassland and wooded grassland) that potentially have similar spectral characteristics. Therefore the classification based on growth form, height and canopy cover proportion differences used in this study was not sufficient to discriminate these classes at this level resulting in confusion of vegetation classes. It would be interesting to investigate how trees and shrubs can be classified as separate strata based on their physiognomic and spectral differences.

There was a further considerable improvement in accuracy when mapping two vegetation (grassland and woodland) classes by 6% and 14% when using Landsat and IKONOS respectively. This trend of results is a further indication that merging of vegetation classes reduces the effect of patchiness on classification. These results are related to the findings by Cherrill et al. (1994) in which they found out that definition of fewer vegetation classes resulted in more meaningful information units to the Landsat recorded data hence improved accuracy. Besides the patterns of reflectance spectra characteristic of grass dominated herbaceous layer are different than those of woody vegetation hence making it much easier to discriminate and map them with a relative higher accuracy. The presence of some patches of woody vegetation merged in grassland dominated class was still the most probable explanation to the inaccuracies at this level. Similarly, Chopping et al. (2006) reported that the occurrence of shrubs in both grassland and woody vegetation makes it difficult to map them as separate classes using satellite images.

5.4.3 Classification Comparisons

When using fuzzy classification, significantly higher accuracy was realised compared to ML. The overall accuracy improved from 63% to 66% and from 76% to 81% with Landsat and IKONOS respectively. These results are of the same magnitude as those in a study by Aynekulu et al. (2008) in which they reported an overall accuracy of 80% with a comparable number of land use/cover classes in Ethiopian rangelands using Landsat imagery. The improvement in accuracy when using fuzzy classification conformed to the assertion that satellite remotely sensed data are imprecise with fuzzy boundaries between different vegetation cover types which in turn are heterogeneous within the boundaries (Jensen, 1996). A hard classifier like ML, which requires precisely defined set boundaries, for which a given pixel is either a member of class or not would most likely result in a relatively lower accuracy compared to a fuzzy based classification. There is also a possibility that taking advantage of other classifiers separately or in combination with ML and fuzzy might have improved the classification results. Potential classifiers in this case would include decision trees, support vector machines and artificial neural networks (Otukei and Blaschke, 2010).

Whereas the vegetation cover was classified into two categories (woodland and grassland) with acceptable level of accuracy, there is need to have separate classes for trees, shrubs and herbaceous layers with an acceptable level of accuracy. Herlocker (1999) indicated that growth form based vegetation communities are desirable for broader planning and establishment of specific ecological and productivity characteristics of a rangeland. Vegetation cover maps that distinguish the three layers would more accurately provide on stocking capacity and habitat conditions at a given rangeland site. To achieve this, there is need to investigate how use of multi-date imagery will improve the classification considering that rangelands in East Africa are characterised by seasonal changes in vegetation spectral characteristics. In such future attempts, where possible, there should be effort to ensure that images for the different sensors are obtained for the same time of the year as much as possible when sensor comparisons are required. This was not realised in the current study. The challenge to some of these attempts will certainly be the cost implications associated with the use of IKONOS imagery, at least within the near future as was similarly noted by Booth and Tueller (2003). Landsat might provide less detail in terms of vegetation distribution and their productivity functions, but it is more affordable and allows for wider area coverage of the seasonal vegetation patterns. Nevertheless, IKONOS could be used to improve classification accuracy in areas characterised by patchy vegetation, hence mixed pixels that are more difficult to classify while using Landsat imagery. However, considering that the classification results of IKONOS were just slightly better than for Landsat, the cost difference and the purpose of classification should be considered while making a choice between the two. It is also possible that better vegetation classification results may be realised by using sample hyperspectral signatures to characterise the different vegetation cover types. While mapping saltmarsh vegetation Schmidt and Skidmore (2003) demonstrated that use of hyperspectral imagery signatures can considerably improve the classification of a high number of classes.

5.5 Conclusions

Results have shown that rangeland vegetation cover in the study area is experiencing changes in species cover and composition with shift from woody to herbaceous dominated. Species dominance is drifting from more desirable to less desirable herbage species for grazing. This situation poses a need to optimise rangeland productivity for sustainable livelihoods and biodiversity conservation, considering the stiff competition among different land uses and their effect on the patterns of vegetation cover. Reduction of woody vegetation cover is likely to lower the herbage quality and species diversity. This calls for proactive remedies such as regulated woody cover cutting and awareness raising on the importance of trees and shrubs in grazing land management.

Only two broad classes of physiognomic vegetation cover types were accurately mapped using fuzzy and ML from Landsat and IKONOS images. Overall, the findings of this study indicate that IKONOS reflectance spectra discriminate rangeland physiognomic vegetation classes better than Landsat imagery. It is also shown that fuzzy classification resulted in higher discrimination ability of the physiognomic vegetation types than maximum likelihood. The better accuracy realised when using fuzzy classifier in this study provides useful insights in the limitations of maximum likelihood classifiers and the need to investigate other classifiers in order to improve rangeland vegetation mapping in East Africa. There is need to develop classification schemes for systematically defining rangeland vegetation classes that can realistically be discriminated by various levels of sensors. Future vegetation class definitions should aim at drawing clear boundaries among trees, shrubs and herbaceous growth forms to ensure reliable rangeland ecological and productivity assessments. Whereas use of IKONOS has been demonstrated to be a better image choice for more accurate vegetation information, cost limitations may not be favourable especially when mapping large areas.

References

Archibald, S. (2008). African grazing lawns—How fire, rainfall, and grazer numbers interact to affect grass community states. *Wildlife Management, 72*(2), 492 - 501.

Aynekulu, E., Kassawmar, T., & Tameme, L. (2008). Applicability of ASTER imagery in mapping land use/cover as a basis for biodiversity studies in drylands of norhern Ethiopia. *African Journal of Ecology, 46*, 19 - 23.

Beeri, O., Phillips, R., Hendrickson, J., Frank, A. B., & Kronberg, S. (2007). Estimating forage quantity and quality using aerial hyperspectral imagery for northern mixed-grass prairie. *Remote Sensing of Environment, 110*(2), 216 - 225.

Bloesch, U. (2002). *The dynamics of thicket clumps in the Kagera savanna landscape, East Africa*. Zurich.

Boelman, N. T., Stieglitz, M., Griffin, K. L., & Shaver, G. R. (2005). Inter-annual variability of NDVI in response to long-term warming and fertilization in wet sedge and tussock tundra. *Oecologia, 143*, 588 - 597.

Booth, D. T., & Tueller, P. T. (2003). Rangeland monitoring using remote sensing. *Arid Land Research and Management, 17*, 455 - 467.

Brower, J. E., Zar, J. H., & von Ende, C. N. (1997). *Field and laboratory methods for general ecology* (4th ed.): Michael D. Lange.

Cherrill, A. J., Lane, A., & Fuller, R. M. (1994). The use of classified 5 Thematic Mapper imagery in characterisation of landscape composition: A case study in northern England. *Journal of Environmental management, 40*, 357 - 377.

Chopping, M., Su, L., Rango, A., Martonchik, J. V., Peters, D. P. C., & Laliberte, A. (2008). Remote sensing of woody shrub cover in desert grasslands using MISR with a geometric-optical canopy reflectance model. *Remote Sensing of Environment, 112*(1), 19-34.

Chopping, M. J., Su, L., Rango, A., Martonchik, J. V., Peters, D. P. C., & Laliberte, A. (2006). Remote sensing of woody shrub cover in desert grasslands using MISR with a geometric-optical canopy reflectance model. *Remote Sensing of Environment, 112*, 19 - 34.

Cingolani, A. M., Renison, D., Zak, M. R., & Cabido, M. R. (2004). Mapping vegetation in a heterogeneous mountain rangeland using landsat data: an alternative method to define and classify land-cover units. *Remote Sensing of Environment, 92*(1), 84-97.

Gordon, I. J. (2009). What is the Future for Wild, Large Herbivores in Human-Modified Agricultural Landscapes? *Wildlife Biology, 15*(1), 1-9.

Herlocker, D. J. (1999). *Rangeland ecology and resource development in eastern Africa*. Nairobi: German Agency for Technical Co-operation.

Homewood, K. M. (2004). Policy, environment and development in African rangelands. *Environmental Science and Policy, 7*, 125 - 143.

Jensen, J. R. (1996). *Introduction to digital image processing* (2nd ed.). New Jersey: Prentice-Hall, Inc.

Kent, M., & Coker, P. (1994). *Vegetaion description and analysis: A practical approach*. London: Belhaven Press.

Kercher, S. M., Frieswyk, C. B., & Zedler, J. B. (2003). Effects of sampling teams and estimation methods on the assessment of plant cover. *Journal of Vegetation Science, 14*, 899 - 906.

Langdale-Brown, I. (1970). Vegetation. In J. D. Jameson (Ed.), *Agriculture in Uganda* (Second ed., pp. 90 - 97). London: Oxford University Press.

Lillesand, T. M., Kiefer, R. W., & Chipman, J. W. (2004). *Remote sensing and image interpretation*. New York: John Wiley & Sons Inc.

McNeely, J. A., Gadgil, M., Leveque, C., Padoch, C., & Redford, K. (1995). Human influence on biodiversity. In V. H. Heywood (Ed.), *Global biodiversity assessment* (pp. 715 - 802). Cambridge: United Nations Environment Programme (UNEP).

Moreau, S., Bosseno, R., GU, X. F., Baret, F. (2003). Assessing the biomass of Andean bofedal and totora high-protein wetland grasses from NOA/AVHRR. *Remote sensing of Environment, 85*, 516-529.

Mueller-Dombos, D., & Ellenberg, H. (1974). *Aims and methods of vegetation Ecology*: John Wiley & Sons, Inc.

NBS. (1992). *Technical report, National Biomass Study, Phase I*. Kampala, Uganda: Forest department.

NEMA. (2004). *State of environment report for Uganda* Kampala: National Environment Management Authority (NEMA).

Osborne, P. L. (2000). *Tropical ecosystems and ecological concepts*. Cambridge: Cambridge University Press.

Otukei, J. R., & Blaschke, T. (2010). Land cover changes assessment using decision trees, support vector machines and maximum likelihood classification algorithms. *International Journal of Applied Earth Observation and Geoinformation, 12S*, S27 - S31.

Phillips, S., Namaganda, M., & Lye, K. A. (2003). *115 Ugandan grasses*. Kampala: Makerere University Herbarium.

Phinn, S., Franklin, J., Hope, A., Stow, D., & Huenneke, L. (1996). Biomass distribution mapping using airborne digital video imagery and spatial statistics in a semi-arid environment. *Journal of Environmental management, 47*(2), 139 - 164.

Pratt, D. J., & Gwynne, M. D. (1977). *Rangeland management and ecology in East Africa*. Huntington, New York: Robert E. Krieger Publishing Co., Inc.

Purseglove, J. W. (1988). *Tropical crops*. Essex: Longman Group Ltd.

Schmidt, K. S. (2003). *Hyperspectral remote sensing of vegetation species distribution in a saltmarsh*. Enschede: ITC.

Townshend. (1983). *Effects of spatial resolution on the classification of land cover type.* Paper presented at the Ecological Mapping from Ground, Air and Space, ITE, Monks Wood Experimental Station, Abbots Ripton, Huntingdon.

Trodd, N. M., & Dougill, A. J. (1998). Monitoring vegetation dynamics in semi-arid African rangelands: Use and limitations of Earth observation data to characterize vegetation structure. *Applied Geography, 18*(4), 315-330.

Turner, M. D. (2003). Methodological reflections on the use of remote sensing and geographic information science in human ecological research. *Human Ecol, 31*(2), 255-279.

UWA. (2003). *Lake Mburo conservation area general management plan*. Kampala: Uganda Wildlife Authority.

Vicente-Serrano, S. M., Cuadrat, J. M., & Romo, A. (2006). Aridity influence on vegetation patterns patterns in the middle Ebro valley (Spain): Evaluation by means of AVHRR images and climate interoration techniques. *Journal of Arid Environments, 66,* 353 - 375.

CHAPTER SIX

6.0 Effect of Soil Properties, Vegetation Cover and Grazing on Herbage Species Composition and Mass

Abstract

This study characterised soil properties interactive effect with vegetation and grazing on herbage species composition and herbage production. An experiment with fenced plots to exclude grazers was conducted on sites grazed by both cattle and wild animals. Sites were selected based on vegetation cover and soil textural classes. Soil and herbage (mass, cover and height) data were analysed using analysis of variance at a significance level of 0.05. A total of 25 grass species were recorded. *Brachiaria decumbens* registered the highest average single species cover of 40% for all the sites. Herbage species cover was significantly higher ($p<0.001$) on grassland patches (GP) than woodland patches (WP). There were no significant differences in herbage species' cover and height associated with soil. Excluding herbage species from grazing resulted in a significant increase ($p< 0.001$) in height. Herbage production was significantly higher ($p=0.023$) on GP than on WP. Clay loam soils had significantly higher ($p< 0.001$) herbage mass production than on loam soils which was in turn higher than on sandy loam. Herbage yield from grazed sites was significantly lower ($p< 0.001$) than from ungrazed sites by 43%. The study revealed that vegetation cover type and grazing were the key factors in determining herbage species composition and production. Management aimed at optimal grazing levels and regulation of woody to herbaceous vegetation ratio is essential for herbage production and biodiversity conservation in the area.

6.1 Introduction

Rangeland and grazers form a great and intricately related ecological complex with dynamic relationships (Facelli and Springbett, 2009). Whenever there is change through rangeland management of any factor of this complex habitat, change will be expected elsewhere (Lanta et al., 2009; Xie et al., 2007). The amount and characteristics of rangeland herbage mass are of direct importance to the animals associated to it by providing feed to them (Mueller-Dombos and Ellenberg, 1974). Herbage yield and distribution determine the energy an animal expends in obtaining forage whereby reduction in yield increases the energy expenditure (Stoddart and Smith, 1955). On the other hand, the presence and density of animals can influence the increase or decrease in the amount and quality of herbage at a given site, through grazing effects (José and Heather, 2009). Therefore site specific herbage mass quantification is very essential in providing rangeland information on rangeland feed abundance (Kent and Coker, 1994) and rangeland health condition (Herlocker, 1999).

There is high demand for information on rangeland forage biomass inventory and monitoring for various decision making processes in Uganda (MoLHUD, 2007; NEMA, 2007). The information is needed for quantifying sustainable production levels of the different rangeland sites. According to Schulze (1997) the information can be used in assessing intrinsic environmental herbage production levels and in comparing the environmental resource potential of one rangeland site with others. Herbage production information has also been recorded to be useful in measuring carrying capacities for different rangeland sites to support animal populations (Baars, 2002). Such measurements help in ensuring that animal numbers and rangeland herbage production are sustainably managed to avoid the risk of negative ecological change, reduced productivity, and reduced flow of goods and services to the rangeland dependent communities (Cowling, 2000).

Rangelands herbage production depends on landscape site specific characteristics like slope, soil and vegetation cover types (de Ridder and Breman, 1993). On the other hand, the variations in the production may be related to climate (Hodgson, 1990; Turner et al., 2005). Landscape characteristics influence both run-off coefficient and site water storage capacity hence its availability for herbage production (de Leeuw and Tothill, 1993; Majaliwa et al., 2010). Therefore a better understanding of the interactive effects of soil physio-chemical properties, vegetation cover types and grazing on herbage mass productivity is pre-requisite for appropriate rangeland management (Bloesch, 2002).

Vegetation cover and species composition have been found to be some of the major causes of variability in herbage mass production due to differences in species physiological responses to landscape site specific conditions (Bartolome et al., 2007). Increase in shrub/tree cover for example decreases herbage production (Sánchez-Jardón et al., 2010; Tiemann et al., 2009; Zarovali et al., 2007). Herbage production and distribution are also species specific (Pontes et al., 2007). According to Herlocker (1995), change from good to poor quality and quantity of species ultimately lower herbage production and vice versa.

Soil properties have also been reported to play a key role in herbage productivity (DeKeyser et al., 2009; Tibor, 2010; Tiemann et al., 2009). Soils properties like nutrients, moisture among others at a given rangeland site are dependent upon other landscape characteristics especially slope (de Leeuw and Tothill, 1993; Majaliwa et al., 2010) and grazing (Lin et al., 2010). Mligo (2009) pointed out that variation in soil organic carbon is influenced by the topography of a rangeland site. In areas with inclinations, hilltops, plateaus, valleys and low plains, the increase of slopes in combination with effects of grazing pressure contribute to decrease in litter deposition, accumulation of organic matter and consequently increase in runoffs and subsequent erosion on bare lands. The influence of soil properties in a given landscape on herbage production is associated with fertility; pH and texture (Tiemann et al., 2009; Turner and Congalton, 1998); nitrogen and phosphorus content (Turner, 1998) and soil moisture (Sánchez-Jardón et al., 2010). However, the way these soil related factors affect herbage production is greatly influenced by amount and seasonal distribution of rainfall at a given rangeland site (Turner, 1998). Soil organic matter affects nutrient availability for plants, improves soil structure and stimulates activities beneficial to micro-organisms and the herbage composition at a given landscape position (Osborne, 2000). Trampling of plants and soils by animals on steep slopes creep downwards under the force of gravity or runoffs making soils of such areas shallow and fragile, hence reducing their productivity (Facelli and Springbett, 2009).

The underlying factors for grazing patterns and consequently, its effect on herbage productivity include rainfall seasons, location of watering points, availability of herbage and its palatability and slope (Pickup, 1994). Whereas various studies concur on most of the several factors that determine animal grazing patterns, the relationships among the factors are not easily understood mainly because their interactions do vary from place to place (Tate et al., 2003; Turner, 2003). Crist et al. (1992) established that inter-site comparisons involving taxonomically similar vegetation structure systems suggest that the mosaic context of patches at various spatial scales can be important determinants of animal grazing patterns in heterogeneous landscapes. Depending on prevailing grazing conditions, some grazing sites may frequently be preferred by animals leading to overgrazing at times. Overgrazing results in variation in organic matter (Han et al., 2008) and contributes to nutrient depletion and redistribution. Grazing effect can decrease organic matter that could function as the major stock for many primary nutrients such as nitrogen and phosphorus and consequently affect herbage quantity and species composition (Bernués et al., 2005; Mligo, 2009). Several other factors determine how grazing intensity and distribution influence herbage productivity (Cid et al., 2008; Lin et al., 2010). These include water availability (Skarpe et al., 2004), land tenure, cropping patterns, availability of herbage, authority to enforce movement restrictions, herd size, production goals of livestock owners, among other factors (Baker and Hoffman, 2006).

Knowledge of site specific herbage supply in the livestock dependant and wildlife conservation areas with respect to grazing and the prevailing landscape characteristics is important for strategic management, such as the timing and intensity of grazing (Belesky et al., 2007). Information on herbage production and composition is needed for establishing grazing stocking rates and carrying capacities for different rangeland sites. Several rangeland sites in Uganda have been reported to be overgrazed and degraded due to overstocking and overgrazing. Hence, there is general need for rangeland site specific information to support decision making processes of biodiversity conservation and sustainable livestock production systems. Key to this required information is inventories on herbage quantity and quality with respect to prevailing environmental factors to serve as basis for establishing productivity levels. Equally important is the identification of specific factors and the extent to which they influence herbage quantity and species composition. Therefore this chapter attempts to answer the question: How do grazing, vegetation cover type and soil type affect site specific herbage species composition and herbage yield?

6.2 Materials and Methods

6.2.1 Research Procedure and Design

A completely randomised design with a split-split plot arrangement was used to determine the effect soil textural classes, vegetation cover types and grazing on herbage species composition and herbage production. Two vegetation cover types based on vegetation cover mapping in chapter five (Woodland (W) and Grassland (G)); three soil textural classes (Clay Loam (CL), Loam (LS), and Sandy Loam (SL)); and two grazing factor categories (grazed and ungrazed) were randomly assigned as whole plot, sub-plot and sub-sub-plot respectively (Figure 6.1). Each treatment was replicated three times except for clay loam grassland and sandy loam grassland treatments which were replicated four times. To establish the effect of grazing (grazed and ungrazed), a 10 x 10m portion of all selected sites was enclosed by fencing using barbed wire to protect then from grazing by big herbivores. For all the experimental sites, baseline information on herbage mass and species composition was established at the start of the study in November 2008. Soil physical (bulk density, hydraulic conductivity), chemical (nutrient content and organic matter) properties were established.

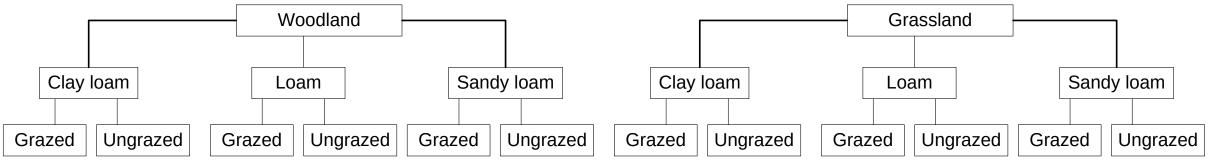


Figure 6.1: The split-split plot experimental arrangement for the study

6.2.2 Soil Sampling and Analysis

A completely randomised design with a split-plot arrangement was used to establish the variations in soil physical and chemical properties of the experimental sites with vegetation assigned whole plot and soil textural class as sub-plot. Soil samples were taken from within the soil depth of 0-15 cm for both physical and chemical properties. Each sample was replicated three times for each treatment described under 6.2.1. Core samples were taken for bulk density and hydraulic conductivity analysis. Standard cores measuring 15 cm by 15 cm were used. Auger sampling was used for texture, nutrient content and organic matter determination. A site composite sample was then taken, clearly labelled and transported to the laboratory and analyzed following methods described by Okalebo *et al.* (2002).

6.2.3 Species Composition and Herbage Mass Sample Collection

Two quadrats of 1 x 1m were randomly placed in each of the treatments for above-ground herbage mass harvesting and quantification in December 2008 and 2009. Before harvesting, three dominant species (with highest percentage canopy cover) and their respective height and percentage foliar cover in each plot were recorded. The above ground herbage mass was harvested by cutting using a sickle to ground level. The harvested herbage was hand sorted to remove litter and other non-herbaceous plant materials. The fresh herbage samples were weighed, thoroughly mixed in the field and sub-sampled to reduce the sample load. The sub-samples of the fresh harvest were also weighed, and then transported to the lab for drying at 60°C till constant weight. The ratio of dry weight of the sub-sample to the full sample weight was used to calculate the dry matter (DM) yield for each quadrat in $gDMm^{-2}$.

6.2.4 Statistical Analysis

Analysis of variance with randomised blocks was used to compare soil physical and chemical properties in the different treatments. Split-split plot design Analysis of variance (ANOVA) was carried out to determine the main effects of vegetation cover types, soil textural classes and grazing and their interaction on herbage species composition and production. All tests were performed at a significance probability of 0.05. The statistical analyses were performed using the statistical package GenStat (GenStat, 2008).

6.3 Results

6.3.1 Soil physical and Chemical Properties of Experimental Sites

The results of ANOVA comparing site variations in soil physical and chemical properties at the different rangeland sites are shown in Table 6.1. There was a significant difference ($p < 0.001$) in bulk density between woodland Patches (WP) and grassland patches (GP). Bulk density was significantly higher in GP than in WP. The interactions between textural and vegetation cover classes showed a significant difference ($p=0.043$) in bulk density properties. The interaction of vegetation cover and textural soil textural classes showed a significant difference ($p<0.001$) in hydraulic conductivity. A significant difference in organic matter in the different vegetation cover classes ($p = 0.026$) and soil classes ($p < 0.001$) was observed. There was higher organic matter in WP than in GP. CL had the highest organic matter content with SL having the lowest.

The experimental sites showed a significant difference in Calcium content for the vegetation ($p = 0.011$) and for soil classes ($p < 0.001$). The interaction between soil and vegetation classes also had a significant influence on soil calcium concentration ($p < 0.001$). WP had a higher Ca concentration than GP. LS registered the highest Ca concentration followed by CL and the least concentration was in SL. The soil classes from the selected rangeland sites registered significant differences in potassium ($p = 0.002$). The levels were higher in CL and lowest in SL. Potassium levels in the two vegetation classes were not statistically different and their interaction did not show any differences in the levels of Potassium. The results for Magnesium concentration for the vegetation classes were not statistically different. However, there were significant differences in the Magnesium concentration in the different soil classes ($p < 0.001$). The interactions between vegetation and soil classes also resulted in significant differences in Magnesium concentration ($p<0.001$). Nitrogen concentration was significantly different in the different soil classes ($p = 0.004$). The percentage of nitrogen was higher in CL and lowest in SL samples. There was no significant difference in Nitrogen concentration between WP and GP. Moreover, the interaction between vegetation cover type and soil did not show significant differences in nitrogen concentration. There were no statistical differences in sodium concentration for both vegetation and soil treatments. There was no significant difference in phosphorus between vegetation classes. On the other hand, there were significant differences in phosphorus among the soil classes. Samples from CL sites had a significantly higher concentration of phosphorus than LS sites which in turn were higher that for SL sites ($p < 0.001$). Results from multiple comparisons also reveal that vegetation and soil class interactions were a cause for significant differences in Phosphorus ($p < 0.001$).

Table 6.1: Means of soil physical and chemical properties for the experimental sites from ANOVA

	Vegetation cover type			**Soil type**			
Physical	Grassland	Woodland	P<0.05	CL	LS	SL	P<0.05
OM (%)	3.77^a	4.88^a	0.157	6.86^b	3.62^c	2.49^c	<0.001
BD (gm-3)	1.44^d	1.21^e	0.007	1.23^f	1.42^f	1.33^f	0.154
HC (cmhr-1)	33.08^g	38.64^g	0.736	35.34^h	37.76^h	34.48^h	0.985
Chemical							
Ca (cmol/kg)	5.07^a	6.03^a	0.104	5.58^{cd}	6.53^{bc}	4.54^d	0.035
K (cmol/kg)	0.66^e	0.84^e	0.28	1.02^{fg}	0.66^{gh}	0.57^h	0.079
Mg (cmol/kg)	1.88^i	2.04^i	0.529	2.19^j	2.24^j	1.45^k	0.029
P(ppm)	14.8^o	16.1^o	0.632	21.1^p	19.7^p	5.5^q	<0.001
Na (cmol/kg)	0.07^m	0.07^m	0.127	0.07n	0.07n	0.07n	0.079
N (%)	0.23^r	0.23^r	>0.05	0.27s	0.22st	0.21t	0.102

Means followed by different letters differ significantly ($p<0.05$) for the respective soil property. BD- Bulk Density (kgm^{-3}); HC- Hydraulic Conductivity ($cmhr^{-1}$); Ca- Calcium (Cmoles/kg); K- Potassium (Cmoles/kg); Mg- Magnesium (Cmoles/kg); N- Nitrogen (Cmoles/kg); Na- Sodium (Cmoles/kg); P- Phosphorus (ppm).

6.3.2 Herbage species composition

A total of 25 grass species were recorded, 24 species were identified while one species could not be identified. The species and their average cover for the different treatments are presented in Table 6.2. *Brachiaria decumbens* registered the highest average single species cover of 40% for all the sites. Results of ANOVA show that there was a significant difference in cover among different herbage species ($p < 0.001$). The difference in height for the species recorded from the study sites was also significant ($p < 0.001$). The data for species average height are presented in table 6.3.

Table 6.2: Herbage species cover (%) per vegetation type, soil type and grazing treatments

Species	Vegetation type				Soil type						Grazing treatment			
	Grassland		***Woodland***		***CL***		***LS***		***SL***		***Ungrazed***		***Grazed***	
	DecFeb 2008	*Dec 2009*	*DecFeb 2008*	*Dec 2009*	*DecFeb 2008*	*Dec 2009*	*DecFeb 2008*	*Dec 2009*	*DecFeb 2008*	*Dec 2009*	*DecFeb 2008*	*Dec 2009*	*DecFeb 2008*	*Dec 2009*
Abildgaardia ovata	-	1	-	-	-	1	-		+	1	-	-	+	+
Andropogon schirensis	+	+	-	-	-	+	+	+	-	-	+	+	+	-
Bothriochloa insculpta	12	11	-	1	20	10	6	3	15	5	14	6	5	6
Brachiaria brizantha	35	1	28	-	29	-	27	-	38	1	33	+	29	-
Brachiaria decumbens	40	28	38	49	29	39	47	49	48	28	45	51	27	26
Brachiaria platynota	55	10	18	8	-	-	18	11	55	14	40		10	9
Chloris gayana	+	1	+	7	+	12	-	-	-	-	-	+	+	1
Chloris pycnothrix	+	1	+	+	-	-	-	-	-	2	-	+	-	+
Cymbopogon nardus	33	16	31	4	-	-	33	8	33	15	24	3	40	8
Cynodon dactylon	35	13	24	8	30	24	-	1	-		35	+	24	5
Cyperus cyperoides	-		+	+	-	-	-	+	+	+	-	+	-	+
Digitaria abyssinica	5	16	+	+	5	24	-	-	+	+	-	+	5	8
Digitaria maitlandii	+	2	+	+	+	2	-	+	+	2	+	1	-	1
Eleusine indica	-	-	5	+	5	+	-	-	-	-	5	-	-	+
Eragrostis exasperata	-	1	-	-	-	1	-	-	-	-	-	-	+	+
Eragrostis tenuifolia	-	1	+	2	-	-	-	-	+	4	+	2	+	+
Hyparrhenia filipendula	20	10	+	2	19	4	21	9	+	6	28	10	12	2
Hyperthelia dissoluta	-	8	-	-	+	11	-	-	-	-	-	-	-	-
Hyparrhenia rufa	10	-	-	-	10	-	-	-	-	-	10	-	-	-
Kyllinga alba	+	1	+	1	+	1	+	2	+	1	-	+	+	1
Loudetia kagerensis	64	32	33		64	27	38	1	25	29	39	16	55	16
Panicum maximum	5	3	5	6	5	8	5	1	+	7	5	8	-	2
Paspalum scrobiculatum	-	1	-	-	+	+	-	-	+	1	+	+	-	+
Setaria homonyma	20	-	+	17	20	-	+	8	+	18	20	6	-	11
Setaria sphacelata	18	3	+	1	18	3	-	-	+	2	27	3	10	+
Sporobolus pyramidalis	18	25	21	23	26	31	12	29	23	12	15	25	24	23
Themeda triandra	5	8	-	-	5	4	+	8	+	1	5	6	-	2

Values shown are the average percentages based on 1m^2 quadrats in which a given species was recorded; CL- Clay Loam, LS- Loam, SL- Sandy Loam; + Grass species present with cover <1%; - Grass species absent

Table 6.3: Herbage species height (m) per vegetation type, soil type and grazing treatments

	Vegetation type				Soil type						Grazing treatment			
	Grassland		***Woodland***		***CL***		***L***		***SL***		***Ungrazed***		***Grazed***	
Species	*DecFeb2009*	*Dec2009*	*DecFeb2009*	*Dec2009*	*DecFeb2009*	*Dec2009*	*DecFeb2009*	*Dec2009*	*DecFeb2009*	*Dec2009*	*DecFeb2009*	*Dec2009*	*DecFeb2009*	*Dec2009*
Abildgaardia ovata	-	0.08	-		-	0.05	-	-	-	0.10	-	-	-	0.08
Andropogon schirensis	-	0.45	-	0.70	-	0.30	-	0.70	-	-	-	0.50	-	-
Bothriochloa insculpta	0.25	0.29	-	0.50	0.20	0.37	0.30	0.48	0.20	0.08	0.23	0.65	0.30	0.29
Brachiaria brizantha	0.29	0.25	0.18		0.18	-	0.35	-	0.16	0.25	0.23	0.25	0.24	-
Brachiaria decumbens	0.19	0.20	0.20	0.33	0.26	0.33	0.10	0.32	0.20	0.15	0.23	0.28	0.13	0.13
Brachiaria platynota	0.10	0.12	0.14	0.35	-	-	0.14	0.35	0.10	0.12	0.15	0.23	0.07	0.21
Chloris gayana	-	0.11	-	0.50	-	0.37	-	-	-	-	-	0.70	-	0.16
Chloris pycnothrix	-	0.15	-	0.15	-	-	-	-	-	0.15	-	0.25	-	0.10
Cymbopogon nardus	0.65	0.82	0.38	0.55	-	-	0.65	1.19	0.38	0.50	0.50	0.46	0.53	0.90
Cynodon dactylon	0.23	0.50	0.15	0.38	0.19	0.42	-	0.45	-	-	0.15	0.42	0.23	0.65
Cyperus cyperoides	-	-	-	0.30	-	-	-	0.35	-	0.28	-	0.35	-	0.28
Digitaria abyssinica	0.20	0.35	-	0.20	0.20	0.35	-	-	-	0.20	-	0.50	0.20	0.20
Digitaria maitlandii	-	0.23	-	0.40	-	0.33	-	0.25	-	0.20	-	0.37	-	0.12
Eleusine indica	-	-	0.40	0.30	0.40	0.30	-	-	-	-	0.40	-	-	0.20
Eragrostis exasperata	-	0.30	-		-	0.30	-	-	-	-	-	-	-	0.30
Eragrostis tenuifolia	-	0.16	-	0.20	-	-	-	-	-	0.17	-	0.21	-	0.09
Hyparrhenia filipendula	0.39	0.58	-	0.48	0.25	0.85	0.53	0.40	-	0.52	0.48	0.60	0.30	0.45
Hyperthelia dissoluta	-	1.30	-		-	1.30	-	-	-	-	-	-	-	-
Hyparrhenia rufa	0.40	-	-		0.40	-	-	-	-	-	0.40	-	-	-
Kyllinga alba	-	0.10	-	0.20	-	0.10	-	0.15	-	0.15	-	0.15	-	0.18
Loudetia kagerensis	0.35	0.39	0.25		0.35	0.58	0.28	0.09	0.20	0.35	0.37	0.35	0.18	0.29
Panicum maximum	0.35	0.27	0.20	0.45	-	0.58	0.28	0.23	-	0.37	0.28	0.69	-	0.28
Paspalum scrobiculatum	-	0.16	-		-	0.25	-	-	-	0.07	-	0.25	-	0.07
Setaria homonyma	0.50	-	-	0.26	0.50	-	-	0.20	-	0.33	0.50	0.28	-	0.21
Setaria sphacelata	0.25	0.35	-	0.55	0.25	0.53	-	-	-	0.28	0.30	0.40	0.20	0.15
Sporobolus pyramidalis	0.31	0.44	0.34	0.45	0.30	0.46	0.39	0.50	0.23	0.39	0.40	0.44	0.24	0.32
Themeda triandra	0.25	0.60	-		0.25	0.70	-	0.56	-	0.54	0.25	0.58	-	0.45

Values shown are the average height in meters based on 1m^2 quadrats in which a given species was recorded; CL- Clay Loam, LS- Loam, SL- Sandy Loam; - species absent

Effect of Soil type on Species Composition

Analysis of variance did not show any statistical difference between herbage cover and height among soil types. Nonetheless, four species *(Chloris gayana, Eleusine indica, Eragrostis exasperata* and *Hyperthelia dissolute)* were only present on CL. Three species (*Brachiaria brizantha*, *Chloris pycnothrix* and *Eragrostis tenuifolia*) were only present on SL. Out of the 25 species identified, eight species (*Bothriochloa insculpta, Brachiaria decumbens, Hyparrhenia filipendula, Loudetia kagerensis, Panicum maximum* and *Themeda triandra*) were present in all the soil types.

Effect of Vegetation Cover Type on Species Composition

Results from ANOVA show that herbage species cover was significantly higher in grassland than in woodland patches (p = 0.019). Seven species (*Abildgaardia ovata, Andropogon schirensis, Brachiaria brizantha, Eragrostis exasperata, Hyperthelia dissolute, Paspalum scrobiculatum and Themeda triandra)* were present only in GP. Two species (*Eleusine indica* and *Setaria homonyma)* were present only in the WP (Table 6.2).

Effect of Grazing on Species Composition

Four species (*Brachiaria platynota, Chloris gayana, Cynodon dactylon* and *Digitaria abyssinica*) were present in both grazed and ungrazed sites but only those with CL soil class. *Brachiaria decumbens* and *Sporobolus pyramidalis* were the most dominant species respect to grazing. However, the average percentage cover for *Brachiaria decumbens* was highest on ungrazed (51%) patches than on grazed patches (27%). The cover for *Sporobolus pyramidalis* on ungrazed was only 1% higher than on grazed sites. Data on the effect of grazing on herbage cover and height are presented in Figure 6.2 and 6.3, respectively. Only species with cover => 1% of the quadrat were considered. There was no statistical difference in herbage cover associated with grazing effect. ANOVA of the effect excluding herbage from grazing resulted in increase in herbage height compared to grazed sites (p = 0.014).

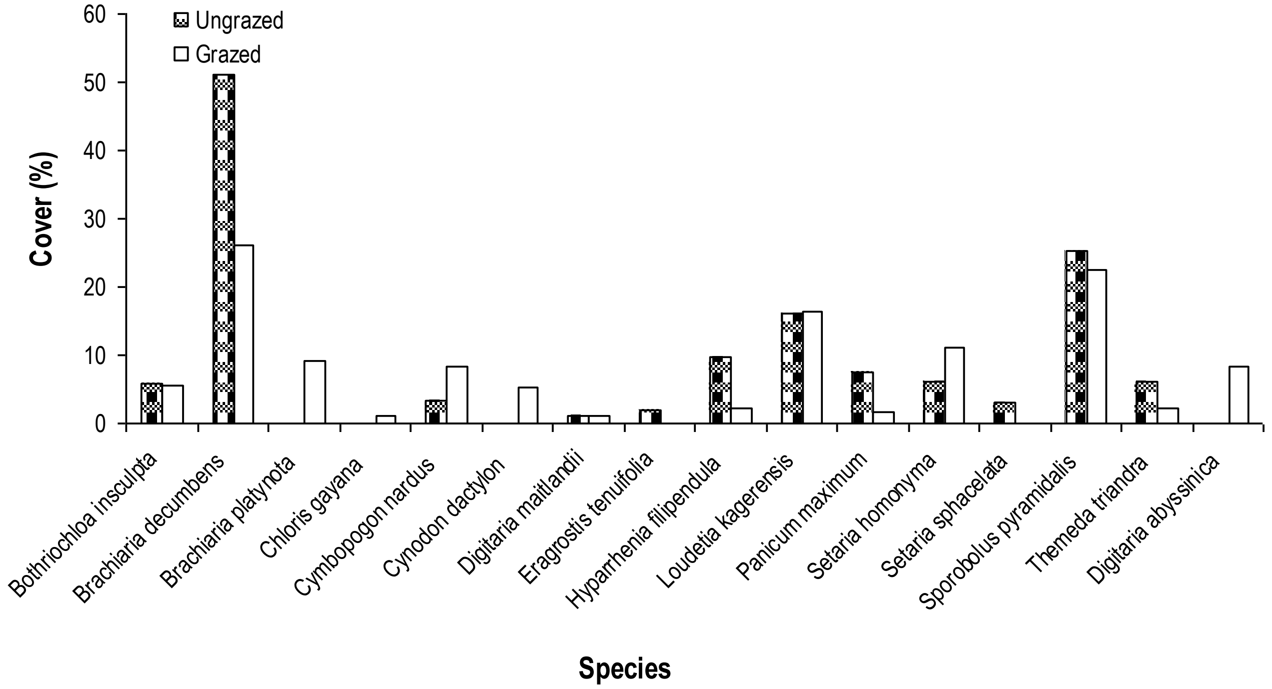


Figure 6.2: Effect of grazing on herbage percentage cover

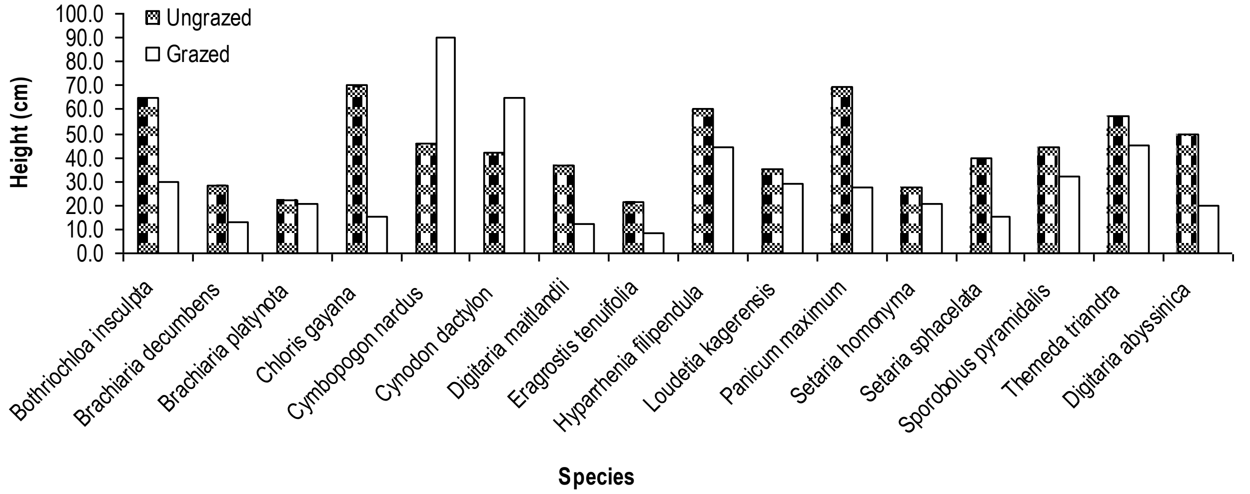


Figure 6.3: Effect of grazing on herbage species height

6.3.3 Herbage Production

The overall mean herbage mass for the experimental site was 315 gm^{-2}. The minimum and maximum harvest for all treatments was 88.5 and 664.3 gm^{-2} respectively. Results of ANOVA showed that the interactions among vegetation cover types, soils types and grazing were not significant in influencing the amount of harvested herbage mass at a given site.

Effect of Soil Type on Herbage Mass

Herbage mass on CL soils was significantly higher than that from LS which was in turn higher than yields from SL ($p < 0.001$). The mean herbage DM (gm^{-2}) was 420 for CL, 322 for LS and 204 for SL (Figure 6.4A).

Effects of Vegetation Cover Type on Herbage Mass

Results from ANOVA show that herbage mass yield in the different vegetation types was significantly different ($p = 0.023$). Grass mass production on grassland patches (GP) was 21% higher than mass in woodland patches (WP). Mean herbage mass (gm^{-2}) for GP and WP was 346 and 285 respectively (Figure 6.4B).

Effect of Grazing on Herbage Mass

Grazing had a significant effect on herbage mass production ($p < 0.001$). Ungrazed sites had significantly higher herbage DM yield than the grazed ones. Mean herbage mass production for grazed sites was 228 and 403 (gDMm^{-2}) for un-grazed sites (Figure 6.4C).

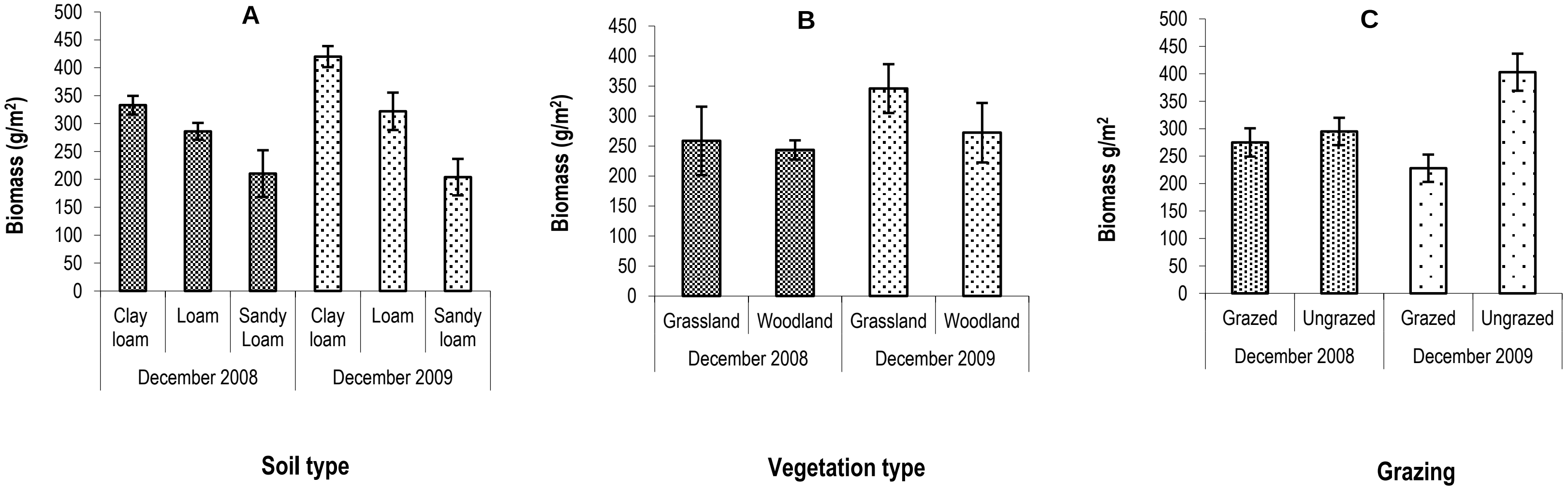


Figure 6.4. The effect of (A) soil type (B) vegetation type and (C) grazing on herbage mass

6.4 Discussion

There was a general variation in physical soil properties in the study sites. Results reveal that soils under grassland patches had a significantly higher bulk density than those with woody vegetation patches. This is most likely because of the differences in grazing trampling effects which leads to soil compaction since livestock and other grazers will most of the time prefer to graze on open patches because of less resistance to movement and hence easier access to herbage compared to woodland patches (Pickup, 1994).. There was a general tendency for sandy soils to have higher hydraulic conductivity than other soil classes but this trend was neither consistent nor statistically significant. This is attributed to narrow range differences of sand content among the soil classes and the interaction effect of vegetation and soil types which was found to be statistically significant. As revealed in the findings organic matter was consistently higher in woodland patches than in grassland patches which can be explained by differences in litter effect from shrubs and trees. Faster decomposition of organic matter and hence its availability in the soil due to the environmental amelioration caused by trees and shrubs has been reported by (Zarovali et al., 2007).

The soil chemical properties of the different sites showed a consistent trend variation in the different soil classes. On the other hand, there was no consistent general pattern on the effect of vegetation cover type on the soil chemical properties. Results from this study show that clay loam soils generally had a higher concentration of the measured chemical elements than other soil classes. Probably this can be explained by the higher organic matter content that was also found associated with this soil class. Organic matter has been reported to be a key factor that affects nutrient availability in soils (Mligo, 2009).

From this study it was revealed that species presence and cover are mainly associated with vegetation cover type with some distinct species associations. For example *Setaria homonyma* was only found in woodland patches. Grassland patches (GP) were found to have a generally higher species cover than woodland patches (WP). This is possibly because of the shade effect from trees and shrubs that lead to competition for light which tends to exclude some species and leaving a few competitive ones as was reported by (Fujita et al., 2009) while studying the effects of livestock grazing on plant diversity. This suggests that GP are likely to be associated with higher grazing stocking rates than WP. A related report was made by Zarovali et al. (2007) in which they indicated that grass species tend to be sensitive to woody vegetation cover changes. Species in GP were found to be significantly taller than those in WP. This difference in height could possibly be due to less vigour associated with herbage under woody vegetation cover as a result of light competition effect. This may cause species to easily break in case of environmental disturbances like grazing and wind, hence not able to grow tall to the heights comparable to those with no light shade effect. However, this subject requires further investigation. Grazed sites had more herbage species than ungrazed sites, an indication that grazing maintains species richness. This pattern in species composition is similar to the trends reported by Fujita et al. (2009) and Lanta et al. (2009) whose studies showed that excluding herbage from livestock grazing decreases species richness and increases it under conditions of grazing pressure. The results for the relationship between grazing and species cover clustered the species into palatable and non-palatable groups. Grazed sites were mainly dominated by non palatable species like *Cymbopogon nardus* and *Sporobolus pyramidalis.* On the other hand, ungrazed sites were more dominated by *Brachiaria decumbens* which is a palatable species to most grazers in the area. This is due to selective grazing which tends to reduce the cover of preferred herbage species in the grazed sites compared to the ungrazed ones. Similar results have been reported by Loeser et al. (2007) and Ao et al. (2008). This indicates that overgrazing may result in the loss of these palatable species depending on the intensity. There was evidence of some species resilience to grazing pressure, for example *Cynodon dactlylon* which has been classified as a palatable and resilient to pressure species by Herlocker (1999) was among the dominant species on grazed sites. Related findings have been reported by Han et al. (2008) while studying the effect of grazing on carbon and nitrogen.

The findings show that herbage mass production is higher on grassland patches than on woodland patches. This is in agreement with the findings by Zarovali et al. (2007) who indicated that woody vegetation affects herbage production because of the reduction of available light to the herbaceous layer. As was expected, grazing significantly reduced the amount of herbage mass harvest at given site compared to ungrazed sites. Results also show that differences in soil classes resulted in significant differences in herbage mass production with clay loam soils having the highest production. Therefore sites with clay loam soils are likely to be associated with high grazing capacity. This trend is consistent with the high nutrient concentrations which were revealed from the results of soil analysis. This implies that there was a positive relationship between soil nutrient value and herbage production. The most plausible explanation of this result is the differences in nutrient levels. It is envisaged that herbage quality is also likely to be higher in this soil type (Han et al., 2008), hence potentially higher stocking rates.

6.5 Conclusions

In this study, vegetation cover, soil type and grazing have been demonstrated as very important factors when assessing herbage production potentials of rangelands. Soil nutrient levels consistently proved very essential in determining herbage production. Soil fertility management considerations therefore should always be included in the pastureland development strategies. Vegetation cover management is key concern in the study area as evidenced by the differences in herbage production for grassland and woodland patches. Tendency towards woody cover leads to low herbage yields and reverse is true for grassland patches. However, still, from the findings of this study it should be noted that woody vegetation cover improves soil organic matter which in turn improves nutrient availability and soil structure conditions. The latter are very important for herbage quantity and quality. The results also demonstrated that grazing increases species richness through reducing species competition effect. There is, therefore a need to establish the grazing levels to which rangeland sustainable herbage production potentials and biodiversity levels can be attained since overgrazing and under grazing are liable to compromise the rangeland health conditions.

References

Ao, M., Ito, M., Ito, K., Yun, J. F., Miura, R., & Tominaga, T. (2008). Floristic compositions of Inner Mongolian grasslands under different land-use conditions. *Grassland Science, 54*(4), 173-178.

Baars, R. M. T. (2002). Rangeland utilisation assessment and modelling for grazing and fire management. *Journal of Environmental Management, 64*(4), 377-386.

Baker, L. E., & Hoffman, M. T. (2006). Managing variability: Herding strategies in communal rangelands of semiarid Namaqualand, South Africa. *Human Ecol, 34,* 765 - 784.

Bartolome, J. W., Jackson, R. D., Betts, A. D. K., Connor, J. M., Nader, G. A., & Tate, K. W. (2007). Effects of residual dry matter on net primary production and plant functional groups in Californian annual grasslands. *Grass and Forage Science, 62*(4), 445-452.

Belesky, D. P., Ruckle, J. M., & Abaye, A. O. (2007). Seasonal distribution of herbage mass and nutritive value of Prairie grass. *Grass and Forage Science, 62*(3), 301-311.

Bernués, A., Riedel, J. L., Asensio, M. A., Blanco, M., Sanz, A., Revilla, R., et al. (2005). An integrated approach to studying the role of grazing livestock systems in conservation of rangelands in protected natural park (Sierra de Guara, Spain). *Livestock Production Science, 96,* 75 - 85.

Bloesch, U. (2002). *The dynamics of thicket clumps in the Kagera savanna landscape, East Africa.* Zurich.

Cid, M. S., Ferri, C. M., Brizuela, M. A., & Sala, O. (2008). Structural heterogeneity and productivity of a tall fescue pasture grazed rotationally by cattle at four stocking densities. *Grassland Science, 54*(1), 9-16.

Cowling, R. M. (2000). Challenges to the 'new' rangeland science. *TREE, 15,* 303 - 304.

Crist, T. O., Guertin, D. S., Wiens, J. A., & Milne, B. T. (1992). Animal Movement in heterogeneous landscapes: an experiment with Eleodes beetles in short grass prairie. *Functional Ecology, 6,* 536 - 544.

de Leeuw, P. N., & Tothill, J. C. (1993). The concept of rangeland carrying capacity in sub-Saharan Africa-myth of eality *Range ecology at disequilibrium : new models of natural variability and pastoral adaptation in African Savannas* (pp. 77-88). London: Overseas Development Institute.

de Ridder, N., & Breman, H. (1993). A new approach to evaluating rangeland productivity in Sahelian countries. In J. R. H. Behnke, I. Scoones & C. Kerven (Eds.), *Range ecology at disequilibrium : new models of natural variability and pastoral adaptation in African Savannas* (pp. 104-117). London: Overseas Development.

DeKeyser, S., Clambey, G., Krabbenhoft, K., & Ostendorf, J. (2009). Are Changes in Species Composition on Central North Dakota Rangelands Due to Non-Use Management? *Rangelands, 31*(6), 16-19.

Facelli, J. M., & Springbett, H. (2009). Why do some species in arid lands increase under grazing? Mechanisms that favour increased abundance of *Maireana pyramidata* in overgrazed chenopod shrubs of South Australia. *Austral Ecology, 34,* 588 -597.

Fujita, N., Amartuvshin, N., Yamada, Y., Matsui, K., Sakai, S., & Yamamura, N. (2009). Positive and negative effects of livestock grazing on plant diversity of Mongolian nomadic pasturelands along a slope with soil moisture gradient. *Grassland Science, 55*(3), 126-134.

GenStat. (2008). GenStat - Seventh Edition (DE3) (Version 7.2.2.222). Hemel Hempstead, United Kingdom: VSN International.

Han, G., Hao, X., Zhao, M., Wang, M., Ellert, B. H., & Willms, W. (2008). Effect of grazing intensity on carbon and nitrogen in soil and vegetation in a meadow steppe in Inner Mongolia. *Agriculture, Ecosystems & Environment, 125*, 21-32.

Herlocker, D. J. (1995). *Range management handbook of Kenya : Vol. III,10, range resource monitoring : field and office guidelines*. Nairobi: Ministry of Livestock Development (MOLD).

Herlocker, D. J. (1999). *Rangeland ecology and resource development in eastern Africa*. Nairobi: German Agency for Technical Co-operation.

Hodgson, J. (1990). *Grazing management: Science into practice*. Essex, England: Longman Group UK Limited.

José, M. F., & Heather, S. (2009). Why do some species in arid lands increase under grazing? Mechanisms that favour increased abundance of Maireana pyramidata in overgrazed chenopod shrublands of South Australia. *Austral Ecology, 34*(5), 588-597.

Kent, M., & Coker, P. (1994). *Vegetaion description and analysis: A practical approach*. London: Belhaven Press.

Lanta, V., Dole, J., Lantová, P., Kelí, J., & Mudrák, O. (2009). Effects of pasture management and fertilizer regimes on botanical changes in species-rich mountain calcareous grassland in Central Europe. *Grass and Forage Science, 64*(4), 443-453.

Lin, Y., Hong, M., Han, G., Zhao, M., Bai, Y., & Chang, S. X. (2010). Grazing intensity affected spatial patterns of vegetation and soil fertility in a desert steppe. *Agriculture, Ecosystems & Environment, 138*(3-4), 282-292.

Loeser, M. R., Sisk, T. D., & Crews, T. E. (2007). Impact of Grazing Intensity during Drought in an Arizona Grassland. *Conservation Biology, 21*(1), 87-97.

Majaliwa, J. G. M., Twongyirwe, R., Nyenje, R., Oluka, M., Ongom, B., Sirike, J., et al. (2010). The Effect of Land Cover Change on Soil Properties around Kibale National Park in South Western Uganda. *Applied and Environmental Soil Science, 2010,* 7 pages.

Mligo, C. (2009). Determination of the soil organic carbon, nitrogen, available phosphorus and the combined aboveground plant materials in the semi-arid Mbulu District, Tanzania. *African Journal of Ecology, 47*(3), 352-359.

MoLHUD. (2007). *The national land use policy*.

Mueller-Dombos, D., & Ellenberg, H. (1974). *Aims and methods of vegetation Ecology*: John Wiley & Sons, Inc.

NEMA. (2007). *State of environment report for Uganda*. Kampala: National Environment Management Authority (NEMA).

Okalebo, J. R., Gathua, K. W., & Woomer, P. L. (2002). *Laboratory methods of soil and plant analysis: A working manual*. Nairobi: Tropical Soil Biology and Fertility Programme. Marvel EPZ, Kenya Press Ltd.

Osborne, P. L. (2000). *Tropical ecosystems and ecological concepts*. Cambridge: Cambridge University Press.

Pickup, G. (1994). Modelling patterns of defoliation by grazing animals in rangelands. *Applied Ecology, 31*(2), 231 - 246.

Pontes, L. S., Carrère, P., Andueza, D., Louault, F., & Soussana, J. F. (2007). Seasonal productivity and nutritive value of temperate grasses found in semi-natural pastures in Europe: responses to cutting frequency and N supply. *Grass and Forage Science, 62*(4), 485-496.

Sánchez-Jardón, L., Acosta, B., del Pozo, A., Casado, M. A., Ovalle, C., Elizalde, H. F., et al. (2010). Grassland productivity and diversity on a tree cover gradient in Nothofagus pumilio in NW Patagonia. *Agriculture, Ecosystems & Environment, 137*(1-2), 213-218.

Schulze, R. E. (1997). Climate. In R. M. Cowling (Ed.), *Vegetation of southern Africa* (pp. 21-41). Cambridge: Cambridge University Press.

Skarpe, C., Aarrestad, P. A., Andreassen, H. P., Dhillion, S. S., Dimakatso, T., du Toit, J. T., et al. (2004). The return of the giants: Ecological effects in an increasing elephant population. *Ambio, 33*(6), 276-282.

Stoddart, L. A., & Smith, A. D. (1955). *Range Management*. New York: McGraw-Hill Book Company, Inc.

Tate, K. W., Atwili, E. R., McDougald, N. K., & George, M. R. (2003). Spatial and temporal patterns of cattle feces deposition on rangeland. *Range manage, 56*, 432 - 438.

Tibor, T. (2010). Medium-term vegetation dynamics and their association with edaphic conditions in two Hungarian saline grassland communities. *Grassland Science, 56*(1), 13-18.

Tiemann, T. T., Franco, L. H., Peters, M., Frossard, E., Kreuzer, M., Lascano, C. E., et al. (2009). Effect of season, soil type and fertilizer on the biomass production and chemical composition of five tropical shrub legumes with forage potential. *Grass and Forage Science, 64*(3), 255-265.

Turner, M. D. (1998). Long-term effects of daily grazing orbits on nutrient availability in Sahelian West Africa: 2. Effects of phosphorus gradient on spatial patterns of annual grassland production. *Journal of Biogeography, 25*, 683-694.

Turner, M. D. (2003). Methodological reflections on the use of remote sensing and geographic information science in human ecological research. *Human Ecol, 31*(2), 255-279.

Turner, M. D., & Congalton, R. G. (1998). Classification of multi-temporal SPOT-XS satellite data for mapping rice field on a West African floodplain. *Int. J. Remote Sensing, 19*(1), 21 - 41.

Turner, M. D., Hiernaux, P., & Schlecht, E. (2005). The distribution of grazing pressure in relation to vegetion resources in sem-arid West Africa: The role of herding. *Ecosystems, 7*, 1-14.

Xie, Y., Becker, U., & Wittig, R. (2007). Vegetation of the Stipa loess steppe in Ningxia (northern China) in relation to grazing intensity. *Grassland Science, 53*, 143 - 154.

Zarovali, M. P., Yiakoulaki, M. D., & Papanastasis, V. P. (2007). Effects of shrub encroachment on herbage production and nutritive value in semi-arid Mediterranean grasslands. *Grass and Forage Science, 62*(3), 355-363.

CHAPTER SEVEN

7.0 Seasonal Patterns of Herbage Species Composition, Biomass and Nutritive value

Abstract

This chapter presents an assessment of seasonal patterns of herbage species composition, mass and nutritive value in relation to vegetation cover, soil types and grazing variables. The assessment was based on monthly data collected for two years and analysed according to seasons of long-term rainfall patterns. Herbage was analysed for dry matter (DM) yield, crude protein (CP) concentration, *in vitro* organic matter digestibility (OMD) and neutral-detergent fibre (NDF). A total of 46 species were recorded. Bush grasslands were recorded with the highest number of species (43) and Woodlands with the lowest (32). The most dominant species were *Brachiaria decumbens, Cynodon dactylon, Loudetia kagerensis* and *Sporobolus pyramidalis.* The highest species number was during March-May season and the least was during June-August dry season. Herbage species height ranged from 11 to 15 and 16 to 23 cm during the dry and rainy seasons respectively. The variables considered explained 85% of DM yield, 77% of CP, 67% OMD, and 64% NDF variations. Grazing significantly ($p < 0.001$) affected DM yield and accounted for 0.35 of total variance. Seasonal DM yield ranged between (252 to 347 gDMm^{-2}; $P<0.05$). Vegetation type was the most important variable for CP concentration explaining 60% of the total variance. CP concentration ranged from 5.7% in June-August to 7.5% in September-November. Season of harvest was the only significant ($p<001$) variable, explaining 47% of total variance in OMD. The highest OMD was during December-February season (59.5%; $P<0.05$) and lowest was in September-November (46.2%; $P<0.05$). NDF ranged from 64.8% during June-August season to 66.4% during March-May. There were substantial differences in seasonal patterns of herbage quantity due to erratic nature of rainfall. Since herbage quality was predominantly controlled by rainfall seasons its improvement may not be well within the control of rangeland users and managers especially under the current management systems.

7.1 Introduction

Rangelands of sub-Saharan Africa experience variations in rainfall on an annual cycle with corresponding variations in forage productivity (Ellis, 1995). Some of the variations are associated with severe droughts in which large stocks of animals die due to highly reduced forage as well as surface and ground water levels (NEMA, 2002). During droughts, herdsmen and their animals move long distances in search for forage whose locations are usually not predetermined. Moreover, due to the unpredictability inherent to rangeland ecosystems, the herbage productivity levels may vary seasonally and inter-annually (Li et al., 2009; Putfarken et al., 2008; Turner et al., 2005) in response to variations in rainfall and nutrient availability (Han et al., 2008). There is therefore a need to continuously monitor the herbage quality and quantity supply and demand conditions (Bernués et al., 2005). Monitoring is essential for understanding spatial and temporal variations of rangeland resources. With such understanding, the likely responses to these variations such as opportunistic exploitation of herbage by animals can easily be explored. Monitoring and prediction are important for sound management of forage in rangeland ecosystems (de Ridder and Breman, 1993; Herlocker, 1999). .

Many important rangeland management decisions require an understanding of vegetation dynamics (Canton et al., 2003; Li Jianlong, 1998) since awareness of change provides an opportunity to either stop or reverse undesirable changes or take advantage of desirable changes (Herlocker, 1999). Continuous monitoring of rangeland herbage quality and quantity provides a basis for ensuring that appropriate responses to changes due to temporal and spatial variations in climatic elements and landscape characteristics are executed (de Ridder and Breman, 1993). Renken (2008); Bernués, (2005) demonstrated the importance of information on herbage quantity and quality in livestock production systems. The information is important for estimating grazing productivity and serves as a basis for planning and hence effective rangeland management (Martin et al., 2005; Reeves et al., 2001; Vermeire and Gillen, 2001). For example Rangeland forage yield is normally used in decisions regarding the maintenance of pastureland-animal production balances (Díaz-solis et al., 2009; Li Jianlong, 1998). Information on forage quantity and quality is also an essential factor in determining the movements of animal herds which is important for predicting and managing the movement patterns for purposes of sustainable grazing in rangelands (Bailey, 2004; Baker and Hoffman, 2006).

Rangeland dynamics are more closely related to the amount and seasonal distribution of rainfall than any other climatic variable (Boer and Stafford, 2003). Seasons of good rainfall result in good herbage and poor rainy seasons may cause little or no growth at all (Moreau, 2003). Herbage with no access to ground water will weaken or die during long droughts. Several seasons of good rains may assist the recovery of weakened degraded herbage or may trigger their reproductive phases (Herlocker, 1995). During rainfall, water may infiltrate and move through the soil profile or run off the soil surface to be lost from that specific site. Although management cannot be used to improve the amount or predictability of rainfall received at a given location, it can improve rainfall effectiveness by: increasing rainfall infiltration rates; reducing evaporation from the soil and plant surface; controlling soil erosion; reducing noxious/toxic plant densities; and increasing herbage harvest efficiencies (McGinty et al., 1991).

Landscape characteristics such as soil type (Boer and Stafford, 2003; Moreau, 2003; Reeves et al., 2001; Tibor, 2010), vegetation cover (Boelman et al., 2005; Canton et al., 2003; Putfarken et al., 2008), landforms and topography (Mutanga, 2004; Santos et al., 2003; Tate et al., 2003) influence both run-off coefficient and storage capacity, which in turn determine the amount of water stored in the soil and hence available for herbage growth (de Leeuw and Tothill, 1993). Loss of a few centimeters of topsoil through sheet or wind erosion for example, can greatly reduce soil fertility and soil's ability to store water thereby reducing water availability for plant growth resulting in poor quality and quantity of herbage. A change from good to poor quality and quantity of herbage species lowers herbage production (Herlocker, 1995). Nevertheless all these elements described are largely interconnected in the way they influence herbage characteristics.

The relative proportions of herbage and woody cover at a given rangeland site influence the quantity (Tiemann et al., 2009) and quality (Sánchez-Jardón et al., 2010) of herbage. Herbaceous and woody plants co-exist in a delicate state of balance controlled by competition for water, minerals and other essentials of life (Mueller-Dombos and Ellenberg 1974; Pihlgren and Lennartsson 2008). Any change which encourages herbage vigour discourages the spread of woody plants, hence increased herbage availability for grazers. On the other hand, any factor such as overgrazing which weakens herbage favours the invasion by shrubs and trees (Archibald, 2008).

Studies have shown that grazing is important in determining seasonal and spatial variations in rangeland productivity (Baker and Hoffman, 2006; Bloesch, 2002; Fujita et al., 2009). Any grazing, whether moderate or heavy or whether early or late, has a measurable influence upon the herbage quantity and quality (Pratt and Gwynne 1977). Grazing intensity is one of the major factors that cause differences in chemical composition and digestibility of herbage (Turner, Hiernaux et al. 2005). Regrowth from frequently grazed herbage is leafier and generally more palatable to animals because it is more tender, high in moisture content, and contains less yellowed and dried material (Olupot et al., 2010). However grazing will in most cases reduce the quantity of herbage (Lin et al., 2010). Grazing during the growing season is desirable to the limit of the capacity of the species composition. Nevertheless, the higher the grazing intensity on a rangeland, the poorer the quality of herbage on that rangeland, unless conditions are favourable for rapid regrowth (Stoddart and Smith 1955). Grazing is most detrimental when: excessively wet soils are coupled with trampling damage (Bernués et al., 2005) ; in seasons when root reserves are low or when plants are not able to replace leafage because of dry conditions (Lin, Hong et al. 2010); and when continued at frequency or intensity which does not allow adequate photosynthetic tissue to remain on the plant (Herlocker 1999).

It is apparent that for each herbivore species or group of species, there must be optimum herbage supply (Moisey et al., 2005) to enable it to obtain maximum intake of nutrients for a minimum expenditure of energy (Pratt and Gwynne, 1977; Putfarken et al., 2008). The quantity of dry matter voluntarily eaten by an animal is the most important factor controlling the productive value of herbage at a given rangeland site. If an animal feeds on insufficient quantities of herbage, production of meat or milk will be low no matter how high the protein, digestible energy or mineral content of each unit feed may be (Skerman et al., 1988). In determining the optimum herbage requirements, considerations must be taken of the spacing of the preferred herbage components, their weight per unit area and their degree of interspersion with other components in the same landscape (Pratt and Gwynne, 1977). Hence, describing spatial and temporal herbage characteristics is prerequisite for understanding and managing grazer-herbage interactions. Studies of pastoral systems reveal that spatial and temporal variation in herbage quantity and quality is of crucial importance in regulating grazers (Ellis, 1995).

In rainy seasons, rangelands will have enough water and herbage supply for animals, but the conditions will deteriorate during dry seasons. Such deterioration is evidenced by both decline in herbage mass and quality on a rangeland (Turner et al., 2005). These patterns of change are usually the main cause of seasonal movements of grazers between dry and wet seasons (Said, 1993; Western, 1975). Seasonal use of natural rangelands has a vital role in agricultural economy and greatly affects animal productivity (Li Jianlong, 1998). A spatial and seasonal assessment of rangeland herbage at different stages and thus their stocking rates allows for better management of forage and livestock resources (Moreau, 2003). In addition, herbage quality and quantity measurements can help in guiding decision makers to understand how rangeland productivity varies spatially and temporarily (Beeri et al., 2007).

Whereas there is a growing interest in using and preserving grazing resources, the questions related to availing temporal and spatial information on forage type specific changes remain unresolved (Bernués et al., 2005). Where effort has been made, the main focus has been mainly on providing information on herbage quantity and quality snapshot assessments. There is limited data and/or information on spatial and seasonal variations in herbage quantity and quality especially under natural and free grazing rangeland systems. There is need to quantify and understand how various factors affect herbage patterns in order to devise management strategies for effective and sustainable rangeland production systems. Two questions were addressed in this chapter: Do season and vegetation physiognomic cover types significantly affect grassy species (grass and grass-like) composition? How are herbage mass and quality seasonal patterns affected by vegetation cover, soil type and grazing?

7.2 Methods and Materials of Data Collection

7.2.1 Grassy Species Cover and Height

Seven vegetation physiognomic classes (bushland, bushland thicket, woodland, shrubland, grassland, bush grassland, and wooded grassland) as established in chapter five, were used as the sampling strata (Table 7.1). The data collection period (December 2008 to November 2010) was divided into three-month seasons according to the long-term rainfall patterns in the study area. The seasons were December to February (DecFeb), March to May (MarMay), June to August (JunAug), and September to November (SepNov) with data collection replicated three times for each season. For each vegetation class, at least 12 quadrats of 2×2m were placed in a 30x30m plot every month using stratified clustered representative random sampling. Within the 2x2m quadrat, individual grassy species cover and height were recorded following the same procedures described in chapter five, section 5.2.2. All quadrat sampling locations (Figure 7.1) were saved in a handheld GPS (Global Positioning System) receiver. Every month, the same quadrat placing points were navigated to using the GPS to ensure consistency in recorded data in different seasons and vegetation cover classes. Field data were entered into Microsoft Office Access software (Microsoft, 2003) relational database for easy retrieval using queries, minimising errors and redundancy (de By, 2001). Information on perceived quality of herbage species was obtained from the field during interactions with livestock owners by asking them to identify the species they preferred for their cattle.

Table 7.1: Vegetation Physiognomic classes used for data collection (adopted from Pratt and Gwynne, 1977)

Cover type	**Descriptions**
Bushland	Assemblage of trees and shrubs; Shrubs are dominant; Trees are conspicuous; Shrubs and trees cover >20%; Height of trees =<10m
Bushland thicket	Extreme form of bushland with a closed form of woody plants; Man or larger ungulates can pass with extreme difficulty
Woodland	With an open or continuous but not thickly connected canopy; Grasses dominate the ground cover ; Trees cover up >20%; Height of trees up to 20m
Shrubland	Land supporting a stand of shrubs; Poor ground cover; Shrub height =< 6m; Shrub cover >20; Trees cover 0 or <10%
Grassland	Dominated by grasses and occasionally other herbs; May have scattered or grouped trees and shrubs; Shrubs and trees cover 0 or <2%
Bush grassland	Grassland with scattered or grouped trees and shrubs—both always conspicuous; Shrub and trees cover <20%
Wooded grassland	With scattered or grouped trees; Trees always conspicuous and determine the classification; Trees cover <20%

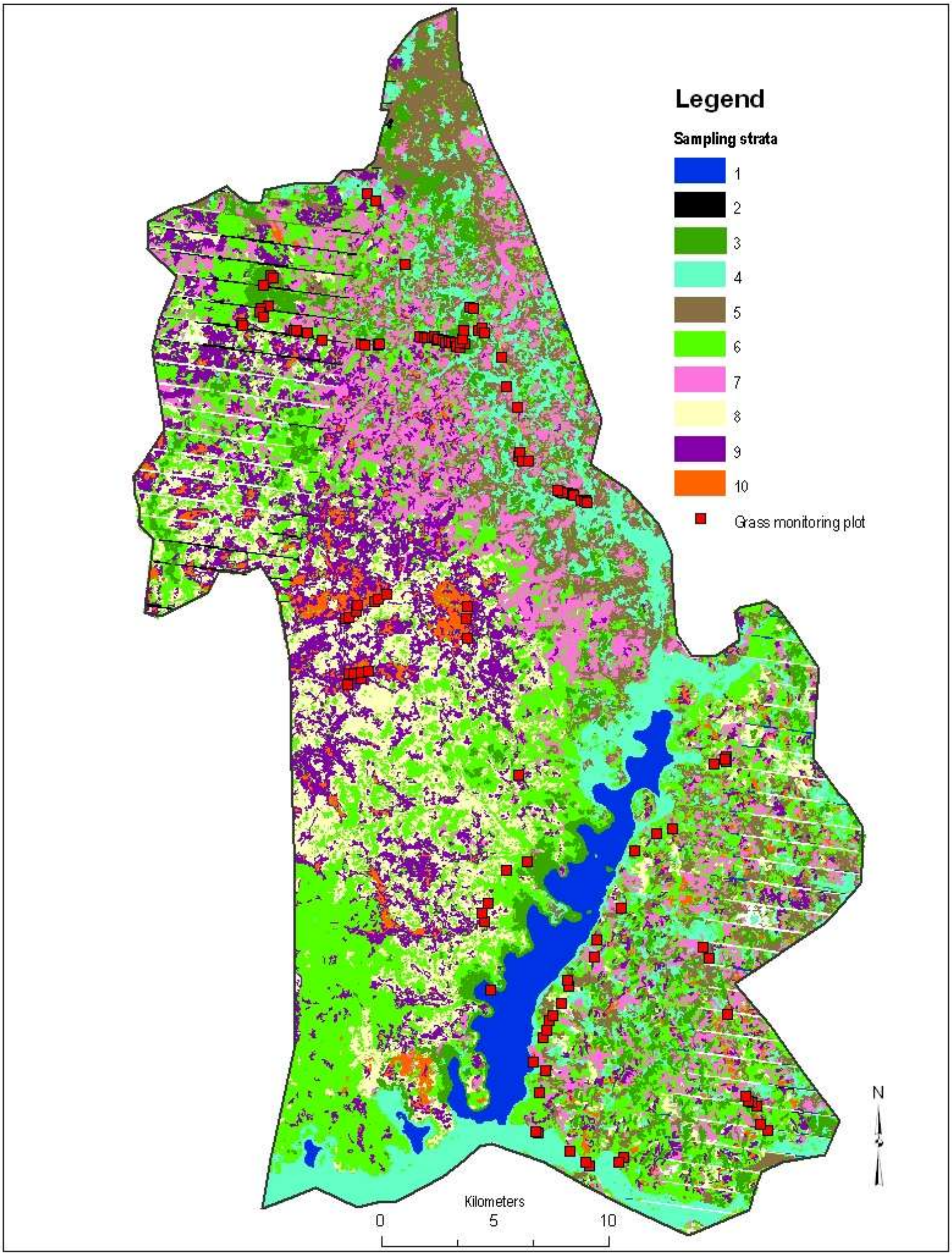


Figure 7.1: Quadrat locations of grassy species composition monitoring plots

7.2.2 Herbage Mass and Nutritive Value

The seven vegetation physiognomic classes in Table 7.1 above, were merged into two strata (woodland and grassland) based on the vegetation classification results in chapter five (Table 5.2; Figure 7.3). Experimental sites (Figure 7.2) were selected using the two completely randomised vegetation strata on which three soil textural classes (clay loam, loam and sandy loam) and two grazing levels (grazed and ungrazed) were arranged as sub-plots and sub-sub-plots respectively (Figure 7.3). Each treatment was replicated at least three times. For each of the ungrazed experiment, 10 x 10 m plots of the selected sites were enclosed by fencing using barbed wire to protect them from big herbivores. After every 30 days from December 2008 to November 2010, two 1x1 m quadrats were randomly placed in all treatments. For each placed quadrat, species composition, grassy height and cover were recorded. All herbage samples in each quadrat were clipped to 'ground level' (about 1 cm high) and all residual litter and herbs were removed by hand picking. The harvested fresh herbage samples were weighed and transported to the lab for oven drying.

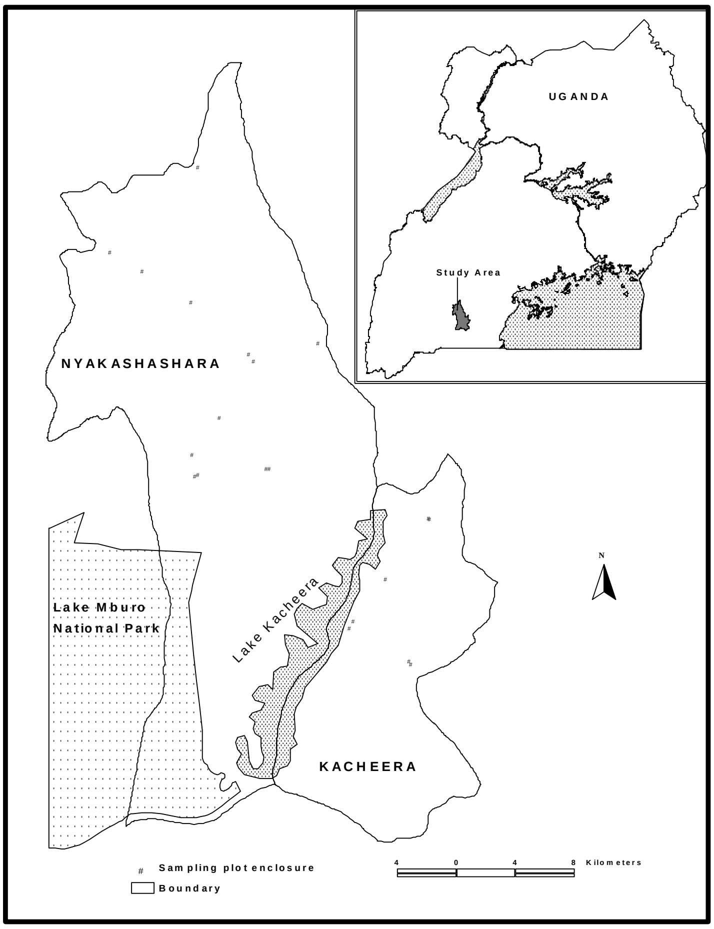


Figure 7.2: Map showing the location experimental sites

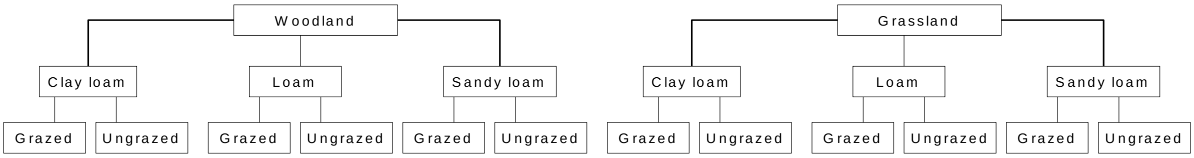


Figure 7.3: Split-Split-Plot experimental arrangement plots used in this study

Herbage Mass Determination

From December 2008 to November 2010, a total of 1499 above ground herbage samples were harvested by cutting using a sickle to ground level. The harvested herbage was hand sorted to remove litter and other non herbage plant materials. The fresh herbage samples were weighed, mixed thoroughly in the field and sub-sampled to reduce the sample load. The sub-samples of the fresh harvest were also weighed, and then transported to the lab. The sub-samples were oven dried at 60°C until constant weight to obtain herbage dry matter weight with respect to sample plots for the different treatments. The ratio of dry weight of the sub-sample to the full sample weight was used to calculate herbage yield as dry matter (DM) yield for each quadrat in $gDMm^{-2}$.

Nutritive Value Determination

The nutritive value of harvested herbage was assessed using 740 samples collected between December 2008 and November 2009. These samples were ground (1 mm) and 192 seasonal composite samples for all treatments were prepared for crude protein (CP) concentration, neutral detergent fiber (NDF) and organic matter digestibility (OMD) analysis. Nutritive value was determined following the procedures described by (Mebrahtu and Tenaye, 1997). Crude protein was determined using the Kjeldahl method (AOAC, 1990); NDF by Van Soest method (Van Soest and Robertson, 1985); and the digestibility was determined using the modified Tilley Terry *in vitro* procedure (Tilley and Terry, 1963).

7.2.3 Data Analyses

Grassy Species Cover, Height and Numbers

To obtain monthly and ultimately seasonal data, 2,783 2x2m quadrat data were retrieved from Microsoft Access program using queries and averaged according to the different vegetation cover classes in Microsoft excel (Microsoft, 2003). Monthly data were averaged according to the vegetation cover types and seasons. Using the statistical package GenStat

(GenStat, 2008) Analysis of Variance (ANOVA) was carried out to compare grassy species cover, height, and species numbers in the different seasons, and vegetation cover types. Separation of means was done using the least significant differences (LSD). Mean values that differed at $P<0.05$ were considered significant. To establish the patterns of influence by vegetation type and season on species cover, rangeland status indicator species (Herlocker, 1999; Phillips, et al., 2003; Skerman, et al., 1988 were subjected to linear discriminate analysis using XLSTAT (Addinsoft, 2011).

Herbage Mass and Nutritive Value

Monthly data for all treatments were averaged according to rainfall seasons (December-February (DecFeb)), March-May (MarMay), June-August (JunAug) and September-November (SepNov)). Split-Split-Plot Analysis of Variance (GenStat, 2008) was performed on data of above-ground herbage DM yield, crude protein, and digestibility to test the statistical significance of vegetation, soil and grazing in different seasons. Separation of means was done using the least significant differences (LSD). Values that differed at $P \leq 0.05$ were considered significant.

7.3 Results

7.3.1 Spatial Patterns of Species Composition

A total of 46 grassy species were found in the study area. Bush grasslands were recorded with the highest number of species (43) and Woodlands with the lowest (32) (Appendix 7.1). Generally, the number of grassy species in the cover types decreased with increasing percentage cover of woody species but this correlation was not significant ($r = -0.319$, $P > 0.05$) (Figure 7.4). There was a significant difference in the overall species cover ($p< 0.001$) but height was not statistically different ($p>0.05$) among different vegetation cover types.

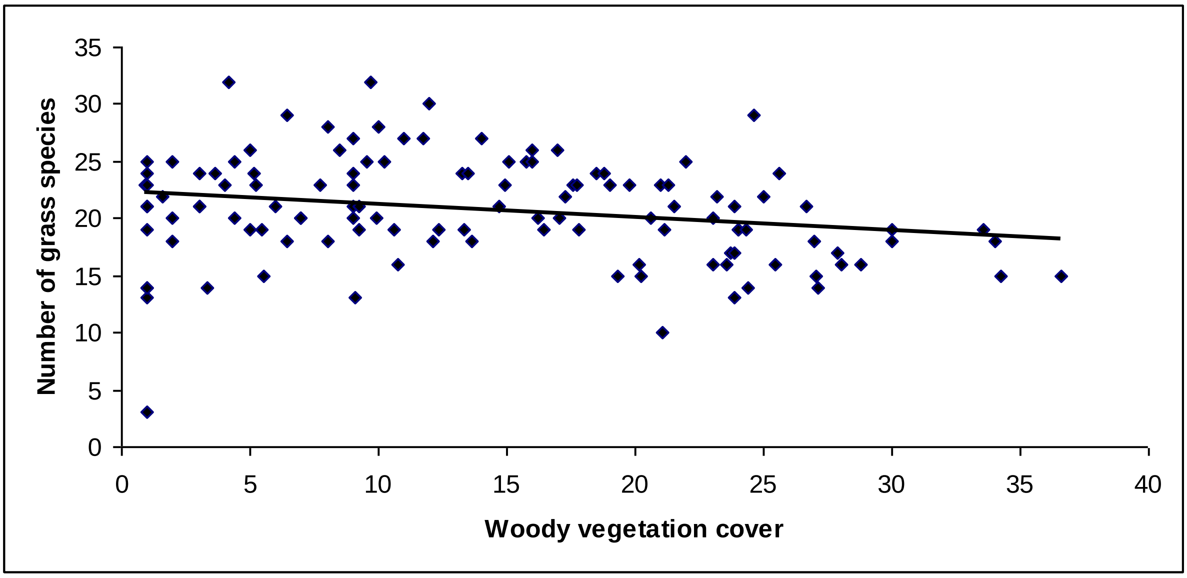


Figure 7.4: Correlation between numbers of grassy species recorded and woody cover.

Twenty eight (61 %) of the recorded species occurred in all the seven vegetation cover types, and only five (11 %) species (*Andropogon amethystinus* and *Setaria kagerensis, Brachiaria jubata*, *Eragrostis macilenta* and *Eragrostis superba)* were restricted to bush grassland, grassland, wooded grassland and bushland respectively.

Species that were reported to be preferred by livestock owners or recorded ≥ 20% cover at least in one vegetation cover type were considered in Table 7.2. Grasslands had by far, the highest number of preferred or dominant species (17), with the rest of the cover types having ≤13%. Though 2 species (*Digitaria ternata* and *Eragrostis racemosa*) recorded the ≥ 20% cover, both appeared once in Bush grassland in March 2010 and August 2009 respectively. About 43% of the dominant grass species were identified as most preferred by livestock owners (Table 7.2). Among these species, *Hyparrhenia rufa* occurred in the least number of vegetation cover classes (bush grasslands, bushlands and grasslands).

Table 7.2: Effect of vegetation cover type on average percentage canopy cover of the most dominant and/or preferred herbage species

Species	**BG**	**B**	**BT**	**G**	**S**	**WG**	**W**
*Bothriochloa insculpta**	3.1	1.3	0.5	5.3	4.2	6.1	2.8
*Brachiaria brizantha**	1.0	12.0	0.5	3.1	−	7.2	−
*Brachiaria decumbens**	28.6	32.3	23.9	21.6	21.5	33.3	32.5
*Brachiaria platynota**	3.7	3.3	2.1	12.2	2.8	4.4	0.8
Chloris pycnothrix	6.6	4.4	1.0	7.4	8.4	3.6	4.3
Cymbopogon nardus	7.1	6.0	9.5	10.2	6.9	5.5	7.2
Cynodon dactylon	20.1	11.4	15.8	20.9	4.1	6.8	12.4
Digitaria abyssinica	10.6	4.2	3.8	7.1	6.4	4.1	6.9
Digitaria maitlandii	1.7	1.3	2.8	3.6	2.8	1.0	0.7
Eragrostis exasperata	0.5	1.1	0.5	1.9	0.8	3.3	−
Eragrostis tenuifolia	3.1	1.8	0.6	4.2	2.4	5.7	2.8
*Hyparrhenia filipendula**	3.7	3.1	4.0	6.1	3.3	4.0	2.6
*Hyparrhenia rufa**	0.8	1.8	−	1.9	−	−	−
Loudetia kagerensis	19.1	5.6	4.4	23.9	17.8	8.9	3.3
Microchloa kunthii	1.8	2.0	6.5	1.6	0.5	2.9	1.0
Panicum maximum	3.7	3.1	2.6	5.5	2.9	7.1	2.7
Paspalum scrobiculatum	3.0	2.6	2.1	1.4	0.8	−	1.1
Setaria homonyma	8.8	9.2	14.1	6.9	12.6	3.0	22.1
Setaria sphacelata	6.3	2.4	3.2	1.9	2.8	3.1	5.4
Sporobolus pyramidalis	17.8	16.8	13.8	19.7	21.6	27.0	13.0
Sporobolus stapfianus	3.6	4.1	4.4	3.0	3.9	4.2	3.5
*Themeda triandra**	4.3	5.6	1.7	10.4	4.8	5.8	3.2

* Most preferred by herders in the study area; BG, bush grassland; B, bushland; BT, bushland thicket; G, grassland; S, shrubland; WG, wooded grassland; W is woodland.

About 86% of the most preferred species occurred in all the seven cover types. *Brachiaria decumbens* and *B. platynota* were the most common preferred species occurring in more than 70% of the cover types. Results from discriminate analysis based on vegetation cover types showed that species cover values were generally clustered into four herbage communities (Figure 7.5). *Bothriochloa insculpta* and *Sporobolus pyramidalis* were more prominent in Shrubland than any other vegetation type. *Brachiaria decumbens* and *Setaria homonyma* were more associated with woodland and wooded grassland vegetation. The abundance of *Hyparrhenia* species especially *Hyparrhenia filipendula* was favoured by grassland vegetation cover. Bush grassland and bushland tended to favour prominence of *Cynodon dactylon* and *Cymbopogon nardus*.

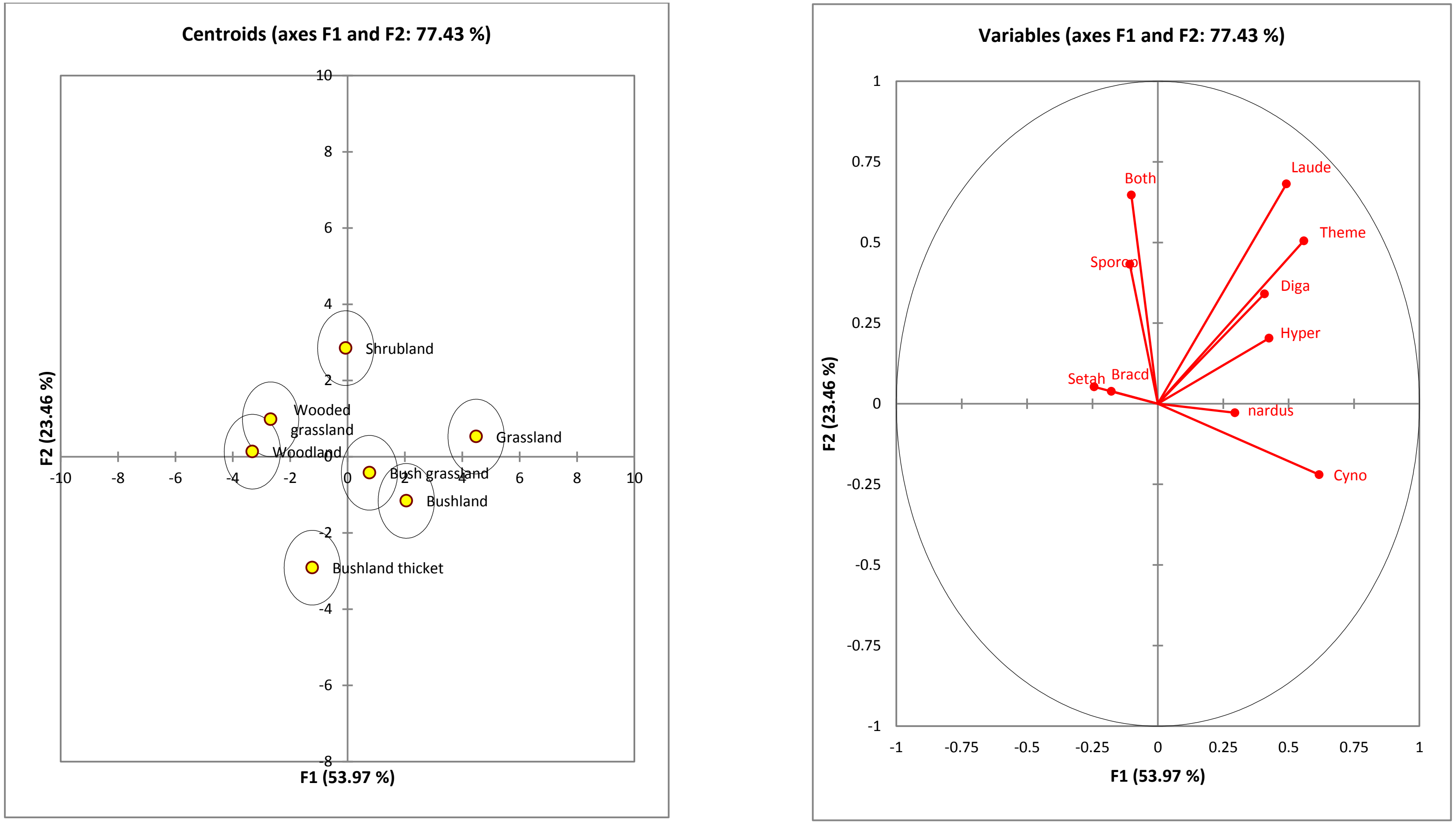


Figure 7.5: Centroids (weighed averages) of vegetation cover types and indicator grass species (weighed averages of site scores). The eigenvalues of axis 1 (horizontally) and axis 2 (vertically) are 8.49 and 3.69 respectively. The species are *Brachiaria decumbens (*Bracd); *Cymbopogon nardus* (nardus); *Cynodon dactylon* (Cyno); *Digitaria abyssinica* (Diga); *Hyparrhenia* spp (Hyper); *Loudetia kagerensis* (Laude); *Setaria homonyma* (Setah); *Sporobolus pyramidalis* (Sporop); *Themeda triandra* (Theme).

7.3.2 Seasonal Patterns of Herbage Composition

Comparisons from ANOVA indicate that the number of species varied significantly (p=0.02) across seasons. Species numbers were significantly different (p=0.004) across seasons. A grand seasonal mean of 25 species was recorded. The highest mean number of species (33) was in December-February season under bush grassland vegetation cover and the lowest number (16) of species was in both June-August in woodlands and December-February in bushland thickets (Table 7.3).

Table 7.3: Effect of vegetation cover types on seasonal means of grassy species numbers

Vegetation type	DecFeb	MarMay	JunAug	SepNov
Bush grassland	33^{aA}	30^{eB}	24^{hC}	31^{kA}
Bushland	29^{bD}	28^{efD}	23^{iE}	27^{mnD}
Bushland thicket	16^{dH}	26^{fgF}	22^{iGG}	24^{noFG}
Grassland	31^{aJ}	31^{eJ}	27^{hK}	30^{kmJ}
Shrubland	27^{bcLM}	28^{efL}	22^{iN}	25^{noM}
Wooded grassland	28^{bO}	28^{efO}	23^{iP}	27^{mnO}
Woodland	24^{cQ}	23^{gQ}	16^{jR}	22^{oQ}

Different lower case letters indicate that vegetation type had a significant effect on number of grassy species; different upper case letters indicate that season had a significant effect on number of grassy species

Seasonal data showed that *Sporobolus pyramidalis* and *Brachiaria decumbens* species were on average recorded with the highest cover (Table 7.4). Results from ANOVA showed that overall herbage species cover significantly differed across seasons (p=0.002). Species height analysis also showed significant difference (p<0.001) among seasons. The overall seasonal mean herbage species cover was 53.9%. The highest mean cover (77%) was in June-August under grassland vegetation cover and the lowest was (27%) in September-November season under bushland thicket vegetation (Table 7.5). The overall mean herbage species height was 17.36 centimetres. The highest mean (23.1cm) was in March-May in wooded grassland vegetation and the lowest was 11.4 cm in September-November season under woodland vegetation (Table 7.6). Indicator species seasonal patterns from discriminate analysis (Figure 7.6) show that *Sporobolus pyramidalis* was most prevalent in the JunAug dry season. In DecFeb dry season the most common species were *Cynodon dactylon* and *Loudetia kagerensis. Setaria homonyma* was most dominant during MarMay wet season. During SepNov wet season *Brachiaria decumbens* was the most predominant species.

Table 7.4: Effect of season on percentage species canopy cover averages of the most dominant and/or preferred grass species

	Season							
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Species	DecFeb2009	MarMay2009	JunAug2009	SepNov2009	DecFeb2010	MarMay2010	JunAug2010	SepNov2010
Bothriochloa insculpta	3.3	2.9	6.8	1.8	4.7	3.3	1.6	3.3
Brachiaria brizantha	5.5	11.3	7.8	1.0	11.3	1.0	0.8	1.0
Brachiaria decumbens	36.6	45.0	24.7	23.6	25.6	25.7	22.1	17.4
Brachiaria platynota	3.0	6.8	3.8	4.0	4.7	9.6	4.5	5.2
Chloris pycnothrix	2.3	17.0	2.7	3.8	8.3	5.0	2.0	1.7
Cymbopogon nardus	9.7	16.5	8.6	5.4	5.4	3.1	1.9	5.7
Cynodon dactylon	7.3	14.8	16.1	12.7	13.9	14.6	8.6	7.7
Digitaria abyssinica	6.6	15.9	5.9	11.1	5.7	1.4	2.4	2.6
Digitaria maitlandii	-	-	-	2.3	1.0	1.5	1.3	3.8
Eragrostis exasperate	0.5	0.6	1.5	1.4	0.5	0.6	1.5	1.4
Eragrostis tenuifolia	0.4	2.8	1.5	3.2	1.6	3.6	2.3	5.2
Hyparrhenia filipendula	0.9	1.7	3.6	6.6	3.1	5.0	3.1	3.4
Hyparrhenia rufa	-	-	1.8	2.9	1.8	1.0	0.8	2.8
Loudetia kagerensis	11.0	15.3	1.3	12.3	19.4	8.6	8.6	9.3
Microchloa kunthii	7.5	3.0	7.0	1.3	2.4	1.4	2.2	6.3
Panicum maximum	4.5	5.6	1.9	4.7	4.5	5.4	2.2	1.4
Paspalum scrobiculatum	0.8	-	-	2.1	3.8	2.0	0.7	0.8
Setaria homonyma	10.4	23.8	12.3	10.6	10.8	12.7	7.3	8.8
Setaria sphacelata	4.2	4.3	7.3	3.6	1.9	0.9	0.5	0.7
Sporobolus pyramidalis	36.3	19.2	17.7	18.3	15.3	14.4	14.5	15.4
Sporobolus stapfianus	7.8	2.1	5.8	4.1	4.1	2.0	4.3	1.3
Themeda triandra	7.6	8.4	5.3	5.4	4.1	5.2	5.6	2.7

Table 7.5: Effect of season and vegetation cover on mean herbage species canopy cover (%)

Vegetation type	March-May	June-August	September-November	December-February
Bush grassland	72^{aA}	64^{bEF}	62.5^{bH}	68.5^{abM}
Bushland	56.5^{cdB}	60.5^{cF}	43.5^{eJ}	53.5^{dN}
Bushland thicket	41^{fC}	38.5^{fG}	27^{gL}	27^{gP}
Grassland	72.2^{hiA}	77^{hD}	68.5^{iH}	69.5^{iM}
Shrubland	50.5^{jkB}	44.5^{kmG}	38.5^{mJK}	53.5^{jN}
Wooded grassland	69.5^{nA}	70n^{DE}	60.5^{oH}	69^{nM}
Woodland	40.5^{pC}	39.5^{pG}	31^{qKL}	41.5^{pO}

Means followed by different lower case letters in a row indicate a significant difference due to season; means followed by different upper case letters in a column indicate a significant difference due to vegetation cover type at $P < 0.05$

Table 7.6: Effect of season and vegetation cover on mean herbage species height (cm)

Vegetation type	March-May	June-August	September-November	December-February
Bush grassland	21.3^{aAB}	15.55^{bEF}	11.85^{cG}	21^{aH}
Bushland	18.15^{dBC}	18.9^{dDE}	13.7^{5eG}	17.65^{dH}
Bushland thicket	21.8^{fAB}	15.15^{gF}	14.8^{gG}	17.05^{gH}
Grassland	20.25^{hABC}	20.45^{hD}	13.95^{iG}	20.3^{hH}
Shrubland	20.2^{jABC}	19.1^{jDE}	14.4^{kG}	19.55^{jH}
Wooded grassland	23.1^{mA}	19.8^{mDE}	11.75^{oG}	19.5^{nH}
Woodland	16.05^{pC}	12.6^{pqF}	11.4^{qG}	16.8^{pH}

Means followed by different lower case letters in a row indicate a significant difference due to season; means followed by different upper case letters in a column indicate a significant difference due to vegetation cover type at $P < 0.05$

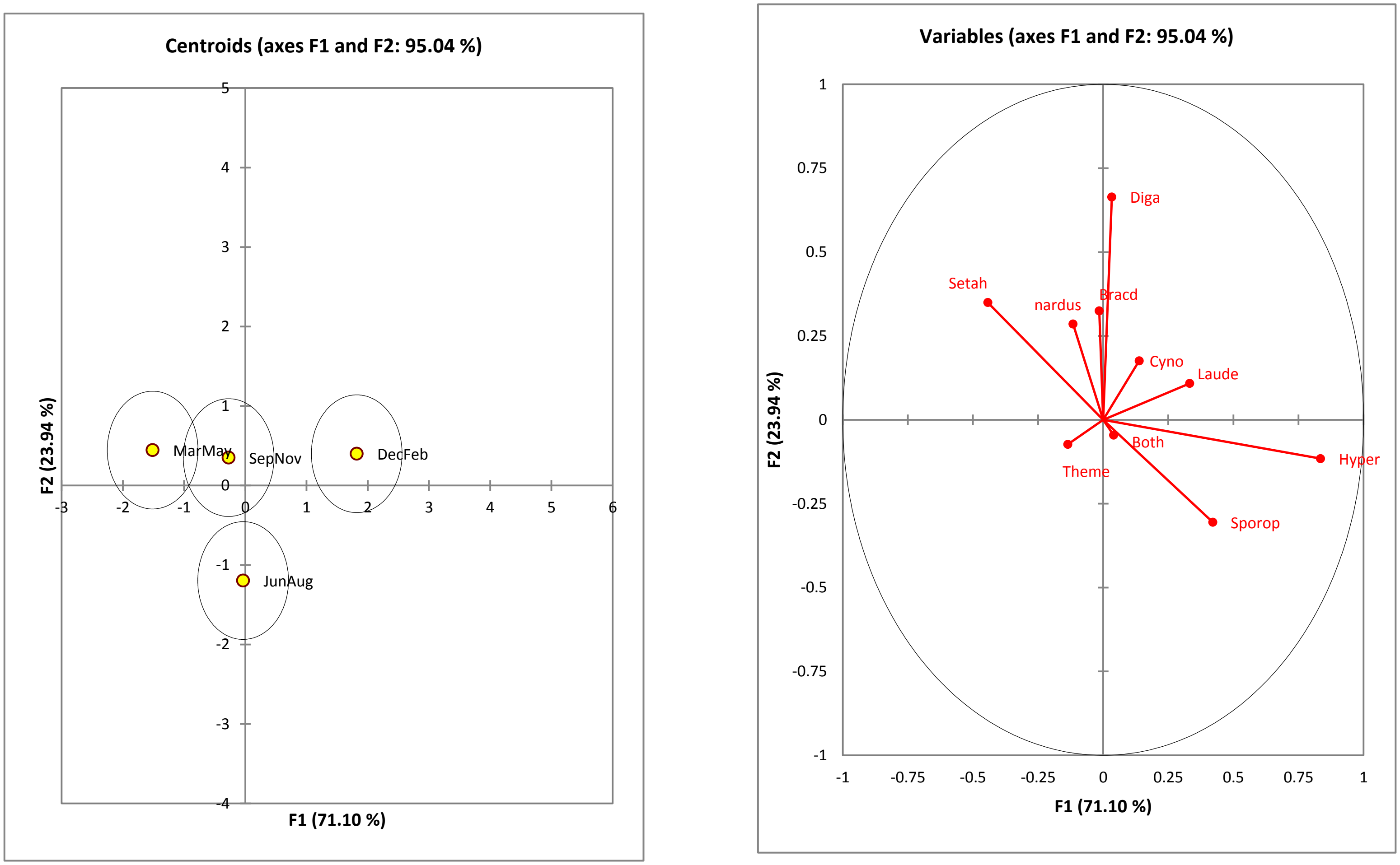


Figure 7.6: Centroids (weighed averages) of seasons and indicator grass species (weighed averages of site scores). The eigenvalues of axis 1 (horizontally) and axis 2 (vertically) are 1.66 and 0.55 respectively. The species are *Brachiaria decumbens (*Bracd), *Cymbopogon nardus* (nardus), *Cynodon dactylon* (Cyno), *Digitaria abyssinica* (Diga), *Hyparrhenia* (Hyper), *Loudetia kagerensis* (Laude), *Setaria homonyma* (Setah), *Sporobolus pyramidalis* (Sporop), *Themeda triandra* (Theme).

7.3.3 Herbage Mass

Outputs of the ANOVA for herbage yield are shown in Table 7.7. The variables considered (grazing, soil, year, season and vegetation) explained 0.85 of herbage mass variation. Grazing had the highest effect on herbage yield explaining 0.35 of the total variance. Soil accounted for 0.09 while the year of harvest accounted for 0.08 of the total variance. Season also significantly ($p < 0.001$) affected herbage yield and explained 0.06 of the total variance. Vegetation significantly ($p = 0.018$) affected herbage yield but was the least important of all the other variables explaining 0.05. Only significant interactions are presented in Table 7.7. For the five variables analysed, the most important in terms of interactions were between vegetation and year and between grazing and year.

Grazing and Seasonal Herbage Variation

Grazing significantly ($p<0.001$) affected seasonal herbage yield. As expected, DM yield from ungrazed sites was higher than from grazed sites with 381.1 and 222.6 mean gDMm^{-2} ($n = 384$) respectively. The highest mean yield for both grazed and ungrazed sites was in MarMay and least was in SepNov season (Table 7.8). The highest and the lowest seasonal mean yields for grazed sites were 440.6 and 328.7 gDMm-^{2} respectively. For grazed sites, seasonal herbage yield ranged between 176.8 and 253.8 gDMm^{-2}.

Effect of Soil Type on Seasonal Herbage Mass

The mean seasonal herbage yields for clay loam (CL) and loam soils (LS) were statistically higher than the yield from sandy loam (SL). The highest herbage mass yield was in MarMay (390; $n = 384$) on CL and the lowest was in SepNov (207.9) on SL. On CL soil, herbage yields in MarMay and DecFeb were significantly higher than in SepNov ($p=0.011$). For loam soil, MarMay was significantly higher than SepNov but other seasons were statistically similar. Similarly, under SL soils, the MarMay DM yield was significantly higher than for SepNov ($p=0.011$).

Effect of Year of Harvest on Seasonal Herbage Mass

All seasonal herbage yields in 2010 were significantly higher than those in 2009. The mean herbage yield in 2010 was 339.4 gDMm^{-2} and 264.4 in 2009. The season that was most affected by the annual underperformance in yield was SepNov (Figure 7.7). There was significant decrease (29%; $P<0.001$) in yield from MarMay to SepNov in 2009. The yield in

MarMay was higher than that for JunAug which was in turn significantly higher than that for SepNov. There was a significant increase (26%; P<0.001) from SepNov to DecFeb. In 2010, herbage yield for MarMay was statistically higher than that for SepNov and DecFeb. As was for 2009, during JunAug DM yield was significantly higher than that in SepNov (p<0.001. Between SepNov and DecFeb, there was a significant increase in herbage mass of 17%.

Effect of Vegetation Cover on Herbage Mass

Grassland was significantly more important (p=0.018) than woodland vegetation in determining seasonal herbage mass variation by a difference of 63gDMm^{-2}. Herbage mass yield from grassland sites was significantly higher in MarMay than in SepNov and DecFeb. Yields for other seasons were statistically similar under grassland vegetation cover. Under woodland vegetation, herbage mass significantly declined between MarMay and SepNov by 34%.

Table 7.7: Proportion of variance explained (V) and statistical significance of ratios (P<0.05) from ANOVA for herbage dry matter (DM) yield

	Degrees of freedom	**Herbage Yield**	
		V	**P<0.05**
Vegetation	1	0.05	0.018
Soil	2	0.09	0.011
Grazing	1	0.35	< 0.001
Season	3	0.06	< 0.001
Year	1	0.08	< 0.001
Vegetation x Year	1	0.07	< 0.001
Grazing x Year	1	0.04	< 0.001

Table 7.8: Seasonal means (s.e. of mean in parentheses) of herbage dry matter (DM) yield (gDMm^{-2}) for vegetation, soil, grazing and year

		Herbage yield			
Treatments		**DecFeb**	**MarMay**	**JunAug**	**SepNov**
Vegetation	Grassland	319 (21.8)	377 (30.6)	341 (27.9)	295 (22.5)
	Woodland	296 (35.3)	317 (26.9)	260 (25.0)	210 (17.5)
Soil	Clay loam	362 (26.3)	394 (41.2)	348 (35.9)	281 (23.4)
	Loam	322 (34.7)	347 (37.2)	311 (23.7)	269 (28.1)
	Sandy loam	236 (30.2)	301 (44.2)	242 (30.4)	208 (29.2)
Grazing	Grazed	247 (16.2)	254 (18.8)	213 (16.7)	177 (14.6
	Ungrazed	367 (26.3)	441 (33.5)	388 (30.0)	329 (22.5)
Year	2009	279 (16.9)	312 (22.7)	245 (19.7)	221 (19.9)
	2010	335 (24.5)	383 (30.7)	355 (32.0)	284 (23.7)

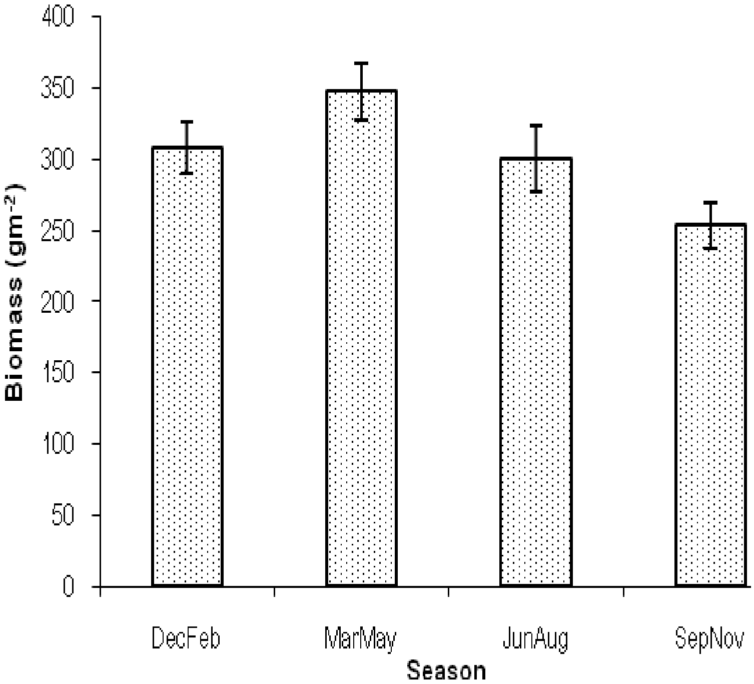


Figure 7.7: Seasonal means for herbage dry matter (DM) yield (gDMm^{-2})

7.3.4 Herbage Nutritive Value

ANOVA results for CP concentration, DM digestibility and NDF are shown in Table 7.9. Grazing, cover type, soil and grazing accounted for 0.77 of the seasonal variation in CP concentration. The most important variable for CP concentration was vegetation which explained 0.6 of the total variance. The season of herbage harvest explained 0.16 of the total variance in CP concentration. Season of herbage harvest was the only statistically significant (p<001) variable, explaining 0.47 of total variance in OM digestibility (Table 7.9). Season of harvest and vegetation had the greatest effect on NDF explaining respectively 0.06 and 0.05 of total variance. Only significant interactions are presented in Table 7.10 together with other details of all results of nutritive value analysis. CP was highest in SepNov, DM digestibility was highest in DecFeb while NDF was highest in SepNov (Figure 7.8).

Effect of Grazing on Herbage Nutritive Value

Grazing increased seasonal CP concentration and NDF but the increase was not significant for CP. On the other hand grazing decreased OM digestibility but the decrease was not significant. The highest and lowest CP concentrations were both from grazed sites in SepNov (7.7%) and MarMay (5.7%) respectively. The highest NDF was in MarMay (67.2%) on ungrazed sites and the lowest was on grazed sites in JunAug and SepNov each with 64.3%.

On the other hand OM digestibility was equally highest for both grazed and ungrazed sites in DecFeb and lowest in SepNov on ungrazed sites. Under ungrazed sites the CP significantly increased from MarMay to SepNoV by 2% but significantly decreased in DecFeb by 1.1%. The CP concentration in MarMay was significantly lower ($p< 0.001$) than the concentration in both SepNov and DecFeb (Table 7.10). CP concentration in SepNov (7.7%) was significantly higher ($p<0.001$) than in both JunAug (6.2%) and DecFeb (6.6%). For grazed sites, there was a significant decrease in CP from MarMay to JunAug by 0.6% followed by a significant increase up to DecFeb. There were no significant differences in NDF among all seasons under ungrazed sites. For grazed sites, NDF in MarMay (67.2%) was significantly higher than for SepNov (65.24%). Digestibility for organic matter harvested in MarMay was significantly higher than for SepNov and DecFeb on both grazed and ungrazed sites. Organic matter harvested in JunAug had significantly higher ($p<0.001$) digestibility than SepNov but significantly lower than the OM harvested in DecFeb (Table 7.10).

Effect of Soil on Herbage Nutritive Value

Considering clay loam soils, there were no statistical differences in seasonal CP concentration but NDF (67.4%) in both SepNov and DecFeb was significantly higher than in MarMay (64.6). OM digestibility significantly decreased between MarMay and SepNov by 9.3%. The interaction between loam soil and season did not result in any significant differences in seasonal CP concentration. On the other hand the interaction caused a significant decrease in NDF from MarMay to DecFeb by 3.7%. However, NDF in DecFeb was significantly higher than for SepNov by 2.6%. Loam soils were associated with a significantly higher ($p=0.011$) OM digestibility in DecFeb (61.6%) than in MarMay (50.8). There was a significant increase in digestibility between JunAug and SepNov of 5.6% followed by a significant decline between SepNov and DecFeb of 12.8%. Interactions between sandy loam soil and season resulted in higher CP concentration in SepNov (7.4%) than MarMay (5.7%) and JunAug (6%). The trend was different with NDF where there was a significant decrease from SepNov to DecFeb of 2.7%. There was a significantly higher DM digestibility in MarMay than in SepNov but was significantly lower than for DecFeb on sandy loam soils (Table 7.10). The same interaction caused a decrease in digestibility of 10% between JunAug and SepNov followed by a significant increase of 16.7% in DecFeb.

Effect of Vegetation Cover on Nutritive value

Grassland vegetation cover type was associated with a significantly higher CP concentration in SepNov and DecFeb than in MarMay and JunAug. There were no statistical seasonal differences in NDF associated with grassland vegetation. OM digestibility in MarMay and JunAug was significantly higher than that in SepNov, but digestibility for DecFeb (57.9%) was significantly higher than in any other season. With respect to woodland vegetation, CP was significantly higher in SepNov than in MarMay and JunAug which were also significantly lower (p=0.018) than for DecFeb. The level of NDF significantly increased from MarMay to SepNov by 2.7% followed by a decline in DecFeb which was not significant. The interaction between woodland and season was coupled with a significant decrease of 7.5% in OM digestibility from JunAug to SepNov followed by an increase of 15.1% during DecFeb season.

Table 7.9: Proportion of variance explained (V) and statistical significance of ratios (P<0.05) from analysis of variance for herbage rude protein concentration (CP), organic matter digestibility (OMD) and neutral detergent fibre (NDF)

	Degrees of freedom	**CP concentration (%)**		**OMD (%)**		**NDF (%)**	
		V	**P<0.05**	**V**	**P<0.05**	**V**	**P<0.05**
Vegetation	1	0.60	<.001	0.01	NS	0.05	0.05
Soil	2	0.02	NS	0.02	NS	0.03	NS
Grazing	1	<0.01	NS	0.01	NS	0.03	0.035
Season	3	0.16	<.001	0.47	<.001	0.06	0.007
Soil x Season	6	0.04	0.027	0.08	0.011	0.20	< 0.001
Grazing x Season	3	0.03	0.01	<0.01	NS	<0.01	NS
Vegetation x Soil x Season	6	0.03	NS	NS	<.001	0.10	0.004

Table 7.10: Seasonal means (s.e. of mean in parentheses) of crude protein (CP) concentration, in vivo organic matter digestibility (OMD) and neutral-detergent fibre (NDF) for vegetation, soil and grazing

		CP concentration (%)				**NDF (%)**			
Treatments		**DecFeb**	**MarMay**	**JunAug**	**SepNov**	**DecFeb**	**MarMay**	**JunAug**	**SepNov**
Vegetation	Grassland	5.788 (0.3)	4.612(0.3)	5.099(0.2)	6.314(0.5)	67.26 (0.8)	66.43(1.2)	65.85(0.6)	65.82(0.7)
	Woodland	8.101 (0.3)	7.603(0.4)	6.88(0.6)	8.683(0.6)	65.48 (0.7)	66.41(0.8)	64.03(0.6)	63.71(1.2)
Soil	Clay loam	6.903(0.5)	6.299(0.4)	5.162(0.3)	7.375(0.7)	67.45(0.9)	64.58(1.8)	65.72(0.6)	67.41(0.5)
	Loam	6.868(0.5)	6.343(0.6)	6.752(0.7)	7.762(1.0)	65.61(0.8)	69.35(0.8)	64.09(0.6)	63.04(1.2)
	Sandy loam	7.061(0.4)	5.681(0.5)	6.05(0.6)	7.359(0.7)	66.06(1.1)	65.35(0.9)	65.00(0.9)	63.84(1.5)
Grazing	Grazed	6.647(0.3)	5.743(0.4)	6.185(0.3)	7.722(0.6)	65.90(0.9)	65.67(1.0)	64.29(0.7)	64.28(0.9)
	Ungrazed	7.241(0.3)	6.472(0.4)	5.794(0.6)	7.275(0.6)	66.84(0.7)	67.17(1.1)	65.58(0.5)	65.24(1.0)

		OMD (%)		
Treatments	**DecFeb**	**MarMay**	**JunAug**	**SepNov**
Vegetation	Grassland	53.25(2.1)	50.96(1.8)	46.27(1.8)
	Woodland	52.55(2.0)	53.62(1.6)	46.11(2.2)
Soil	Clay loam	54.94(2.3)	48.25(2.5)	45.59(2.9)
	Loam	50.83(2.8)	54.36(1.8)	48.80(2.0)
	Sandy loam	52.93(2.5)	54.26(1.7)	44.17(2.7)
Grazing	Grazed	53.67(1.8)	53.55(1.6)	46.78(2.0)
	Ungrazed	52.13(2.2)	51.03(1.9)	45.60(2.2)

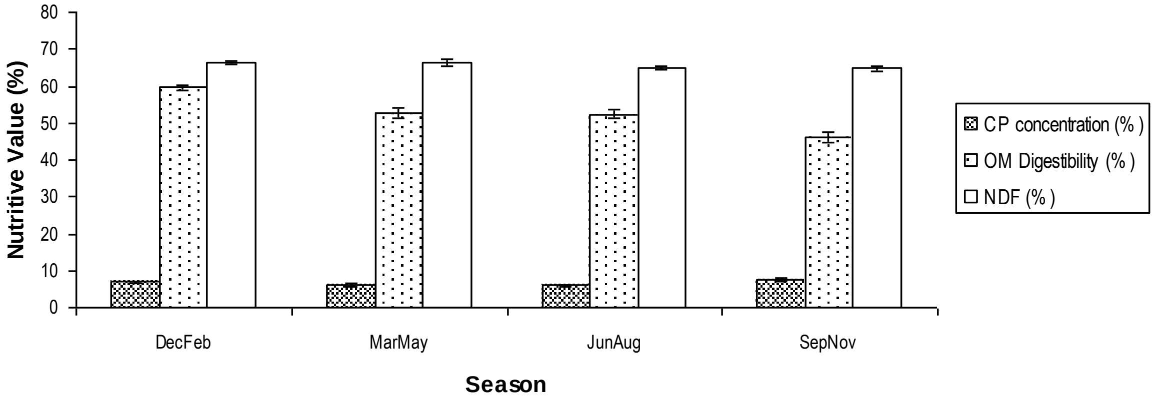


Figure 7.8: Seasonal means (%) for herbage CP concentration, ODM digestibility and NDF

7.4 Discussion

7.4.1 Spatial Patterns in Species Composition

Whereas most herbaceous species generally flourish in open environments (Herlocker, 1999) a higher number of these species occur in habitats that offer varied microhabitats. From this study, bush grasslands, grasslands, wooded grasslands and bushlands respectively recorded the highest number of species. This can probably be explained by the differences in shade effects in these vegetation cover types. Bush grasslands, wooded grasslands and bushlands are mainly constituted of combinations and alternations of grassland and scattered woody vegetation patches in different proportions. This vegetation pattern offers microhabitats suitable for both shade and non shade tolerant herbage species compared to where they occurred in pure stands. The scattered trees and shrubs offer varied amounts of shade that support shade tolerant species like *Setaria homonyma* in addition to other species that are associated with open grasslands as well like *Brachiaria decumbens*. The relatively higher species richness can also be attributed to the different microhabitat conditions caused by differences in grazing pressure distribution that is common on open grasslands (Castillo et al., 2009; Lin et al., 2010; Xie et al., 2007).

However, wooded grasslands were recorded with fewer species compared to open grasslands because of their characteristic tree shade that supports relatively fewer herbage species as result of competition for light (Osborne, 2000). As the amount of shade increases, in this case from the woody species present in the ecosystems, the number and percentage cover of shade tolerant herbage species, like *Setaria homonyma*, also increases but species with no adaptations to shade like *Brachiaria jubata* and *Chloris gayana* are limited. The negative correlation that was found between woody cover and number of herbage species from this study supports this classical fact. The least number of species was in bushland thickets because of their extremely closed woody plants that only favours shade tolerant herbaceous plants (Pihlgren and Lennartsson, 2008).

Herbaceous cover was slightly dominated by species that were not preferred by livestock herders, which could probably be an indication of selective grazing pressure on preferred species. The least dominant species were *D. maitlandii*, *E. exasperata*, *E. tenuifolia*, *Hyparrhenia filipendula*, *Panicum maximum*, *Paspalum scrobiculatum* and *Sporobolus stapfianus*. These are mainly species documented to be associated with disturbed habitats like old cultivations, roadsides, field margins and compacted soils (Phillips, et al., 2003) which constituted a relatively very small proportion of the study area. The preferred but dominant *B. decumbens* is an aggressive invader by nature because of its creeping habit, and tolerance to both open and shaded habitats.

The grazing lands of Rakai and Kiruhura districts have varied physiognomic vegetation cover types (seven recorded here) but generally, they all support a similar composition of grassy species. Only 46 species were recorded, possibly because of the climate which offers long dry spells. Sometimes the area also experiences short, but heavy rain seasons characterized by flooding in many places which can be tolerated by relatively few species. Also human management practices like seasonal burning and cutting of woody vegetation that were observed during data collection may contribute to maintaining the climax of those species that are tolerant to such disturbances. However, a higher number of grass species (70) was reported by Kalema (2005) in a study carried out in the same region but only within Lake Mburo National Park. This can possibly be explained by the differences in grazing systems between these studies with protected rangeland sites having higher species numbers compared to a predominantly communal grazing system (Mohammed and Bekele, 2009). This further suggests that some species may have been alienated from the areas outside the national park most likely because of higher grazing pressure. A study by Namaganda (2003) in Nakasongola of central Uganda which has related climatic and grazing system conditions recorded 51 grassy species.

Grasslands showed a unique species dominance pattern. Though not as dominant as *B. decumbens* and *S. pyramidalis,* other species like *B. jubata*, *B. platynota*, *Chloris gayana*, *Cymbopogon nardus*, *Cynodon dactylon*, *Digitaria abyssinica*, *Loudetia kagerensis*, *Setaria homonyma*, *S. pyramidalis* and *Themeda triandra* were also generally abundant. Species like *Themeda triandra* and *B. jubata* were relatively dominant probably because they were mainly found in flooded sites that are generally avoided by grazers especially in seasons of herbage abundance hence subjected to less grazing pressure. However, the pattern exhibited by *Themeda triandra* could as well be attributed to fire influence (Prober et al., 2007). It was conspicuous in grassland patches that are more favoured by fires compared to woodland patches (Olupot et al., 2010). Nevertheless, dominance by species like *Cynodon dactylon*, *Cymbopogon nardus,* and *Loudetia kagerensis* could be explained by their low palatability hence not selected by grazers. Dominance of these species has also been reported to be an indication of overgrazed rangeland sites by Herlocker (1999).

Based on patterns of indicator herbage species composition, four vegetation communities could be distinguished based on grassy species. These were: Shrubland- *Bothriochloa* spp and *Sporobolus* ssp; wooded grassland- *Brachiaria* spp and *Setaria* spp; *Hyparrhenia* spp grassland and bushland- *Cymbopogon* spp and *Cynodon* spp. These associations reveal that species preferred by cattle were more dominant on sites with higher herbaceous to woody vegetation cover ratio. This can possibly be explained by higher grazing pressure on preferred grass species in vegetation dominated by thickets which have a relatively smaller grazing area compared to other vegetation cover types. As a way of ensuring sustainable grazing land management, there is therefore need to determine site specific grazing suitability for the different vegetation cover types based on foraging habits of the animals in the area. This will be essential in supporting both animal and plant diversity (Skerman et al., 1988). Moreover the clustering of vegetation cover types using indicator herbage species might also provide a basis for assessment and mapping of grazing land units' capability.

7.4.2 Seasonal Patterns of Herbage Composition

December-February and March–May seasons were associated with higher species numbers than other seasons which can be attributed to relatively higher amounts or prolonged rainfall compared to June-August and September-November. On the other hand, December-February recorded higher species numbers than March-May and yet the later is expected to have the highest amounts of rainfall in a year. This could probably be explained by a relatively lower amount of rainfall (91mm) received in 2010 during March-May compared to 208.6 mm received in 2009 and 324.6 mm of long term average rainfall recorded for this area. Moreover the very heavy rainfall during March-May 2009 was associated with a lot of flooding that may have alienated some species (Skerman et al., 1988). Nevertheless, results indicated that June-August which was the driest season had the lowest number of species most likely due to drought stress especially in woodlands. High grazing pressure in this vegetation type during dry seasons is a probable explanation of this occurrence since animals prefer to graze in these areas because of the availability of shade from big trees. In addition, grazers are attracted to this vegetation type for relatively greener herbage species under shade that usually don’t quickly wither like the ones in the open cover types. They may sometimes have more moisture available from the shading effect of the tree species and are less exposed to transpiration and eventual withering. The dominance of *Cynodon dactlyon* which is resistant to trampling stress and common in areas used as resting grounds for animals is further evidence to this. The fact that species that are resistant to grazing pressure like *Hyparrhenia rufa* were very rare points to the same possibility.

The seasonal peak of herbage species cover was found to be in June-August season. This was generally a dry season, but preceded by the longest rain season which is expected to cause the highest vegetation growth. Hence the highest cover in the season was not as a result of growth within that season but due to accumulated growth during the preceding season. A consistent trend was observed for the lowest herbage species cover in September-November. Whereas this season was generally rainy especially at end, the preceding season was very dry with the effect being pronounced in the middle of the season. Therefore by the end of the season the rain had not caused a recovery growth from the drought stress during June-August. This season in 2009 was characterized by death of both wild and domestic animals due to lack of herbage. This suggests that climatic changes associated with increase in temperatures and persistent droughts will most likely lead to economic losses to farmers and national economies where there is dependence on livestock production systems.

7.4.3 Seasonal Patterns of Herbage Mass

Herbage yield was highest in March-May and lowest in September-November season. September-November was partly dry and partly a recovery season from a very dry spell that started in June, hence little herbage mass accumulation was associated with it. One would have expected June-August which was the driest season to be associated with the lowest herbage yield but the decline from the March-May season was more pronounced in September November. The recovery effect of the rains that started in September-November was realised during December-February. Moreover, December-February received relatively higher rainfall total than the long term mean for the season. This is consistent with the pattern that was exhibited by herbage cover and height that were earlier presented in this chapter. In 2009 the herbage yield was significantly lower than in 2010 but the trends were consistent for the two years. This was because of the severe drought in 2009 especially between June and September that was associated with death of many wild and domestic animals. These patterns showed that there was sufficient herbage for grazers during rainy seasons followed by deterioration of rangeland conditions due to dry seasons leading to decline in herbage mass (Turner et al., 2005).

As expected, the seasonal herbage yield was lower on grazed than on ungrazed sites. Overall, grazing decreased seasonal yield by 42%. The herbage yield was most affected by grazing in September-November. It was the only season at the end of which the amount of herbage mass was below the proportions of total herbage production that could be left ungrazed to ensure sustainable rangeland productivity (Behnke and Scoones, 1993; de Leeuw et al., 1993; Vallentine, 1989). Therefore the stocking rate in this season was most likely above the grazing sustainable rate compared to March-May and December-February where herbage yields were within the recommended levels. Herbage yield in June-August season was barely (2%) below what was expected for a healthy rangeland condition. The seasonal patterns of herbage mass variations on grazed sites were different from those on ungrazed sites. Whereas the herbage yield in June-August was significantly higher than for September-November under ungrazed sites, the yield from grazed sites in the two seasons was statistically similar. Similarly, under grazed sites December-February had higher yields than September-November season but the yields under ungrazed sites were similar. This trend of results is most probably due to increased stress on herbage plants from grazing pressure that were already affected by physiological stress from the dry season effect in June-August and part of September-November seasons (Lin et al., 2010).

All soil types exhibited a consistent pattern of seasonal herbage mass with September-November having the lowest herbage yield. Generally, clay loam soil was associated with the significantly higher herbage yields than on sandy loam which was similar to loam. This is possibly due to higher water holding capacity by clay loam soils hence more soil water availability for growth. In cases of limited soil moisture, clay loam soils are likely to be less affected by physiological stress and desiccation compared to sandy loam soils (Diaz-Solis et al., 2003). This is consistent with the unique trends observed where clay loam soil type had higher yields during June-August dry season than September-November, which was not observed on sandy loam soils.

Significantly higher seasonal yields were found under grassland than woodland. The lower herbage yield in woodland patches can possibly be attributed to competition effect from the dominant woody plants that reduce herbaceous species vigour (Pihlgren and Lennartsson, 2008; Sánchez-Jardón et al., 2010; Tiemann et al., 2009). The significantly lower herbage yield in June-August than in March-May under woodland was not observed under grassland. This is potentially because of tree shade effect on grazing distribution where animals tend to graze and rest under tree shade from sun heat during June-August hot days, leading to more grazing pressure in woodland patches, hence reduced herbage mass. The trend was consistent with the results of the interaction among vegetation, grazing and season. On grassland the herbage yield during June-August was higher than in December-February for both grazed and ungrazed sites. A similar trend was observed for ungrazed woodland sites but for grazed woodland sites a reverse trend was observed which further suggests that there was tendency to have more grazing pressure on woodland patches during June-August season. Nonetheless, this trend of results points to a less effect of drought stress on herbage under woodland than grasslands during the dry seasons. Under grassland, June-August dry season DM yield was higher than for December-February which was the opposite for woodland vegetation. This difference seems to suggest a faster herbage recovery rate under woodland from the long dry period (June to September) especially in 2009 than for grasslands probably due to differences in soil moisture availability and hence differences in desiccation rates (Osborne, 2000). It might be interesting to investigate the seasonal growth patterns of herbage species under woody cover and in open grassland with consideration of the changes in microhabitat environmental conditions.

7.4.4 Seasonal patterns of Nutritive Value

Crude Protein Seasonal Patterns

Crude protein (CP) concentration was highest during the September-November season which is attributable to the onset of rains after a severe drought that was coupled with early growth of protein-rich young herbage that accounted for the trend (Belesky et al., 2007; Trott et al., 2004). The lowest CP concentration was after the peak of the longest growing season in June-August which was a severely dry season characterised by senescence and limited or no growth hence a lower CP compared to other seasons (Hofmann and Isselstein, 2005; Pratt and Gwynne, 1977). There was a similar seasonal pattern in CP in both woodland and grassland vegetation but in all seasons CP was significantly higher in woodland than grassland. A possible explanation to this might have been higher organic matter from shaded tree and shrub leaves in the soils under woody cover that may have contributed to relatively higher soil nitrogen that translated to higher CP (Critchley et al., 2002). There is also a possibility that the higher CP in herbage under woodland due to relatively higher soil nitrogen from animal faeces and urine during resting which is usually done under tree and shrub shade. However, to come up with more precise explanations, there is need for further experimental investigation. Both grazed and ungrazed sites showed similar trends in CP but grazing treatment alone did not have a significant effect. However, the interaction between grazing and season increased CP concentration in wet seasons. This may be attributable to re-growth of fresh grass tillers that usually follows defoliation during growing seasons (Bovolenta et al., 2008; Olupot et al., 2010; Turner et al., 2005).

Organic Matter Digestibility Seasonal Patterns

The season of herbage harvest was the most important factor in determining the percent OM digestibility. The percent seasonal digestibility ranged from 65% to 66% which was within the recommended minimal range of herbage intake by ruminants (Langer, 1982). The highest OM digestibility in December-February can be attributed to a higher leaf:stem ratio from the growth that started with rains in September-November. Moreover the December-February season which is usually dry, received 192 mm of rainfall which sustained the growth from September-November resulting in good quality herbage. The lowest OM digestibility was during September-November after a very severe dry season which left most of the herbage dominated by dry stems hence the low leaf:stem ratio which is normally associated with low

OM digestibility (Arzani et al., 2004; Boval et al., 2002). This inverse trend to the results of CP analysis exhibited by OM digestibility was similarly noted by Smetham (1982).

Neutral Detergent Fibre Seasonal Patterns

Herbage harvested during March-May and December-February had the highest NDF in that order. March-May was the longest growing season and therefore was most probably associated with high accumulation of structural carbohydrates and other cell constituents needed to support large and taller grass parts especially with accumulated growth from December February. The trend shown by the results of herbage cover and height earlier presented are consistent with this explanation. The amounts of rains received in December-February were relatively higher than normal hence explaining the accumulated herbage mass and the trend in NDF levels. By the end of March-May it was about a period of more than eight months of growth, long enough for lignification to become particularly important due to reproductive and senescent stages (Bovolenta et al., 2008; Pontes et al., 2007). September – November which was a season of early growth from the start of rains after a severe dry season was coupled with the lowest percent fibre because of the young herbage with lower fibre content. However, the percent NDF was relatively higher than one would expect possibly because of the presence of a relatively high proportion of dry grass stems without leaves left after the foregoing dry season.

Generally, there was no considerable effect of woody vegetation cover on NDF. However, there was substantial decline in NDF under woodland vegetation between June-August dry season and September-November rain season a trend that was not observed under grassland. This is possibly attributable to faster improvement of soil moisture conditions under woody cover as a result of microhabitat modification in terms of soil structure and temperature by trees and shrubs (Osborne, 2000) hence faster appearance of fresh leaves with low NDF. Under grassland, the early leaf growth may have been offset by relatively higher dry stems from the previous dry season causing a lower leaf:stem ration hence higher NDF.

Percent NDF was slightly but significantly affected by the interaction between grazing and season especially during March-May rain season where it was higher than the September-November dry season. This was most probably because of herbage dominance by species like *Sporobolus pyramidalis* as was earlier shown due to high selective grazing pressure on more palatable species during September-November dry season leaving such species that are known to be fibrous and generally of low nutritive value (Hofmann & Isselstein, 2005; Phillips, et al., 2003).

7.5 Conclusions

Results of this study confirm that rainfall seasons and vegetation cover types were considerably important in determining herbage composition species cover and richness. Dry weather conditions led to low herbage species cover and diversity. Vegetation cover type was not as important as season in influencing the patterns of herbage quantity. Results also show that the variables considered (vegetation type, soil type, season and grazing) are important in understanding the patterns of herbage quantity and nutritive value. Regardless of the significant seasonal changes in herbage quantity and quality, the variations for each response variable were clearly explained by specific important factor(s). Grazing explained most of the variability in herbage yield. Variability in crude protein concentration was mainly explained by vegetation type. On the other hand, season was the most important factor for the seasonal patterns of organic matter digestibility. The explanatory variables presented a contrasting seasonal pattern in percent NDF which was mainly explained by vegetation and the season of herbage harvest. There were substantial differences in seasonal patterns of herbage composition and biomass within a given year and across different years due to the erratic nature of rainfall in the area. Therefore, regular assessments to capture the corresponding changes in herbage quality and quantity are inevitable to ensure availability of accurate information needed for sustainable grazing management by farmers, wildlife authorities, and agriculture and production extension workers among others.

References

Addinsoft. (2011). XLSTAT www.xlstat.com.

AOAC. (1990). *Official methods of analysis* (15th ed.). Arlington, Virginia 22201, USA: AOAC (Association of Official Analystical Chemists) Inc.

Archibald, S. (2008). African grazing lawns—How fire, rainfall, and grazer numbers interact to affect grass community states. *Wildlife Management, 72*(2), 492 - 501.

Arzani, H., Zodhi, M., Fish, E., Zhahedi Amiri, G. H., Nikkhah, A., & Wester, D. (2004). Phenological effects on forage quality of five grass species. *J. Range Manage, 57*, 624 - 629.

Bailey, D. W. (2004). Management strategies for optimal grazing distribution and use of arid rangelands. *Animal Science, 82*, 147 - 153.

Baker, L. E., & Hoffman, M. T. (2006). Managing variability: Herding strategies in communal rangelands of semiarid Namaqualand, South Africa. *Human Ecol, 34*, 765 - 784.

Beeri, O., Phillips, R., Hendrickson, J., Frank, A. B., & Kronberg, S. (2007). Estimating forage quantity and quality using aerial hyperspectral imagery for northern mixed-grass prairie. *Remote Sensing of Environment, 110*(2), 216 - 225.

Behnke, J. R. H., & Scoones, I. (1993). Range ecology at disequilibrium : new models of natural variability and pastoral adaptation in African Savannas. London: Overseas Development Institute (ODI).

Belesky, D. P., Ruckle, J. M., & Abaye, A. O. (2007). Seasonal distribution of herbage mass and nutritive value of Prairie grass. *Grass and Forage Science, 62*(3), 301-311.

Bernués, A., Riedel, J. L., Asensio, M. A., Blanco, M., Sanz, A., Revilla, R., et al. (2005). An integrated approach to studying the role of grazing livestock systems in conservation of rangelands in protected natural park (Sierra de Guara, Spain). *Livestock Production Science, 96*, 75 - 85.

Bloesch, U. (2002). *The dynamics of thicket clumps in the Kagera savanna landscape, East Africa.* Zurich.

Boelman, N. T., Stieglitz, M., Griffin, K. L., & Shaver, G. R. (2005). Inter-annual variability of NDVI in response to long-term warming and fertilization in wet sedge and tussock tundra. *Oecologia, 143*, 588 - 597.

Boer, M., & Stafford, S. M. (2003). A plant functional approach to the prediction of changes in Australian rangeland vegetation under grazing and fire. *Journal of Vegetation Science, 14*, 333-344.

Boval, M., Cruz, P., Ledet, J. E., Coppry, O., & Archimede, H. (2002). Effect of nitrogen on intake and digestibility of tropical grass grazed by Creole heifers. *Agricultural Science, 138*, 1371 - 1376.

Bovolenta, S., Spanghero, M., Dovier, S., Orland, D., & Clementel, F. (2008). Chemical composition and net energy content of alpine pasture species during the grazing season. *Animal Feed Science and Technology, 146*, 178 - 191.

Canton, Y., Del Barrio, G., Sole-Benet, A., & Lazaro, R. (2003). Topographic controls on the spatial distribution of ground cover in the Tabernas badlands of SE Spain. *CATENA, 55*, 341 - 365.

Castillo, E., Valles, B., Jarillo, J., & Ocaña, E. (2009). Pasture height distribution of grazed tropical native grammas in Veracruz State, Mexico. *Grassland Science, 55*(3), 140-148.

Critchley, C. N. R., Chambers, B. J., Fowbert, J. A., Sanderson, R. A., Bhogal, A., & Rose, S. C. (2002). Association between lowland grassland plant communities and soil properties. *Biological Conservation, 105*(2), 199-215.

de By, R. A. (2001). Principles of geographic information systems.

de Leeuw, P. N., Diarra, L., & Hiernaux, P. (1993). An analysis of feed demand and supply for pastoral livestock. In J. R. H. Behnke, I. Scoones & C. Kerven (Eds.), *Range ecology at disequilibrium : new models of natural variability and pastoral adaptation in African Savannas* (pp. 136-152). London: Overseas Development Institute.

de Leeuw, P. N., & Tothill, J. C. (1993). The concept of rangeland carrying capacity in sub-Saharan Africa-myth of eality *Range ecology at disequilibrium : new models of natural variability and pastoral adaptation in African Savannas* (pp. 77-88). London: Overseas Development Institute.

de Ridder, N., & Breman, H. (1993). A new approach to evaluating rangeland productivity in Sahelian countries. In J. R. H. Behnke, I. Scoones & C. Kerven (Eds.), *Range ecology at disequilibrium : new models of natural variability and pastoral adaptation in African Savannas* (pp. 104-117). London: Overseas Development.

Díaz-solis, H., Grant, W. E., M.M., K., Teague, W. R., & Díaz-García, J. A. (2009). Adaptive management of stocking rates to reduce effects of drought on cow-calf production systems in semi-arid rangelands. *Agricultural Systems, 100*, 43-50.

Diaz-Solis, H., Kothmann, M. M., Hamilton, W. T., & Grant, W. E. (2003). A simple ecological sustainability simulator (SESS) for stocking rate management on semi-arid grazinglands. *Agricultural Systems, 76*(2), 655-680.

Ellis, J. E. (1995). Climate variability and complex ecosystem dynamics: Implications of for pastoral development. In I. Scones (Ed.), *Living with uncertainity: New directions in pastoral development in Africa* (pp. 37 - 39). London: Intermediate technology publications Ltd.

Fujita, N., Amartuvshin, N., Yamada, Y., Matsui, K., Sakai, S., & Yamamura, N. (2009). Positive and negative effects of livestock grazing on plant diversity of Mongolian nomadic pasturelands along a slope with soil moisture gradient. *Grassland Science, 55*(3), 126-134.

GenStat. (2008). GenStat - Seventh Edition (DE3) (Version 7.2.2.222). Hemel Hempstead, United Kingdom: VSN International.

Han, G., Hao, X., Zhao, M., Wang, M., Ellert, B. H., & Willms, W. (2008). Effect of grazing intensity on carbon and nitrogen in soil and vegetation in a meadow steppe in Inner Mongolia. *Agriculture, Ecosystems & Environment, 125*, 21-32.

Herlocker, D. J. (1995). *Range management handbook of Kenya : Vol. III,10, range resource monitoring : field and office guidelines*. Nairobi: Ministry of Livestock Development (MOLD).

Herlocker, D. J. (1999). *Rangeland ecology and resource development in eastern Africa*. Nairobi: German Agency for Technical Co-operation.

Hofmann, M., & Isselstein, J. (2005). Species enrichment in an agriculturall improved grassland and its effects on botanical composition, yield and forage quality. *Grass and Forage Science, 60,* 136 - 145.

Kalema, J. (2005). *Diversity and distribution of vascular plants in Uganda's important bird area.* Makerere University, Kampala.

Langer, R. H. M. (1982). Growth of grasses and clovers. In R. H. M. Langer (Ed.), *Pastures and pasture plants* (pp. 41 - 64). London: Lincolin College.

Li, C., Hao, X., Willms, W. D., Zhao, M., & Han, G. (2009). Seasonal response of herbage production and its nutrient and mineral contents to long-term cattle grazing on a Rough Fescue grassland. *Agriculture, Ecosystems & Environment, 132*(1-2), 32-38.

Li Jianlong, T., L., Quangong, C. (1998). Estimating grassland yields using remote sensing and GIS technologies in China. *New Zealand Journal of Agricultural Research, 41*, 31 - 38.

Lin, Y., Hong, M., Han, G., Zhao, M., Bai, Y., & Chang, S. X. (2010). Grazing intensity affected spatial patterns of vegetation and soil fertility in a desert steppe. *Agriculture, Ecosystems & Environment, 138*(3-4), 282-292.

Martin, R. C., Astatkie, J. M., & Fredeen, A. H. (2005). A comparison of methods used to determine biomass on naturalized swards. *Journal of Agronomy and crop science, 191*, 152-160.

McGinty, A., Thurow, T. L., & Taylor, C. A. (1991). Improving rainfall effectiveness on rangeland. *Texas Agricultural Extension Bulletin, L-5029*, 6 pages.

Mebrahtu, O., & Tenaye, S. B. (1997). *Analytical methods for feeds, animal excrements and animal tissues*.

Microsoft. (2003). Microsoft office access 2003 (11.5614.8117). Washington, USA: Microsoft corporation.

Mohammed, A. S., & Bekele, T. (2009). Forage production and plant diversity in two managed rangelands in the Main Ethiopian Rift. *African Journal of Ecology, 48*(1), 13-20.

Moisey, D. M., Bork, E. W., & Willms, W. D. (2005). Non-destructive Assessment of cattle forage selection: A test of skim grazing in fescue grassland. *Appl. Anim. Behav., 94*, 205 - 222.

Moreau, S., Bosseno, R., GU, X. F., Baret, F. (2003). Assessing the biomass of Andean bofedal and totora high-protein wetland grasses from NOA/AVHRR. *Remote sensing of Environment, 85*, 516-529.

Mutanga, O., Prins, H.H.T., Skidmore, A.K., van Wieren, S., Huizing, H., Grant, R., Peel, M. (2004). Explaining grass-nutrient patterns in a savanna rangeland of southern Africa. *Journal of biogeography, 31*, 819-829.

Namaganda, M. (2003). *The distribution of grasses along the rainfall gradient from Entebbe to Kafu, Central Uganda.* Makerere University, Kampala.

NEMA. (2002). *State of Environment report for Uganda*. Kampala, Uganda: National Environment Authority (NEMA).

Olupot, W., Parry, L., Gunnes, M., & Plumptre, A. J. (2010). *Conservation research in Uganda's savannas*. New York: Nova Science Publishers, Inc.

Osborne, P. L. (2000). *Tropical ecosystems and ecological concepts*. Cambridge: Cambridge University Press.

Phillips, S., Namaganda, M., & Lye, K. A. (2003). *115 Ugandan grasses*. Kampala: Makerere University Herbarium.

Pihlgren, A., & Lennartsson, T. (2008). Shrub effects on herbs and grasses in sem-natural grassland: positive, negative or neutral relationships? *Grass and Forage Science, 63*, 9-21.

Pontes, L. S., Carrère, P., Andueza, D., Louault, F., & Soussana, J. F. (2007). Seasonal productivity and nutritive value of temperate grasses found in semi-natural pastures in Europe: responses to cutting frequency and N supply. *Grass and Forage Science, 62*(4), 485-496.

Pratt, D. J., & Gwynne, M. D. (1977). *Rangeland management and ecology in East Africa*. Huntington, New York: Robert E. Krieger Publishing Co., Inc.

Prober, S. M., Thiele, K. R., & Lunt, I. D. (2007). Fire frequency regulates tussock grass composition, structure and resilience in endangered temperate woodlands. *Austral Ecology, 32*(7), 808-824.

Putfarken, D., Dengler, J., Lehmann, S., & Härdtle, W. (2008). Site use of grazing cattle and sheep in a large scale pasture landscape: A GPS/GIS assessment. *Applied Animal Behaviour Science, 111*, 54-67.

Reeves, M. C., Winslow, J. C., & Running, S. W. (2001). Mapping weekly Rangeland Vegation Productivity using MODIS Algorithms. *J. Range Manage, 54*, A90 - A105.

Renken, W. J., Howey, L. D., & Ruyle, G. B. (2008). Cattle generalise visual cues from the pen to the field to select initial feeding patches. *Applied Animal Behaviour Science, 109*, 128-140.

Said, M. Y. (1993). *Modelling relationships between large herbivores, vegetation, soils and climate in the mara ecosystem.* Unpublished MSc, International institute for aerospace survey and earth sciences (ITC), Encshede.

Sánchez-Jardón, L., Acosta, B., del Pozo, A., Casado, M. A., Ovalle, C., Elizalde, H. F., et al. (2010). Grassland productivity and diversity on a tree cover gradient in Nothofagus pumilio in NW Patagonia. *Agriculture, Ecosystems & Environment, 137*(1-2), 213-218.

Santos, F. L., Reis, J. L., Martins, O. C., Castanheira, N. L., & Serralheiro, R. P. (2003). Comparative Assessment of Infiltration, Runoff and Erosion of Sprinkler Irrigated Soils. *Biosystems Engineering, 86*(3), 355-364.

Skerman, P. J., Cameron, D. G., & Riveros, F. (1988). *Tropical forage legumes*. Rome: Food and Agriculture Organisation of the United Nations.

Smetham, M. L. (1982). Grazing management. In R. H. M. Langer (Ed.), *Pastures and pasture plants* (pp. 179 - 228). London: Lincolin College.

Tate, K. W., Atwili, E. R., McDougald, N. K., & George, M. R. (2003). Spatial and temporal patterns of cattle feces deposition on rangeland. *Range manage, 56*, 432 - 438.

Tibor, T. (2010). Medium-term vegetation dynamics and their association with edaphic conditions in two Hungarian saline grassland communities. *Grassland Science, 56*(1), 13-18.

Tiemann, T. T., Franco, L. H., Peters, M., Frossard, E., Kreuzer, M., Lascano, C. E., et al. (2009). Effect of season, soil type and fertilizer on the biomass production and chemical composition of five tropical shrub legumes with forage potential. *Grass and Forage Science, 64*(3), 255-265.

Tilley, J. M. A., & Terry, R. A. (1963). *J. Br. Grassland Soc., 18*, 104 - 111.

Trott, M., Wachendorf, M., Ingwersen, B., & Taube, F. (2004). Performance and environmental effects of forage production on sandy soils. I. Impact of defoliation system and nitrogen input on performance and N balance of grassland. *Grass and Forage Science, 59*, 41 - 55.

Turner, M. D., Hiernaux, P., & Schlecht, E. (2005). The distribution of grazing pressure in relation to vegetion resources in sem-arid West Africa: The role of herding. *Ecosystems, 7*, 1-14.

Vallentine, J. F. (1989). *Rangeland development and improvement*. San Diego, California: Academic press Inc.

Van Soest, P. J., & Robertson, J. B. (1985). Analysis of forage and fibrous foods. A laboratory manual for animal science. Cornell University, Ithaca, Newyork, USA.

Vermeire, L. T., & Gillen, R. L. (2001). Estimating herbage standing crop with visual obstruction in tallgrass prairie. *J. Range manage., 54*(1), 57 - 60.

Western, D. (1975). Water availability and its influence on the structure and dynamics of a savannah large mammal community. *East African Wildlife Journal, 13*, 265-286.

Xie, Y., Becker, U., & Wittig, R. (2007). Vegetation of the Stipa loess steppe in Ningxia (northern China) in relation to grazing intensity. *Grassland Science, 53*, 143 - 154.

CHAPTER EIGHT

8.0 Proxy Quantification and Mapping of Seasonal Herbage

Abstract

This study aimed at estimating herbage mass functional relationship with rainfall and soil physical properties related to depth and drainage. Herbage mass as dry matter (DM) measurements from quadrat harvesting method and estimations based on herbaceous cover was done. Herbage on 1X1 m quadrats was harvested and oven dried at $60^{o}C$ until constant weight. Herbage cover data collection was based on spectral strata of vegetation cover types from unsupervised classification of a Landsat image. Rainfall data were collected from 14 rain gauge stations in the study area. Soil profiles of the different strata were described and their drainage characteristics determined. A multi-linear regression was performed to determine the relationship between DM, herbage cover, rainfall effectiveness, and drainage. Results showed a strong relationship between the above variables and DM ($R^2 = 0.76$; $P<0.001$). Herbage cover was found to be the most important variable for DM estimation explaining 0.66 ($p<0.01$) of the total variation in DM. A correlation analysis of estimated and harvested DM resulted in a positive relationship ($R^2=0.85$). Estimated DM (kg/ha) ranged between 895 and 1923 with the highest DM in March-May and the lowest in September-November. This study has demonstrated that herbage cover is an important proxy measurement of spatial and seasonal patterns of rangeland herbage mass. The results provide useful insights on the importance of vegetation cover as a major indicator of rangeland health and productivity. It is recommended that rangeland herbage monitoring should be based on cover measurements rather than quadrat harvesting methods to minimise the costs, destruction and information timeliness implications associated with the latter.

8.1 Introduction

Herbage mass is an important measure for assessing rangeland animal production and ecosystem health condition (Herlocker, 1999). In rain-fed rangelands, herbage production is characterised by seasonal and annual disparities which are generally attributed to the erratic nature of rainfall (Fujita et al., 2009; Tueller, 1993). Such changeability calls for continuous quantification and monitoring of herbage availability so as to provide reliable information for livestock and wildlife management. The recent common and unpredictable occurrences of droughts and the associated deaths of livestock and wild animals in East African rangelands requires quick and accurate management responses based on reliable spatial and temporal information. Knowledge of patterns of herbage production in space and time is essential for monitoring and prediction of its availability and quality. With such understanding, the likely responses to herbage variations can easily be explored for sustainable utilization of rangeland ecosystems (de Ridder and Breman, 1993; Teague and Foy, 2002). Rangeland resource inventory and monitoring information is needed for decision making on land use; and promoting practices and strategies that minimize the impact of climate variability and change (MoLHUD, 2007).

Rangeland herbage quantification and monitoring processes require methodological approaches that provide reliable information for decision making and management processes (Reeves et al., 2001). Martin et al. (2005) highlight the challenges of identifying a reliable and consistent method for monitoring and predicting herbage mass in a variety of field conditions. These challenges include differences in sampling dates that affect accuracy, differences in instrument calibrations for different harvest occasions, inconsistencies in results (Roy and Ravan, 1996) and rigorous and expensive data collection procedures (Li Jianlong, 1998; Martin et al., 2005; Vermeire and Gillen, 2001).

Remote sensing (RS) and Geographical Information System (GIS) are powerful tools in addressing the above challenges. Annual or inter-annual maps of herbage obtained using these tools can guide decision makers to understand how rangelands vary spatially and temporally (Beeri et al., 2007; Woodward et al., 1995). Several studies have attempted to use RS imagery and GIS to map rangeland vegetation and herbage mass (Liang and Chen, 1999; Moreau, 2003; Price et al., 2002; Reeves et al., 2006; Zhang et al., 2006). However, most studies have extensively been centred on low resolution satellite sensor data especially

NOAA-AVHRR and the Moderate Resolution Imaging Spectro-radiometer (MODIS). Satellite sensors like Landsat, ASTER, SPOT, IKONOS and Indian Remote Sensing Satellite (IRS) which provide relatively larger scale spatial information are not yet fully exploited for purposes of understanding rangeland forage biomass dynamics (Reeves et al., 2006). Forage mapping is usually derived from global public domain data sets that do not reflect landscape differences in radiation use efficiency which can vary significantly across landscapes and between rangeland sites. As such, productivity estimates over areas with variable weather conditions and landscape characteristics may be subject to error.

Beeri et al. (2007) highlight the need for research that integrates remote sensing and ground based data including herbage quantity related measurements to establish forage availability for large herbivores. Herbage cover measurement is one of the key indicators of herbage quantity at a given rangeland site (Mueller-Dombos and Ellenberg, 1974). Understanding spatial patterns of herbage cover is thus very important in estimating herbage available for grazers (Castillo et al., 2009). Remote sensing-based herbage cover observations can facilitate large-scale hypothesis testing necessary for scaling up spatial and temporal information on rangeland condition from field plots to eco-regions (Beeri et al., 2007). Such information is useful to livestock owners, agricultural extension workers, and wildlife managers in determining how many and when animals can be grazed on specific sites.

In this chapter, an attempt was made to quantify spatial and seasonal patterns of herbage mass using herbage cover proportions of vegetation spectral strata derived from Landsat Enhanced Thematic Mapper (ETM+). It is assumed that herbage production (expressed as herbage cover) is a direct result of interactions among rainfall, soil and topographic characteristics (Canton et al., 2003; Santos et al., 2003; van Wijngaarden, 1985). Here, the differences in the site interactions are referred to as rainfall effectiveness. The specific focus was on: (i) estimating spatial and seasonal herbage mass from herbage cover and its functional relationship with rainfall and soil physical properties; (ii) testing whether herbage mass measurements from quadrat harvesting method are significantly different from proxy herbage mass estimations based on herbage cover.

8.2 Material and methods of data collection and preparation

8.2.1 Herbage Cover Sampling

Herbage cover data collection was based on Landsat TM image spectral strata. Landsat was the outright image of choice because the IKONOS image available for the study only covered small portion of the study area. Based on observations during the field reconnaissance, Landsat TM image was classified into 10 spectral pattern cover classes using unsupervised classification in ERDAS IMAGINE 9.1. The classes were verified and modified using vegetation survey field data. This was done so as to ensure that sampling strata belonged to similar cover types. Water and wetland were two of the ten cover classes. Consequently, eight classes were used as the sampling strata for herbage cover data collection (Chapter five). The data were collected using clustered random sampling. Sampling sites were selected (clustered) in such way that a maximum number of strata were represented at a given data collection area (cluster). This was devised as a mechanism to minimise movement between strata (Mueller-Dombos and Ellenberg, 1974). All strata of minimum mapping size of 60 x 60 meters (16 pixels) or greater (Townshend, 1983) were considered for sampling irrespective of their size. Sampling point locations were randomly selected and saved in a Garmin 12 Global Positioning System (GPS) for navigation during field data collection. For each stratum, at least 12 quadrats of (2 × 2m) were placed every month from December 2008 to November 2009. In each quadrat, percent herbage cover was estimated and recorded. Herbage cover data for the different strata and months were averaged according to seasons. The seasons used were December to February, March to May, June to August, and September to November. The data were then used to assign end of growing season and dry season average herbage cover classes to all the eight vegetation strata.

8.2.2 Rainfall Data

Fourteen rain gauges were evenly distributed in the entire study area (Appendix 8.1). Recording of rainfall (mm) data was done every morning at 09:00 hours for the whole period of herbage cover data collection. Monthly and seasonal rainfall totals were computed for each raingauge. The station seasonal rainfall data were interpolated using spline tool in ArcGIS 9.3. The estimated rainfall values for every 30 x 30m grid on a map (ESRI, 2010).

8.2.3 Herbage Mass Estimation

Seasonal herbage mass was estimated from seasonal herbage cover, rainfall and rainfall effectiveness factor. The estimation followed the equation developed by Toxopeus (1999).

$$PSC = R*RE*PG \qquad (i)$$

Where:

PSC = Peak standing herbage mass (gm^{-2})
R = Seasonal rainfall (mm)
RE = Rainfall effectiveness factor
PG = Herbage cover (%)

8.2.4 Soil and Rainfall Effectiveness Data

Rainfall effectiveness was based on the premise that soil water availability for herbage growth at a given rangeland site is directly related to rainfall and water holding capacity properties of soil. In order to classify soils according to rainfall effectiveness groups, soil profile (mini pits 1x1x1m) were dug and described according to standard procedures as described by FAO (1990). In addition, drainage data were also collected and described following the FAO (1990) guidelines. Soil samples were obtained from each strata resulting from GIS spatial overlay of six FAO soil and two slope (%) classes (<8.65 and >8.65). Slope classes were generated from a 90m resolution SRTM (Shuttle Radar Topographic Mission) digital elevation model Three replicates of soil samples were collected from each of the resulting 12 soil-slope strata; texture, hydraulic conductivity, and bulk density. Soil texture was determined using the hydrometer methods described by Okalebo et al.(2002). Bulk density and hydraulic conductivity (Appendix 8.2) were determined using the core method and the constant head method; respectively. This information was used to classify the soil-slope strata into drainage (rocky, poorly drained or well drained) categories (Appendix 8.3). These categories were assigned rainfall effectiveness factors as described by van Wijngaarden (1985). Each FAO map unit was subsequently assigned respective rainfall effectiveness value (Table 8.1) to come up with a rainfall effectiveness map.

Table 8.1: FAO soil physical groups and respective rainfall effectiveness factors

Soil group	Rainfall effectiveness factor
Deep well drained soils	0.0120
Deep poorly drained soils	0.0137
Shallow well drained soils	0.0059

8.2.5 Data Integration

The estimation equation variables were integrated using ModelBuilder in ArcGIS 9.3 (ESRI, 2008) (Appendix 8.4) to come up with spatial and seasonal herbage mass distribution.

8.2.6 Herbage Mass from Clipping for Validation

In November 2009, quadrats of 1m x1m were randomly laid at three locations of each of the 8 sampling strata that were selected for herbage cover measurements during the same month. Herbage in the quadrats was harvested for aboveground dry matter (DM) determination. All residual litter and other non-herbaceous plant materials were removed by hand picking from the harvest. The harvested fresh herbage samples were oven dried at 60^{o}C until constant weight. The weight of dry samples in $gDMm^{-2}$ was recorded for the resulting 24 samples.

8.3 Results

Rainfall variability was witnessed in the study area with high rainfall totals received during September-November season while June-August season recorded the lowest rainfall totals (Figure 8.1; Table 8.2; Appendix 8.5). Conversely, herbage cover was highest during March-May period with the lowest cover occurring in September-November period (Table 8.3, Appendix 8.6).

The correlation analysis between the estimated and harvested herbage mass (DM) resulted in a very low correlation with an R^2 of 0.43(Figure 8.2). However it was observed that DM was correlated with the different factors in the Toxopeus (1999) equation. This equation was then linearized using the natural logarithm function and used to fit the dataset to the equation. This resulted in a new equation (ii) below which was used for estimations of herbage mass spatial and seasonal patterns.

$$PSC= e^{k}*RF^{\alpha}*RE^{\beta}*PG^{\gamma} \qquad \text{(ii)}$$

Where:

e^{k} is the exponential of regression intercept

α, β and γ are regression coefficients for RF, RE and PG respectively

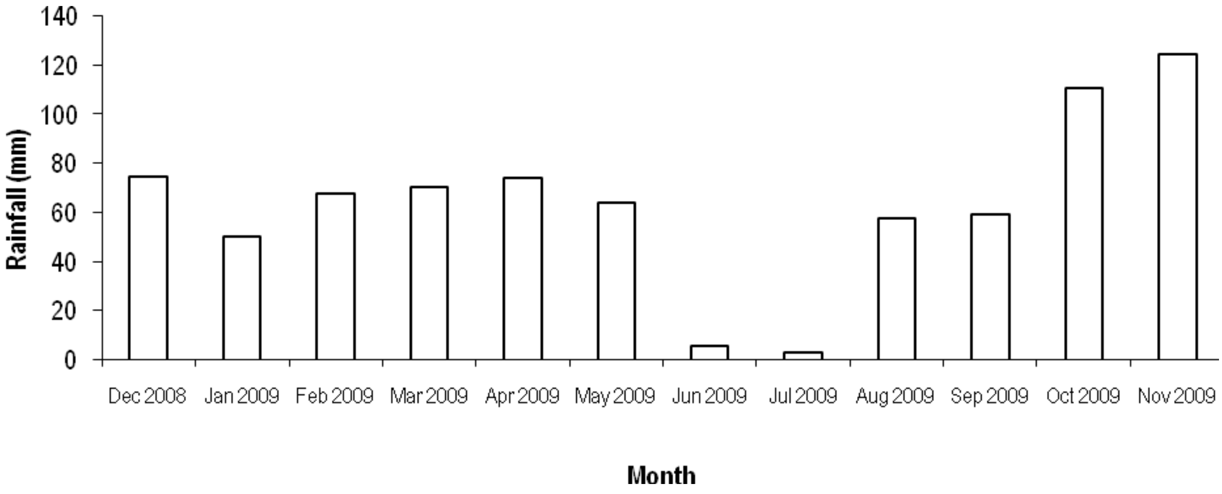


Figure 8.1: Monthly rainfall distribution during the study period

Table 8.2: Seasonal rainfall totals

Season	**Rainfall (mm)**
December-February	194.6
March-May	202.3
June-August (Dry season)	58.3
September-November	302.1

Table 8.3: Average seasonal herbage cover

Season	**Herbage cover (%)**
December-February	53.4
March-May	58.1
June-August (Dry season)	56.3
September-November	51.4

Multiple regression analysis of harvested DM with rainfall, herbage cover and rainfall effectiveness resulted in an R^2 of 0.76 ($p<0.001$). The coefficients used in herbage mass estimation are shown in Table 8.4. Herbage cover was found to be the most important variable for herbage mass estimation explaining 0.66 ($p<0.01$) of total variation. Details of the regression analysis results are shown in appendix 8.7. Results of correlation analysis between estimated and harvested herbage mass showed that there is a significant positive relationship ($R^2=0.87$) (Figure 8.2). A t-test showed no significant difference between estimated and measured DM ($p=0.5$). The highest herbage mass average estimate (1923 kg DM/ha) was in March-May season and the lowest was in September-November (895 kg

DM/ha) (Table 8.5). Spatial distribution of the herbage mass (Figure 8.3) exhibited a pattern that conformed to that of herbage cover (Appendix 8.6).

Table 8.4: Regression coefficients and statistics of rainfall, herbage cover and rainfall effectiveness

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	5.2608	4.0372	1.3031	0.2081
			-	
Rainfall	-0.7884	0.5724	1.3774	0.1844
Herbage cover	1.4354	0.2048	7.0102	<0.001
Effectiveness	0.3938	0.2720	1.4478	0.1640

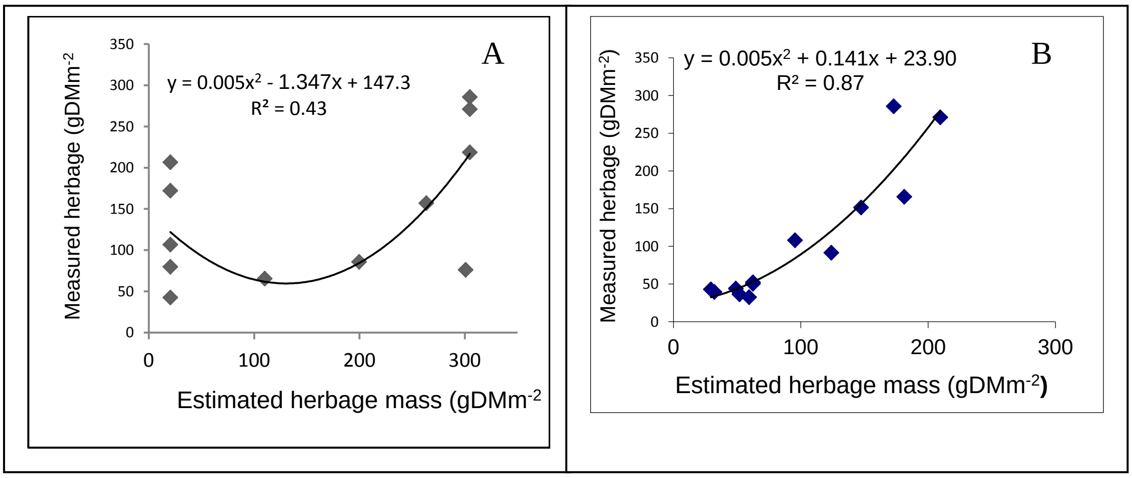


Figure: 8.2: Correlation between estimated and measured herbage mass: Toxopeus Equation (A); Modified equation (B)

Table 8.5: Seasonal herbage mass yield

Season	**Average herbage mass (**kg DM/ha**)**
December-February	1591
March-May	1923
June-August (Dry season)	1194
September-November	895

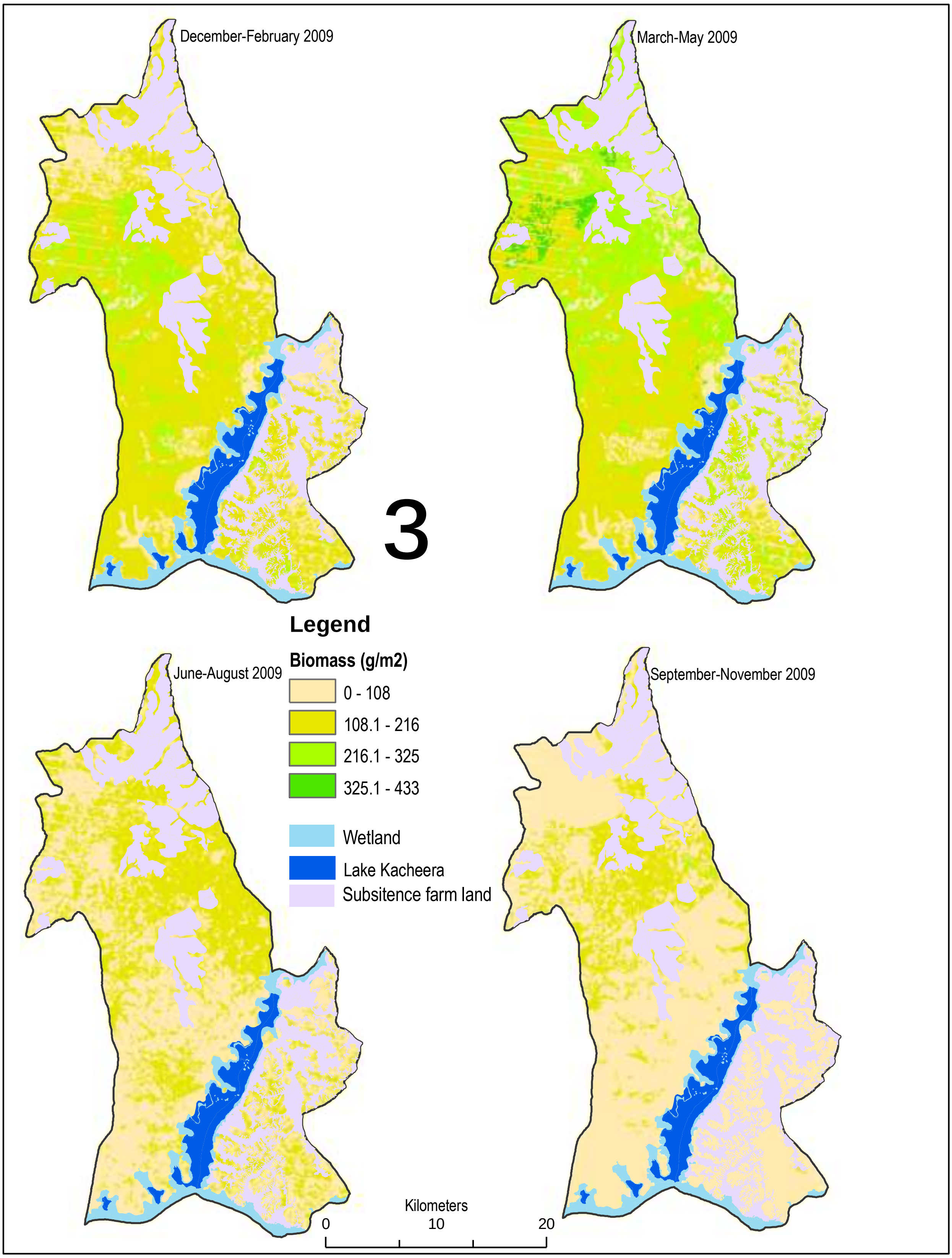


Figure 8.3: Seasonal and spatial herbage mass distribution

8.4 Discussion

Results of this study show that there is a consistent positive relationship between rainfall and herbage cover. However, this relationship is associated with time lag in herbage cover response to dry and wet seasons. Consequently this relationship is translated into herbage mass seasonal patterns. The lag can be explained by the time taken before rain effects growth and the dry season effect on herbage cover decline due to desiccation and grazing pressure (Boelman et al., 2005). Whereas September-November season received higher amounts of rainfall, it recorded the lowest herbage yields compared to June-August which was the driest season. The herbage mass in June-August was a result of accumulated growth during the preceding March-May rainy season. Similarly the June-August dry season effect was realised during September-November season. The recovery effect of September-November rains was realised during December-February season.

The 76% explanation of herbage mass patterns by the variables considered in this study indicates that the relationship between rainfall and herbage cover is a good estimator for herbage DM. Results indicate that most (66%) of the variation in herbage yield could be estimated from herbage cover measurements. Such a relationship shows that herbage cover can reasonably be an acceptable proxy measurement for herbage mass in situations where finances and time are constraints to executing the laborious quadrat harvesting method. Although the inclusion of rainfall and rainfall effectiveness in the equation improved the estimation of herbage mass by 11%, the improvement in the explained variation in DM was not significant. This finding underscores the significance of cover measurements in estimating herbage quantity and its distribution (Mueller-Dombos and Ellenberg, 1974; Tueller, 1993). With herbage cover estimates based on satellite image spectral strata as used in this study, spatial and temporal herbage patterns can easily and accurately be monitored (Herlocker, 1999). Since the herbage cover estimation is simple, faster and does not require expensive equipment, it can potentially be effectively used by rangeland management stakeholders at all levels. This will require training in estimation methods; data recording and simple herbage mass pattern interpretations and predictions.

The herbage mass seasonal trends exhibited by results of this study are related to the findings by (Mulindwa et al., 2009) in which they reported the highest carrying capacity during March-May season in the same area. The low herbage in September-November season due to the effect of June-August dry season poses productivity management challenges to livestock managers and users. While there was sufficient herbage during other seasons, many animals died at the end of the dry season in September 2009. Currently, the dry season response mechanisms to herbage scarcity by livestock owners involve selling of some of their animals to avoid death related losses. Usually during such dry spells, there is overgrazing with most of rangeland sites left bare. This has often caused soil erosion especially at the beginning of the rainy seasons.

According to the National Environment Management Authority, if this situation is not addressed,, this cycle of events and processes is likely to reduce the productivity of the rangelands, compromise water quality and quantity due to sediment and nutrient loading (NEMA, 2007). One of the potential remedies is irrigation and increased watering points, but this will require financial investment in water distribution and storage infrastructure. Herbage conservation especially during March-May growing season is alternative strategy of availing animal feed at the end of the dry season. This is an important strategy as it makes use of the herbage that would have otherwise been lost through trampling during the growing season (Osborne, 2000).

Whereas the estimations were based on the regression coefficients for one season, it is possible that differences might occur with clipping data from other seasons and more so in different years. For instance, December to February which received relatively higher rainfall and considered a growing season in this study, has been reported to be drier in some years (Bloesch, 2002). Therefore, the estimation procedures outlined in the study will have to change accordingly based on seasonal rainfall patterns.

8.5 Conclusions

It has been demonstrated that herbage cover could, within certain limits be used as an important proxy measurement of spatial and seasonal patterns of rangeland herbage. Dry matter predictions obtained using herbage cover were not significantly different from those measured using the classical quadrat clipping method. Hence, herbage mass can in reality be monitored based on cover measurements to avoid and/or minimise the cost, destruction and information timeliness implications that are known to be associated with harvesting methods. Moreover, the method can potentially be easily adopted by ordinary farmers with fewer and cheaper materials through training. Given that the estimation method is reasonably accurate and eliminates the lengthy weighing and drying procedures, the intensity of data collection for monitoring can be increased tremendously to ensure regular and more precise updates on rangeland productivity conditions. It is therefore recommended that the approach described in this study be adopted and up-scaled for herbage mass estimations in Uganda and other areas with similar ecological conditions especially in Kagera region of Tanzania and parts of north eastern Rwanda. The applicability of the model in most of the other parts of the 'cattle corridor' will most likely be limited by differences in biophysical conditions especially rainfall amount and distribution and soil characteristics. It is further recommended that the estimation procedures be improved with seasonal specific prediction equations which should be regularly updated whenever there are drastic shifts in rangeland conditions.

References

Addinsoft. (2011). XLSTAT www.xlstat.com.

AOAC. (1990). *Official methods of analysis* (15th ed.). Arlington, Virginia 22201, USA: AOAC (Association of Official Analystical Chemists) Inc.

Archibald, S. (2008). African grazing lawns—How fire, rainfall, and grazer numbers interact to affect grass community states. *Wildlife Management, 72*(2), 492 - 501.

Arzani, H., Zodhi, M., Fish, E., Zhahedi Amiri, G. H., Nikkhah, A., & Wester, D. (2004). Phenological effects on forage quality of five grass species. *J. Range Manage, 57*, 624 - 629.

Bailey, D. W. (2004). Management strategies for optimal grazing distribution and use of arid rangelands. *Animal Science, 82*, 147 - 153.

Baker, L. E., & Hoffman, M. T. (2006). Managing variability: Herding strategies in communal rangelands of semiarid Namaqualand, South Africa. *Human Ecol, 34,* 765 - 784.

Beeri, O., Phillips, R., Hendrickson, J., Frank, A. B., & Kronberg, S. (2007). Estimating forage quantity and quality using aerial hyperspectral imagery for northern mixed-grass prairie. *Remote Sensing of Environment, 110*(2), 216 - 225.

Behnke, J. R. H., & Scoones, I. (1993). Range ecology at disequilibrium : new models of natural variability and pastoral adaptation in African Savannas. London: Overseas Development Institute (ODI).

Belesky, D. P., Ruckle, J. M., & Abaye, A. O. (2007). Seasonal distribution of herbage mass and nutritive value of Prairie grass. *Grass and Forage Science, 62*(3), 301-311.

Bernués, A., Riedel, J. L., Asensio, M. A., Blanco, M., Sanz, A., Revilla, R., et al. (2005). An integrated approach to studying the role of grazing livestock systems in conservation of rangelands in protected natural park (Sierra de Guara, Spain). *Livestock Production Science, 96,* 75 - 85.

Bloesch, U. (2002). *The dynamics of thicket clumps in the Kagera savanna landscape, East Africa.* Zurich.

Boelman, N. T., Stieglitz, M., Griffin, K. L., & Shaver, G. R. (2005). Inter-annual variability of NDVI in response to long-term warming and fertilization in wet sedge and tussock tundra. *Oecologia, 143,* 588 - 597.

Boer, M., & Stafford, S. M. (2003). A plant functional approach to the prediction of changes in Australian rangeland vegetation under grazing and fire. *Journal of Vegetation Science, 14,* 333-344.

Boval, M., Cruz, P., Ledet, J. E., Coppry, O., & Archimede, H. (2002). Effect of nitrogen on intake and digestibility of tropical grass grazed by Creole heifers. *Agricultural Science, 138*, 1371 - 1376.

Bovolenta, S., Spanghero, M., Dovier, S., Orland, D., & Clementel, F. (2008). Chemical composition and net energy content of alpine pasture species during the grazing season. *Animal Feed Science and Technology, 146*, 178 - 191.

Canton, Y., Del Barrio, G., Sole-Benet, A., & Lazaro, R. (2003). Topographic controls on the spatial distribution of ground cover in the Tabernas badlands of SE Spain. *CATENA, 55*, 341 - 365.

Castillo, E., Valles, B., Jarillo, J., & Ocaña, E. (2009). Pasture height distribution of grazed tropical native grammas in Veracruz State, Mexico. *Grassland Science, 55*(3), 140-148.

Critchley, C. N. R., Chambers, B. J., Fowbert, J. A., Sanderson, R. A., Bhogal, A., & Rose, S. C. (2002). Association between lowland grassland plant communities and soil properties. *Biological Conservation, 105*(2), 199-215.

de By, R. A. (2001). Principles of geographic information systems.

de Leeuw, P. N., Diarra, L., & Hiernaux, P. (1993). An analysis of feed demand and supply for pastoral livestock. In J. R. H. Behnke, I. Scoones & C. Kerven (Eds.), *Range ecology at disequilibrium : new models of natural variability and pastoral adaptation in African Savannas* (pp. 136-152). London: Overseas Development Institute.

de Leeuw, P. N., & Tothill, J. C. (1993). The concept of rangeland carrying capacity in sub-Saharan Africa-myth of eality *Range ecology at disequilibrium : new models of natural variability and pastoral adaptation in African Savannas* (pp. 77-88). London: Overseas Development Institute.

de Ridder, N., & Breman, H. (1993). A new approach to evaluating rangeland productivity in Sahelian countries. In J. R. H. Behnke, I. Scoones & C. Kerven (Eds.), *Range ecology at disequilibrium : new models of natural variability and pastoral adaptation in African Savannas* (pp. 104-117). London: Overseas Development.

Díaz-solis, H., Grant, W. E., M.M., K., Teague, W. R., & Díaz-García, J. A. (2009). Adaptive management of stocking rates to reduce effects of drought on cow-calf production systems in semi-arid rangelands. *Agricultural Systems, 100*, 43-50.

Diaz-Solis, H., Kothmann, M. M., Hamilton, W. T., & Grant, W. E. (2003). A simple ecological sustainability simulator (SESS) for stocking rate management on semi-arid grazinglands. *Agricultural Systems, 76*(2), 655-680.

Ellis, J. E. (1995). Climate variability and complex ecosystem dynamics: Implications of for pastoral development. In I. Scones (Ed.), *Living with uncertainity: New directions in pastoral development in Africa* (pp. 37 - 39). London: Intermediate technology publications Ltd.

Fujita, N., Amartuvshin, N., Yamada, Y., Matsui, K., Sakai, S., & Yamamura, N. (2009). Positive and negative effects of livestock grazing on plant diversity of Mongolian nomadic pasturelands along a slope with soil moisture gradient. *Grassland Science, 55*(3), 126-134.

GenStat. (2008). GenStat - Seventh Edition (DE3) (Version 7.2.2.222). Hemel Hempstead, United Kingdom: VSN International.

Han, G., Hao, X., Zhao, M., Wang, M., Ellert, B. H., & Willms, W. (2008). Effect of grazing intensity on carbon and nitrogen in soil and vegetation in a meadow steppe in Inner Mongolia. *Agriculture, Ecosystems & Environment, 125*, 21-32.

Herlocker, D. J. (1995). *Range management handbook of Kenya : Vol. III,10, range resource monitoring : field and office guidelines*. Nairobi: Ministry of Livestock Development (MOLD).

Herlocker, D. J. (1999). *Rangeland ecology and resource development in eastern Africa*. Nairobi: German Agency for Technical Co-operation.

Hofmann, M., & Isselstein, J. (2005). Species enrichment in an agriculturall improved grassland and its effects on botanical composition, yield and forage quality. *Grass and Forage Science, 60*, 136 - 145.

Kalema, J. (2005). *Diversity and distribution of vascular plants in Uganda's important bird area.* Makerere University, Kampala.

Langer, R. H. M. (1982). Growth of grasses and clovers. In R. H. M. Langer (Ed.), *Pastures and pasture plants* (pp. 41 - 64). London: Lincolin College.

Li, C., Hao, X., Willms, W. D., Zhao, M., & Han, G. (2009). Seasonal response of herbage production and its nutrient and mineral contents to long-term cattle grazing on a Rough Fescue grassland. *Agriculture, Ecosystems & Environment, 132*(1-2), 32-38.

Li Jianlong, T., L., Quangong, C. (1998). Estimating grassland yields using remote sensing and GIS technologies in China. *New Zealand Journal of Agricultural Research, 41*, 31 - 38.

Lin, Y., Hong, M., Han, G., Zhao, M., Bai, Y., & Chang, S. X. (2010). Grazing intensity affected spatial patterns of vegetation and soil fertility in a desert steppe. *Agriculture, Ecosystems & Environment, 138*(3-4), 282-292.

Martin, R. C., Astatkie, J. M., & Fredeen, A. H. (2005). A comparison of methods used to determine biomass on naturalized swards. *Journal of Agronomy and crop science, 191*, 152-160.

McGinty, A., Thurow, T. L., & Taylor, C. A. (1991). Improving rainfall effectiveness on rangeland. *Texas Agricultural Extension Bulletin, L-5029*, 6 pages.

Mebrahtu, O., & Tenaye, S. B. (1997). *Analytical methods for feeds, animal excrements and animal tissues*.

Microsoft. (2003). Microsoft office access 2003 (11.5614.8117). Washington, USA: Microsoft corporation.

Mohammed, A. S., & Bekele, T. (2009). Forage production and plant diversity in two managed rangelands in the Main Ethiopian Rift. *African Journal of Ecology, 48*(1), 13-20.

Moisey, D. M., Bork, E. W., & Willms, W. D. (2005). Non-destructive Assessment of cattle forage selection: A test of skim grazing in fescue grassland. *Appl. Anim. Behav., 94*, 205 - 222.

Moreau, S., Bosseno, R., GU, X. F., Baret, F. (2003). Assessing the biomass of Andean bofedal and totora high-protein wetland grasses from NOA/AVHRR. *Remote sensing of Environment, 85*, 516-529.

Mutanga, O., Prins, H.H.T., Skidmore, A.K., van Wieren, S., Huizing, H., Grant, R., Peel, M. (2004). Explaining grass-nutrient patterns in a savanna rangeland of southern Africa. *Journal of biogeography, 31*, 819-829.

Namaganda, M. (2003). *The distribution of grasses along the rainfall gradient from Entebbe to Kafu, Central Uganda.* Makerere University, Kampala.

NEMA. (2002). *State of Environment report for Uganda*. Kampala, Uganda: National Environment Authority (NEMA).

Olupot, W., Parry, L., Gunnes, M., & Plumptre, A. J. (2010). *Conservation research in Uganda's savannas*. New York: Nova Science Publishers, Inc.

Osborne, P. L. (2000). *Tropical ecosystems and ecological concepts*. Cambridge: Cambridge University Press.

Phillips, S., Namaganda, M., & Lye, K. A. (2003). *115 Ugandan grasses*. Kampala: Makerere University Herbarium.

Pihlgren, A., & Lennartsson, T. (2008). Shrub effects on herbs and grasses in sem-natural grassland: positive, negative or neutral relationships? *Grass and Forage Science, 63*, 9-21.

Pontes, L. S., Carrère, P., Andueza, D., Louault, F., & Soussana, J. F. (2007). Seasonal productivity and nutritive value of temperate grasses found in semi-natural pastures in Europe: responses to cutting frequency and N supply. *Grass and Forage Science, 62*(4), 485-496.

Pratt, D. J., & Gwynne, M. D. (1977). *Rangeland management and ecology in East Africa*. Huntington, New York: Robert E. Krieger Publishing Co., Inc.

Prober, S. M., Thiele, K. R., & Lunt, I. D. (2007). Fire frequency regulates tussock grass composition, structure and resilience in endangered temperate woodlands. *Austral Ecology, 32*(7), 808-824.

Putfarken, D., Dengler, J., Lehmann, S., & Härdtle, W. (2008). Site use of grazing cattle and sheep in a large scale pasture landscape: A GPS/GIS assessment. *Applied Animal Behaviour Science, 111*, 54-67.

Reeves, M. C., Winslow, J. C., & Running, S. W. (2001). Mapping weekly Rangeland Vegation Productivity using MODIS Algorithms. *J. Range Manage, 54*, A90 - A105.

Renken, W. J., Howey, L. D., & Ruyle, G. B. (2008). Cattle generalise visual cues from the pen to the field to select initial feeding patches. *Applied Animal Behaviour Science, 109*, 128-140.

Said, M. Y. (1993). *Modelling relationships between large herbivores, vegetation, soils and climate in the mara ecosystem.* Unpublished MSc, International institute for aerospace survey and earth sciences (ITC), Encshede.

Sánchez-Jardón, L., Acosta, B., del Pozo, A., Casado, M. A., Ovalle, C., Elizalde, H. F., et al. (2010). Grassland productivity and diversity on a tree cover gradient in Nothofagus pumilio in NW Patagonia. *Agriculture, Ecosystems & Environment, 137*(1-2), 213-218.

Santos, F. L., Reis, J. L., Martins, O. C., Castanheira, N. L., & Serralheiro, R. P. (2003). Comparative Assessment of Infiltration, Runoff and Erosion of Sprinkler Irrigated Soils. *Biosystems Engineering, 86*(3), 355-364.

Skerman, P. J., Cameron, D. G., & Riveros, F. (1988). *Tropical forage legumes*. Rome: Food and Agriculture Organisation of the United Nations.

Smetham, M. L. (1982). Grazing management. In R. H. M. Langer (Ed.), *Pastures and pasture plants* (pp. 179 - 228). London: Lincolin College.

Tate, K. W., Atwili, E. R., McDougald, N. K., & George, M. R. (2003). Spatial and temporal patterns of cattle feces deposition on rangeland. *Range manage, 56*, 432 - 438.

Tibor, T. (2010). Medium-term vegetation dynamics and their association with edaphic conditions in two Hungarian saline grassland communities. *Grassland Science, 56*(1), 13-18.

Tiemann, T. T., Franco, L. H., Peters, M., Frossard, E., Kreuzer, M., Lascano, C. E., et al. (2009). Effect of season, soil type and fertilizer on the biomass production and chemical composition of five tropical shrub legumes with forage potential. *Grass and Forage Science, 64*(3), 255-265.

Tilley, J. M. A., & Terry, R. A. (1963). *J. Br. Grassland Soc., 18*, 104 - 111.

Trott, M., Wachendorf, M., Ingwersen, B., & Taube, F. (2004). Performance and environmental effects of forage production on sandy soils. I. Impact of defoliation system and nitrogen input on performance and N balance of grassland. *Grass and Forage Science, 59*, 41 - 55.

Turner, M. D., Hiernaux, P., & Schlecht, E. (2005). The distribution of grazing pressure in relation to vegetion resources in sem-arid West Africa: The role of herding. *Ecosystems, 7*, 1-14.

Vallentine, J. F. (1989). *Rangeland development and improvement*. San Diego, California: Academic press Inc.

Van Soest, P. J., & Robertson, J. B. (1985). Analysis of forage and fibrous foods. A laboratory manual for animal science. Cornell University, Ithaca, Newyork, USA.

Vermeire, L. T., & Gillen, R. L. (2001). Estimating herbage standing crop with visual obstruction in tallgrass prairie. *J. Range manage., 54*(1), 57 - 60.

Western, D. (1975). Water availability and its influence on the structure and dynamics of a savannah large mammal community. *East African Wildlife Journal, 13*, 265-286.

Xie, Y., Becker, U., & Wittig, R. (2007). Vegetation of the Stipa loess steppe in Ningxia (northern China) in relation to grazing intensity. *Grassland Science*, 53, 143 - 154.

CHAPTER NINE

9.0 General Discussion and Conclusions

9.1 General Discussion

Results of this study showed that herbage patterns were a product of the interactions among soil types, rainfall, vegetation cover type and anthropogenic factors such as land use and land cover changes (Chapters five, six and seven). Results of herbage quantity from quadrat harvesting approach exhibited a similar seasonal pattern with those from predictions based on herbage cover measurements in different vegetation strata derived from Landsat satellite image (Chapter eight). Herbage quantity peak was during March to May wet season for both approaches and lowest in September-November wet season (Chapters seven and eight). Herbage quantity and quality assessment, monitoring and prediction outcomes indicated that integrated consideration of the above considered factors is essential for sustainable grazing management. Soil improvement for better herbage quantity and quality will require appropriate management measures to ensure that the amount and distribution of soil water needed for herbage growth are conducive. On the other hand, vegetation cover changes mainly arising from anthropogenic influence need to be managed well (Chapter five). Poor management may lead to loss of balance among species diversity, soil nutrient and water condition, herbage yield and quality which is essential for a healthy rangeland ecosystem.

9.1.1 Vegetation Physiognomic and Species Composition

Compared to previous studies (Langdale-Brown, 1970; Pratt and Gwynne, 1977), results of this study revealed a general shift from woody to herbaceous dominated vegetation composition (Chapter five). The shift was attributed to a combined effect of factors related to human population increase such as woody vegetation clearing for cultivation and more grazing land. The major driver of the changes is possibly, the increasing number of immigrants into the area resulting into clearing of land for settlement and crop fields. Another factor could have been a change in lifestyles of pastoralists who are currently more involved in growing food crops especially around their homesteads as compared to the 1970s when the previous studies were done. Such changes in vegetation patterns are indications of increasing pressure on the rangeland which usually result in overgrazing, land degradation and loss of biodiversity (Gordon, 2009). Such changes in vegetation composition are known to be typical of sub-Saharan rangelands with site variability depending on the magnitude of the factors at play (Homewood & Brocking, 1999).

The study indicated proliferation of herbage species that were not preferred by grazers to the expense of species that were preferred. There was an apparent shift from *Hyperrhenia* to S*porobolus* dominated herbage species composition which could mainly be attributed to increasing grazing pressure (Facelli and Springbett, 2009; McNeely et al., 1995). The most dominant herbage species that was indicated by farmers to be desirable was *Brachiaria decumbens*. *Brachiaria decumbens* is a perennial plant that survives harsh dry seasons and grazing pressure. . It easily proliferates from its underground stolons soon after the rains and fills up any available bare gaps left by the less hardy species like *Hyparrhenia rufa* (Phillips, et al., 2003). On the other hand *Sporobolus pyramidalis* predominated because of its fibrous nature, hence avoided by grazers. It is also very resilient to disturbances like trampling, seasonal flooding, and excessive drought and burning (Herlocker, 1999). The sharp decline in percentage cover of *B. decumbens* compared to *S. pyramidalis* during dry seasons, further suggested that grazing pressure was a key factor in determining the proportions of these two dominant species since *B. decumbens* is preferred to *S. pyramidalis* by grazers.

9.1.2 Spatial Patterns of Herbage

Vegetation cover type related influence on herbage patterns was mainly from differences in grassland and woodland proportions in the study area (Chapter six and seven). Results showed that grassland patches had higher herbage yield than those dominated by woody vegetation. This was attributed to competition for space and limited light availability for primary production with herbage under woody cover (Zarovali et al., 2007). On the other hand, herbage nutritive value was better in woodland than in grassland patches especially for crude protein concentration (Chapter seven). Better herbage quality under woody vegetation cover especially during and immediately after dry seasons was attributed to better moisture conditions under woody vegetation and hence less herbage physiological stress (Sánchez-Jardón et al., 2010). The inverse response of herbage quality and quantity to changes in vegetation physiognomic composition poses vegetation management implications. Reduction in woody cover may improve herbage yield but may also reduce the level of its quality (Neel et al., 2008). Optimal levels of woody and herbaceous vegetation cover need to be established to ensure that animal production management interventions promote both good herbage quality and quantity. Such interventions should consider the potential effects on species diversity that exhibited different patterns in different physiognomic vegetation cover types in this study.

The influence of soil on herbage quantity and quality patterns was mainly attributed to differences in nutrient content of the soil types (Chapters six and seven). Clay loams soil was associated with higher herbage yields and better quality than sandy loam and loam soils. Water holding capacity characteristics of clay loam soils also could have influenced the patterns of herbage mass and nutritive value (Han et al., 2008). Consistent results were reflected in the response patterns of herbage cover measurements, dry matter yields, nutritive value and species composition to soil type. However, most of response patterns of herbage related to the soil variable could be explained by differences in soil nutrients and organic matter. Management interventions aimed at improving soil moisture and nutrient conditions are most likely to improve herbage quality and quantity.

Grazing effect on herbage quantity was mainly reflected through differences in biomass yield between grazed and ungrazed sites Chapters six and seven). As expected, grazed sites were associated with relatively lower herbage mass compared to ungrazed sites. The results pointed to the need for putting grazing management measures in place to avoid overgrazing and decline in herbage productivity (Loeser et al., 2007). Results showed evidence of selective grazing pressure related stress on herbage quality and quantity where grazed sites were dominated by unpalatable fibrous grass species like *Sporobolus pyramidalis* with some species like *Hyparrhenia rufa* which are known to be less tolerant to grazing pressure being rare. Similarly, lower herbage quality on grazed sites was observed from results of nutritive value analysis which was in agreement with the low percentages cover of palatable species. Conversely, grazed sites were found to be associated with higher species richness compared to ungrazed sites. Therefore there is need to establish the appropriate grazing intensity levels that will harmonise the need for good herbage quantity and quality while promoting vegetation species diversity.

9.1.3 Seasonal Patterns of Herbage

The study indicated significant seasonal variations in herbage quantity and quality (Chapter seven). Such variations point to the unreliability of long term predictions of herbage productivity. When seasonal herbage mass for grazed and ungrazed sites were compared, results showed that grazing during rainy seasons was within the recommended sustainable level up to a maximum of 50% herbage consumption (Baars, 1996). On the other hand, results revealed that at the end of June-August dry season and through September-November season, consumption was above 50% of the total herbage production. September-November was a season of herbage scarcity that resulted in deaths of many animals especially in 2009. There are economic and ecological implications associated with such herbage related problems in the area. Loss of animals implies loss of investments made in the animal production sector. On the other hand shortage of herbage may mean increased negative effects of grazing pressure such as loss of soil cover that may lead to soil erosion and consequently rangeland deterioration (Brower et al., 1997). Based on information on seasonal patterns of herbage in relation to grazing, monitoring of seasonal stocking rates should to regularly done to avoid rangeland degradation that may arise from overstocking. The seasonal trends from nutritive value analysis were quite diverse especially for Organic matter digestibility and Neutral detergent fibre Chapter seven). Seasonal patterns of herbage quality were mainly attributed to stage of herbage growth (Belesky et al., 2007) and leaf: stem ratios (Arzani et al., 2004). However, results from nutritive value analysis could not show distinct predictive seasonal patterns. Probably a longer period of quality assessment might result in more discrete patterns that can be more useful in developing quality predictive models.

The interactions among season, vegetation, soil type and grazing substantially influenced the patterns of herbage quantity and quality (Chapter seven). At the start of rainy season, woody vegetation cover type was associated with faster herbage recovery rates from dry season than grassland cover type. This suggested that the shading effect from woody vegetation may have provided favourable conditions for faster herbage recovery attributable to faster improvement in soil moisture conditions at the start of rainy seasons (Osborne, 2000). Such seasonal changes in herbage mass may have influenced grazing patterns with respect vegetation cover types (Pickup, 1994). Results showed that the effect of grazing on the patterns of herbage mass in different vegetation cover types varied with season whereby grazed grassland patches had lower herbage yield during wet seasons than grazed woody vegetation patches (Chapter seven). A reverse trend was observed during dry seasons. This trend was associated with faster seasonal herbage quantity declines in cover types that were under grazing. Sensitivity of herbage species to grazing was more pronounced during dry seasons most probably because of additional stress from desiccation. Selective grazing in dry seasons might have resulted in reduced species richness in favour of drought resistant species that are usually of low nutritive value (Lin et al., 2010). On the other hand results showed that there was higher crude protein concentration on grazed sites than ungrazed ones during wet seasons. This may be attributed to re-growth of fresh herbage tillers that usually follow defoliation during growing seasons (Bovolenta et al., 2008; Turner et al., 2005).

9.1.4 Herbage Biomass Prediction

Herbage mass was predicted with an accuracy of 87% using proxy assessment based on herbage cover for different vegetation spectral strata derived from satellite images (Chapter eight). The results of predicted biomass values were similar both in quantity and patterns to those based on direct harvesting methods. The seasonal variations in herbage mass resulting from rainfall and herbage cover changes indicated that there was herbage mass response time lag to dry and wet seasons. The observed inter-seasonal herbage mass transition lag required management measures that will optimise herbage utilisation while minimising the negative effects from grazing pressure. Different rangeland sites had different rates of herbage mass response to this transition from dry or wet season and hence required different grazing management measures. Areas with longer time lag from dry to wet season were more susceptible to degradation and therefore need to be exposed to less grazing pressure especially during the dry seasons to minimise soil exposure to erosion and loss of soil moisture which may lead to rangeland retrogression (Ao et al., 2008). On the other hand, rangeland sites that take a shorter time to recover from dry seasons are less likely to be affected by grazing pressure. Such sites are usually areas of grazing concentration at the start of wet seasons. When not well managed, such grazing concentration may eliminate some herbage species that are sensitive to grazing pressure such as *Themeda triandra* (McIntyre et al., 2003). However, well managed and moderate grazing distribution through growing seasons may enhance herbage quality while maintaining high production and herbage cover as well (Osborne, 2000).

9.1.5 Implication of Results on Grazing Management

Results from this study revealed that the present vegetation physiognomic cover in the study area is dominated by grasslands, wooded grasslands and bush grasslands (Chapter five). Generally, the area was a more (60%) grassland than woodland dominated vegetation cover type. About 25% of the vegetation was suitable for browsers. The predominance of herbaceous vegetation makes the area suitable for grazers, a situation that is currently true. The area is dominated by cattle farms characterised by perimeter fencing and extensive bush clearing. Most herbage was dominated by *Sporobolus pyramidalis* species which is known to be of low nutritive value to grazers (Herlocker, 1999). Other species preferred by grazers known to have been dominant in the area such as *Themeda triandra* and *Hyparrhenia rufa* (Langdale-Brown, 1970) could hardly be observed during the study. All these pointed to a condition of a rangeland undergoing degradation which was most evident during dry seasons especially due to over grazing. In some areas, it was only *Sporobolus pyramidalis* herbage species that was available for grazers. Despite its low quality value, animals have to depend on it as a major feed during herbage scarcity. Efforts towards better herbage quality should therefore focus on improving soil moisture and grazing conditions. Most especially during dry and drought periods when there was evidence of overstocking due to reduced herbage quantity and quality.

The on going vegetation cover changes towards herbaceous dominated cover need to be given attention. At the moment most of vegetation management interventions are aimed at improving herbage quantity by clearing woody vegetation. Such practices are likely to have negative implications on herbage quality and biodiversity conservation. In a short run, clearing of woody vegetation cover may lead to increased herbage yield. However, it may in the long run lower soil organic matter, which in turn lowers nutrient availability. Ultimately, this may lead to degradation of soil structure, hence low herbage quantity and quality. Thus there is need to establish the rangeland vegetation physiognomic cover composition balancing point with respect to all these factors for optimal herbage productivity, hence grazing capacity. The relationship between vegetation cover and species composition showed that increasing grassland over woodland or vice versa will lead to a shift in species composition both in terms of abundance and richness (Chapter seven). This implies that vegetation management should always establish whether herbage response trends are in favour of the management objectives and respond accordingly.

Herbage quantity improvement and to a small extent quality required grazing management interventions that can improve soil moisture conditions in times of water stress, soil fertility and ensure that animal numbers are in conformity with seasonal and spatial patterns of rangeland stocking capacity. Herbage quality was predominantly controlled by environmental factors and its improvement may not be well within the control of rangeland users and managers especially under the current ecological and production management systems. Sustainable herbage production in the study area was faced with a challenge of overgrazing during and immediately after the dry seasons due to higher herbage demand than supply. There is need for measures to curtail the potential and on-going ecological and economic damages such as loss of species diversity and death of animals partly due to dry season over stocking. The results presented here will go a long way in providing a basis for developing livestock and wildlife management options such as establishing the animal populations that are proportionate to a given pastureland seasonal capacity and potential; biodiversity conservation strategies; informed land use policy formulation; forage monitoring strategies; improved early warning systems among others.

9.2 Conclusions

Herbage mass predictions based on herbage cover were similar to those from direct quadrat harvesting method (Chapter eight). Similarly, results of species composition as proxy measure of herbage quality showed similar trends with those from laboratory analysis of herbage quality (Chapter seven). Generally, results revealed a rangeland degradation trend, with its effects mainly manifested during dry seasons. There were significant differences in herbage quantity and quality between herbaceous and woody vegetation dominated cover types. Different vegetation physiognomic strata exhibited unique spatial and seasonal patterns in herbage, most especially quantity. There were varied responses of herbage to soil conditions in different seasons especially soil water and nutrients.

Overall, the spatial and temporal patterns of herbage quantity and quality were reliably assessed, monitored and predicted based on vegetation composition, rainfall and soil types (Chapter six and seven). It has been established that herbage patterns were more governed by abiotic than any other factors, especially rainfall. The integrated approach presented in this thesis demonstrated that proxy measurements can be used to monitor the temporal and spatial patterns of herbage quantity and quality with reliable output information for decision making. A basis for medium and long term rangeland grazing management information system has been established, tested and confirmed useful. It has been clearly shown that:

- Spatial and seasonal patterns of herbage quantity and quality can be monitored using species cover and composition of vegetation strata derived from Landsat images.
- The model developed based on vegetation strata derived from Landsat images can accurately estimate and predict herbage yield and its spatial distribution in the rangelands.

- Reliable methods for information needed to assess and monitor herbage productivity are available and hence protocols and manuals for range assessment and monitoring can developed.

9.3 Recommendations

From the findings of the studies presented in this thesis, it has been recommended that:

- There is need to develop a Classification scheme for systematically defining rangeland vegetation classes that can realistically be discriminated from high and medium resolution satellite images
- The proxy estimation model developed should be validated and up-scaled for herbage mass estimations in rangelands of the rest of the 'cattle corridor'
- There is evidence that vegetation cover has changed therefore there is need to upscale and produce current vegetation cover maps and updated species composition/diversity list for the rangelands of East Africa
- To avert rangeland degradation, there is need to devise interventions for improved animal production systems and biodiversity conservation at both farm and landscape levels. Based on the findings of this study, the key measures should focus on long term ecological vegetation management, appropriate spatial and seasonal stocking rates, soil and water conservation and land use planning.
- There is need to avert the common practice of clearing bushes at farm level to avoid the imminent elimination of herbage species restricted to bushland habitat like *Eragrostis superba.* This should be done together with raising awareness among farmers on the importance of species diversity on their grazing land
- Water conservation strategies need to be devised especially in rangeland sites that were predominated by sandy loam soils to improve herbage quality and quantity especially during dry seasons.

References

Ao, M., Ito, M., Ito, K., Yun, J. F., Miura, R., & Tominaga, T. (2008). Floristic compositions of Inner Mongolian grasslands under different land-use conditions. *Grassland Science, 54*(4), 173-178.

Arzani, H., Zodhi, M., Fish, E., Zhahedi Amiri, G. H., Nikkhah, A., & Wester, D. (2004). Phenological effects on forage quality of five grass species. *J. Range Manage, 57*, 624 - 629.

Belesky, D. P., Ruckle, J. M., & Abaye, A. O. (2007). Seasonal distribution of herbage mass and nutritive value of Prairie grass. *Grass and Forage Science, 62*(3), 301-311.

Bovolenta, S., Spanghero, M., Dovier, S., Orland, D., & Clementel, F. (2008). Chemical composition and net energy content of alpine pasture species during the grazing season. *Animal Feed Science and Technology, 146*, 178 - 191.

Brower, J. E., Zar, J. H., & von Ende, C. N. (1997). *Field and laboratory methods for general ecology* (4th ed.): Michael D. Lange.

Facelli, J. M., & Springbett, H. (2009). Why do some species in arid lands increase under grazing? Mechanisms that favour increased abundance of *Maireana pyramidata* in overgrazed chenopod shrubs of South Australia. *Austral Ecology, 34,* 588 -597.

Gordon, I. J. (2009). What is the Future for Wild, Large Herbivores in Human-Modified Agricultural Landscapes? *Wildlife Biology, 15*(1), 1-9.

Han, G., Hao, X., Zhao, M., Wang, M., Ellert, B. H., & Willms, W. (2008). Effect of grazing intensity on carbon and nitrogen in soil and vegetation in a meadow steppe in Inner Mongolia. *Agriculture, Ecosystems & Environment, 125*, 21-32.

Herlocker, D. J. (1999). *Rangeland ecology and resource development in eastern Africa*. Nairobi: German Agency for Technical Co-operation.

Langdale-Brown, I. (1970). Vegetation. In J. D. Jameson (Ed.), *Agriculture in Uganda* (Second ed., pp. 90 - 97). London: Oxford University Press.

Lin, Y., Hong, M., Han, G., Zhao, M., Bai, Y., & Chang, S. X. (2010). Grazing intensity affected spatial patterns of vegetation and soil fertility in a desert steppe. *Agriculture, Ecosystems & Environment, 138*(3-4), 282-292.

Loeser, M. R., Sisk, T. D., & Crews, T. E. (2007). Impact of Grazing Intensity during Drought in an Arizona Grassland. *Conservation Biology, 21*(1), 87-97.

McIntyre, S., Heard, K. M., & Martin, T. G. (2003). The relative importance of cattle grazing in subtropical grasslands: does it reduce or enhance plant biodiversity? *Journal of Applied Ecology, 40*(3), 445-457.

McNeely, J. A., Gadgil, M., Leveque, C., Padoch, C., & Redford, K. (1995). Human influence on biodiversity. In V. H. Heywood (Ed.), *Global biodiversity assessment* (pp. 715 - 802). Cambridge: United Nations Environment Programme (UNEP).

Neel, J. P. S., Feldhake, C. M., & Belesky, D. P. (2008). Influence of solar radiation on the productivity and nutritive value of herbage of cool-season species of an understorey sward in a mature conifer woodland. *Grass and Forage Science, 63,* 38 - 47.

Osborne, P. L. (2000). *Tropical ecosystems and ecological concepts*. Cambridge: Cambridge University Press.

Pickup, G. (1994). Modelling patterns of defoliation by grazing animals in rangelands. *Applied Ecology, 31*(2), 231 - 246.

Pratt, D. J., & Gwynne, M. D. (1977). *Rangeland management and ecology in East Africa*. Huntington, New York: Robert E. Krieger Publishing Co., Inc.

Sánchez-Jardón, L., Acosta, B., del Pozo, A., Casado, M. A., Ovalle, C., Elizalde, H. F., et al. (2010). Grassland productivity and diversity on a tree cover gradient in Nothofagus pumilio in NW Patagonia. *Agriculture, Ecosystems & Environment*, *137*(1-2), 213-218.

Turner, M. D., Hiernaux, P., & Schlecht, E. (2005). The distribution of grazing pressure in relation to vegetion resources in sem-arid West Africa: The role of herding. *Ecosystems*, *7*, 1-14.

Zarovali, M. P., Yiakoulaki, M. D., & Papanastasis, V. P. (2007). Effects of shrub encroachment on herbage production and nutritive value in semi-arid Mediterranean grasslands. *Grass and Forage Science*, *62*(3), 355-363.

APPENDICES

Appendix 3.1: Data sheet used for vegetation inventory and monitoring data recording

Data form and sample information

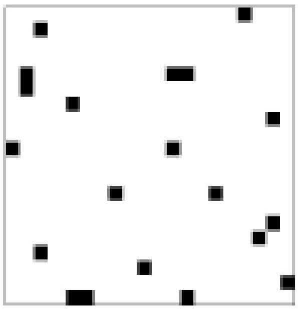
Sheet no.	Locality name:		Vegetation type	Quadrat no.
Observer:			Mapping unit Code:	Sample code:
Date:	Plot size:		Coordinates X:	Y:
Altitude (m):	Soil Texture:		Slope (%):	
Distance to a drainage line:		Drainage description:		

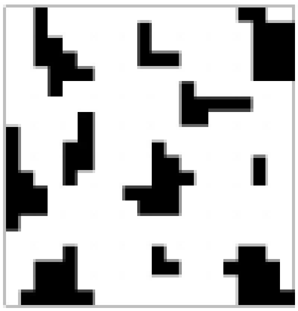
Vegetation structure						**Species Composition**			
Layer	% cover	Layer code	% Layer cover	Height (m)	No. of species	Local name	Scientific name	Height (m/cm)	% cover
TREE LAYER		T1							
		T2							
SHRUB LAYER		S1							
		S2							
GRASS LAYER		G1							
		G2							
FORB LAYER		F1							
		F2							

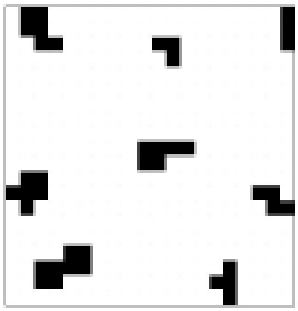
Other Environmental Observations /Comment

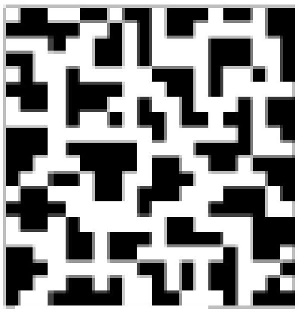
Land use/Cover	
Grazing	
Fires	
Signs of flooding	
Other comments	

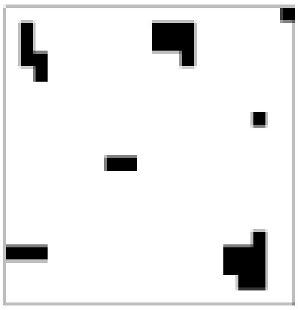
Appendix 3.2: Measured block dots used for estimating cover percentages

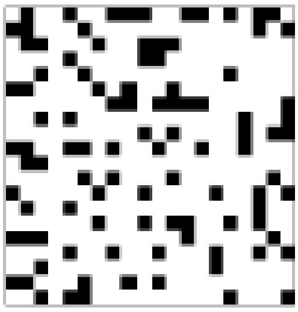

(1) cover:

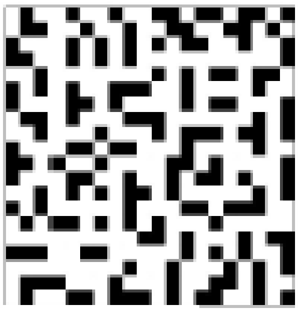

(2) cover:

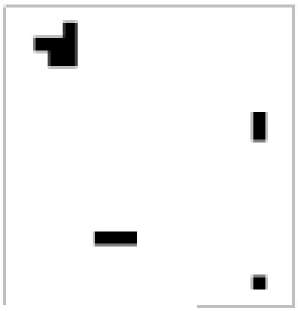

(3) cover:

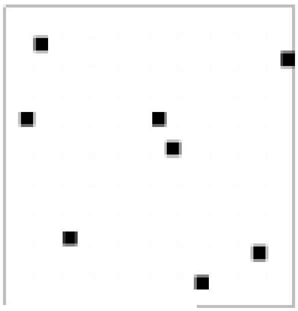

(4) cover:

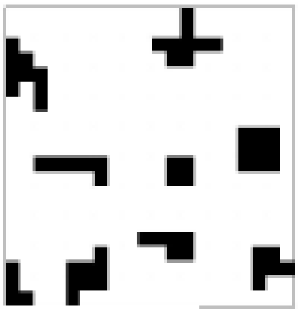

(5) cover:

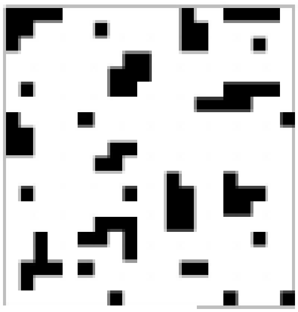

(6) cover:

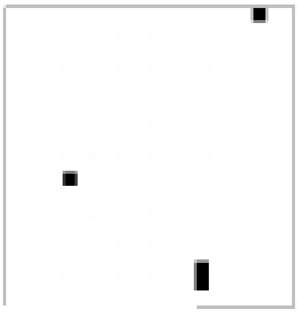

(7) cover:

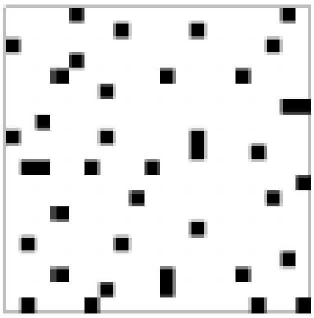

(8) cover:

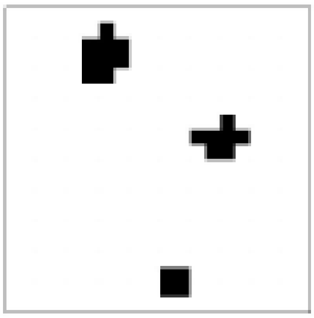

(9) cover:

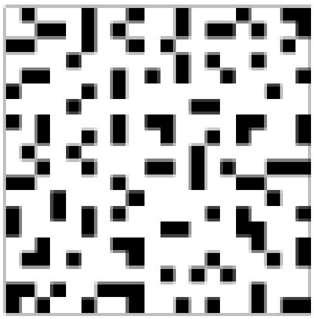

(10) cover:

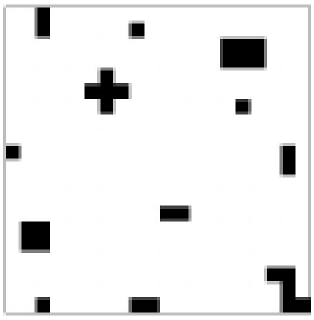

(11) cover:

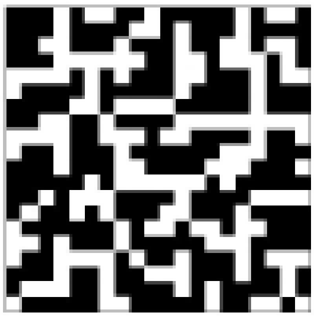

(12) cover:

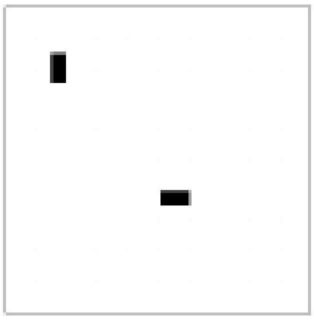

(13) cover:

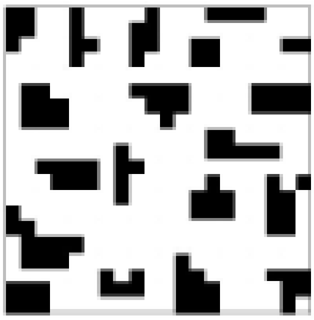

(14) cover:

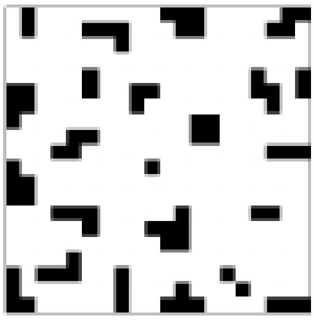

(15) cover:

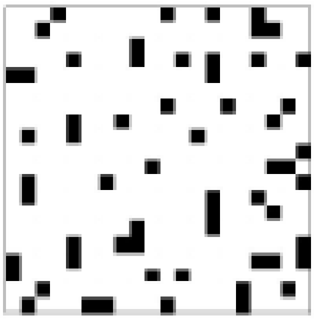

(16) cover:

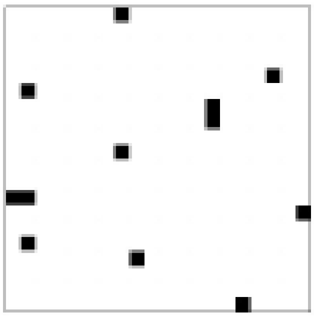

(17) cover:

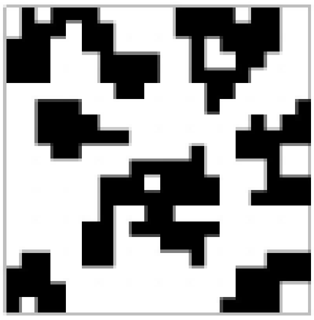

(18) cover:

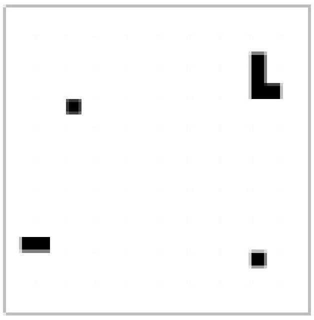

(19) cover:


(20) cover:


(21) cover:


(22) cover:


(23) cover:


(24) cover:

Appendix 5.3: Details of classification accuracy assessment results

Producer’s and user’s accuracy of Landsat and IKONOS imagery using maximum likelihood and fuzzy classification

	Landsat				IKONOS			
	Producers Accuracy (%)		Users Accuracy (%)		Producers Accuracy (%)		Users Accura (%)	
Class Name	ML	Fuzzy	ML	Fuzzy	ML	Fuzzy	ML	Fuzz
Bush Grassland	33.3	33.3	13.33	13.3	50	50	50	50
Bushland	0.0	10.0	10	10.0	0	100	0	25
Grassland	28.6	8.3	100	62.5	100	50	33.3	100
Shrubland	4.2	9.1	100	100	33.3	100	20	33
Bushland thicket	9.1	35.7	62.5	100	33.3	0	14.3	0
Wooded grassland	41.7	41.7	31.25	31.3	16.7	25	33.3	33
Woodland	12.5	37.5	13.04	13.0	0	33	0	50

	Landsat				IKONC		
	Producers Accuracy (%)		Users Accuracy (%)		Producers Accuracy (%)		
Class Name	ML	Fuzzy	ML	Fuzzy	ML	Fuzzy	M
Grassland	58.3	75	75	20.8	100	91.7	5
Bushland	0	17.7	0	28	0	0	
Bushland thicket	33.33	57.1	14.29	47.1	-	-	
Shrubland	18.2	17	16.67	9	33.33	9.1	6
Wooded grassland	16.7	6.25	50	4.5	16.67	16.7	1
Woodland	50	15.2	0	16.1	0	25	5

	Landsat				IKONOS		
	Producers Accuracy (%)		Users Accuracy (%)		Producers Accuracy (%)		Users
Class Name	ML	Fuzzy	ML	Fuzzy	ML	Fuzzy	ML
Grassland	81.3	87.5	63.9	68.9	55.6	56	71.4
Bushland	37.1	40	68.4	60.9	80	80	61.54
Woodland	0	0	0	0	0	0	0

Confusion matrix (7 classes)

Classified Data	Bush grassland	Bushland	Bushland thicket	Grassland	Shrubland	Wooded
Bushgrassland	4	6	4	12	2	
Bushland	1	0	1	2	5	
Bushland thicket	0	0	4	0	1	
Grassland	1	1	0	1	0	
Shrubland	0	0	0	0	1	
Wooded grassland	3	1	3	1	0	
Woodland	3	1	2	8	2	
Column Total	12	10	14	24	11	

Confusion matrix (6 classes)

Classified Data	**Reference Data**					
			Bushland thicket		**Wooded grassland**	

	Grassland	**Bushland**		**Shrubland**		**Wo**
Grassland	21	5	2	2	9	0
Bushland	0	0	0	1	0	0
Bushland thicket	4	2	8	1	0	2
Shrubland	1	0	0	2	0	0
Wooded grassland	9	1	3	3	2	2
Woodland	0	1	1	1	1	4
Column Total	36	10	14	11	12	8

Confusion matrix (3 classes)

Classified Data	Reference Data					
	Grassland	shrubland	Woodland	Water	Wetland	Row Total
Grassland	42	15	4	0	0	61
Shrubland	5	14	4	0	0	23
Woodland	1	4	0	0	0	5
Column Total	48	35	8	0	0	91

Confusion matrix (2 classes)

Classified Data	Reference Data		
	Grassland	Woodland	Row Total
Grassland	6	3	9
Woodland	1	11	12
Column Total	7	14	21

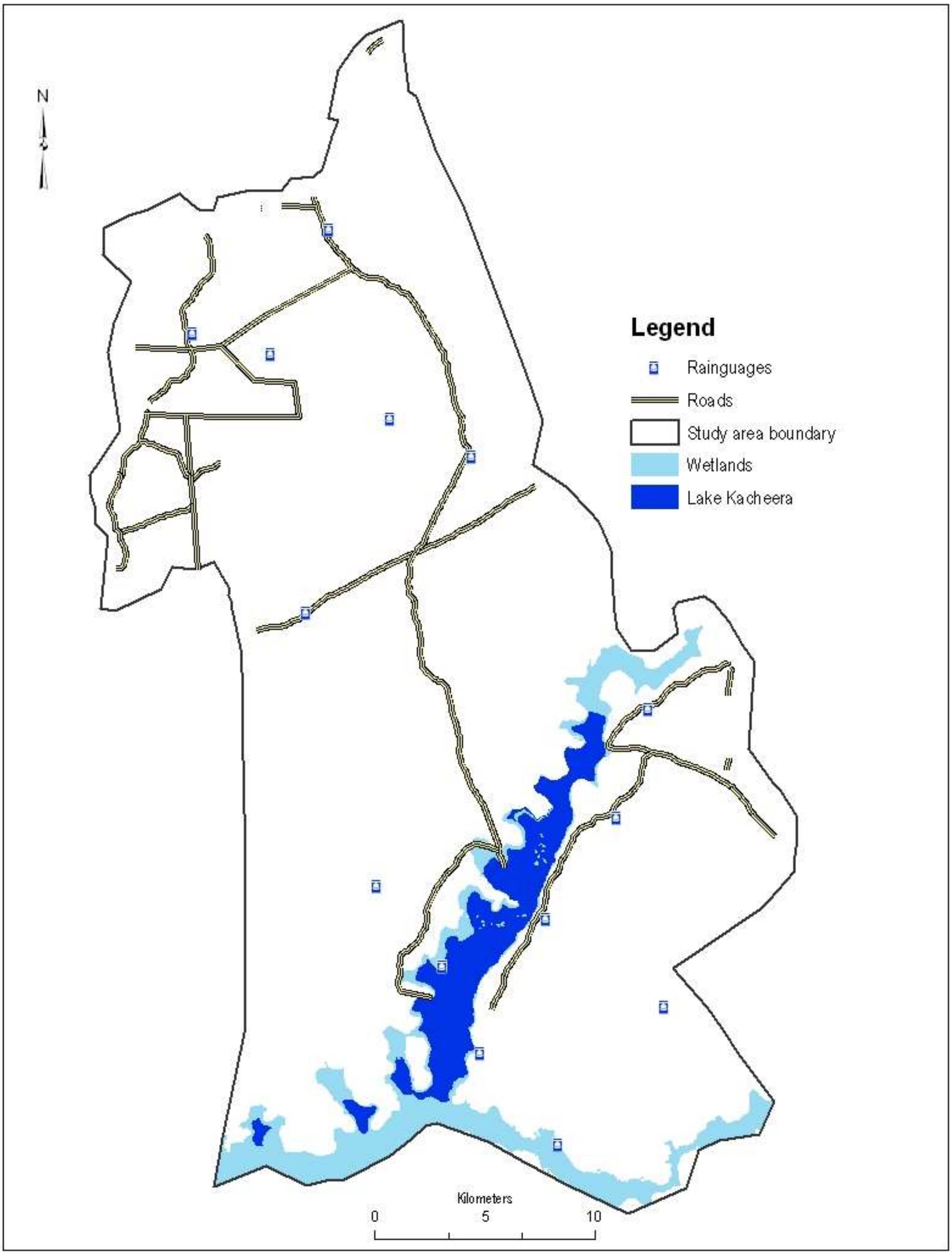
Classified Data	Reference Data		
	Grassland	Woodland	Row Total
Grassland	30	7	37
Woodland	15	27	42
Column Total	45	34	79

Appendix 7.1: Species presence in the different vegetation cover types

Species	**Bush grassland**	**Bushland**	**Bushland thicket**	**Grassland**	**Shrubland**	**Wooded grassland**	**Woodland**	**Habitat totals**
Abildgaardia ovata Burm.f.	1	1	1	1	1	1	1	**7**
Andropogon abyssinicus	1	1	-	-	-	-	-	2
Andropogon amethystinus	1	-	-	-	-	-	-	1
Andropogon schirensis Hochst.	1	-	1	1	1	1	-	5
Aristida adoensis	1	1	1	1	1	1	1	**7**
Bothriochloa insculpta (A. Rich) A.Camus	1	1	1	1	1	1	1	**7**
Brachiaria brizantha (A. Rich) Stapf	1	1	1	1	-	1	-	5
Brachiaria decumbens Stapf.	1	1	1	1	1	1	1	**7**
Brachiaria jubata	-	-	-	1	-	-	-	1
Brachiaria platynota K. Schum.	1	1	1	1	1	1	1	**7**
Bulbostylis boeckeleriana	1	1	1	1	1	1	-	6
Chloris gayana Kunth.	1	1	1	1	1	1	1	**7**
Chloris pycnothrix Trin.	1	1	1	1	1	1	1	**7**
Cymbopogon nardus L. Rendle	1	1	1	1	1	1	1	**7**
Cynodon dactylon L. Pers.	1	1	1	1	1	1	1	**7**
Cyperus (yellow)	1	1	1	1	1	1	1	**7**
Cyperus cyperoides Kuntze.	1	1	1	1	1	1	1	**7**
Digitaria abyssinica Hochst. ex A. Rich. Stapf.	1	1	1	1	1	1	1	**7**
Digitaria longiflora	1	1	1	1	1	1	1	**7**
Digitaria maitlandii Stapf & C.E. Hubb.	1	1	1	1	1	1	1	**7**
Digitaria ternata	1	1	1	1	1	1	1	**7**
Digitaria velutina	1	1	-	1	1	-	1	5
Eleusine indica Steud.	1	1	1	1	1	1	1	**7**
Eragrostis exasperata Peter.	1	1	1	1	1	1	-	6
Eragrostis macilenta	-	-	-	-	-	1	-	1
Eragrostis racemosa	1	1	-	1	1	1	-	5
Eragrostis superba	-	1	-	-	-	-	-	1
Eragrostis tenuifolia (A. Rich.) Hochst. ex Steud.	1	1	1	1	1	1	1	**7**
Fimbristylis dichotoma	1	-	1	1	-	1	-	4
Hyparrhenia filipendula Stapf.	1	1	1	1	1	1	1	**7**
Hyparrhenia rufa (Nees) Stapf.	1	1	-	1	1	1	1	6

*Hyperthelia dissoluta (*Nees ex Steud.) C.E. Hubb.	1	1	-	1	1	1	-	5
Imperata cylindrica	1	1	-	1	1	1	1	6
Kyllinga alba Nees.	1	1	1	1	1	1	1	**7**
Loudetia kagerensis (K.Schum.) C.E.Hubb.	1	1	1	1	1	1	1	**7**
Microchloa kunthii	1	1	1	1	1	1	1	**7**
Panicum maximum Nees.	1	1	1	1	1	1	1	**7**
Panicum porphyrizos	1	-	-	1	-	1	1	4
Paspalum scrobiculatum L.	1	1	1	1	1	1	1	**7**
Setaria homonyma (Steud.) Chiov.	1	1	1	1	1	1	1	**7**
Setaria kagerensis (Schumach.) Stapf & C.E. Hubb. ex M.B. Moss.	1	-	-	-	-	-	-	1
Setaria sphacelata	1	1	1	1	1	1	1	**7**
Sporobolus paniculatus	1	-	-	1	-	-	-	2
Sporobolus pyramidalis P. Beauv.	1	1	1	1	1	1	1	**7**
Sporobolus stapfianus	1	1	1	1	1	1	1	**7**
Themeda triandra Forssk.	1	1	1	1	1	1	1	**7**
Total no. of species		**38**	**33**	**41**	**36**	**39**	**32**	

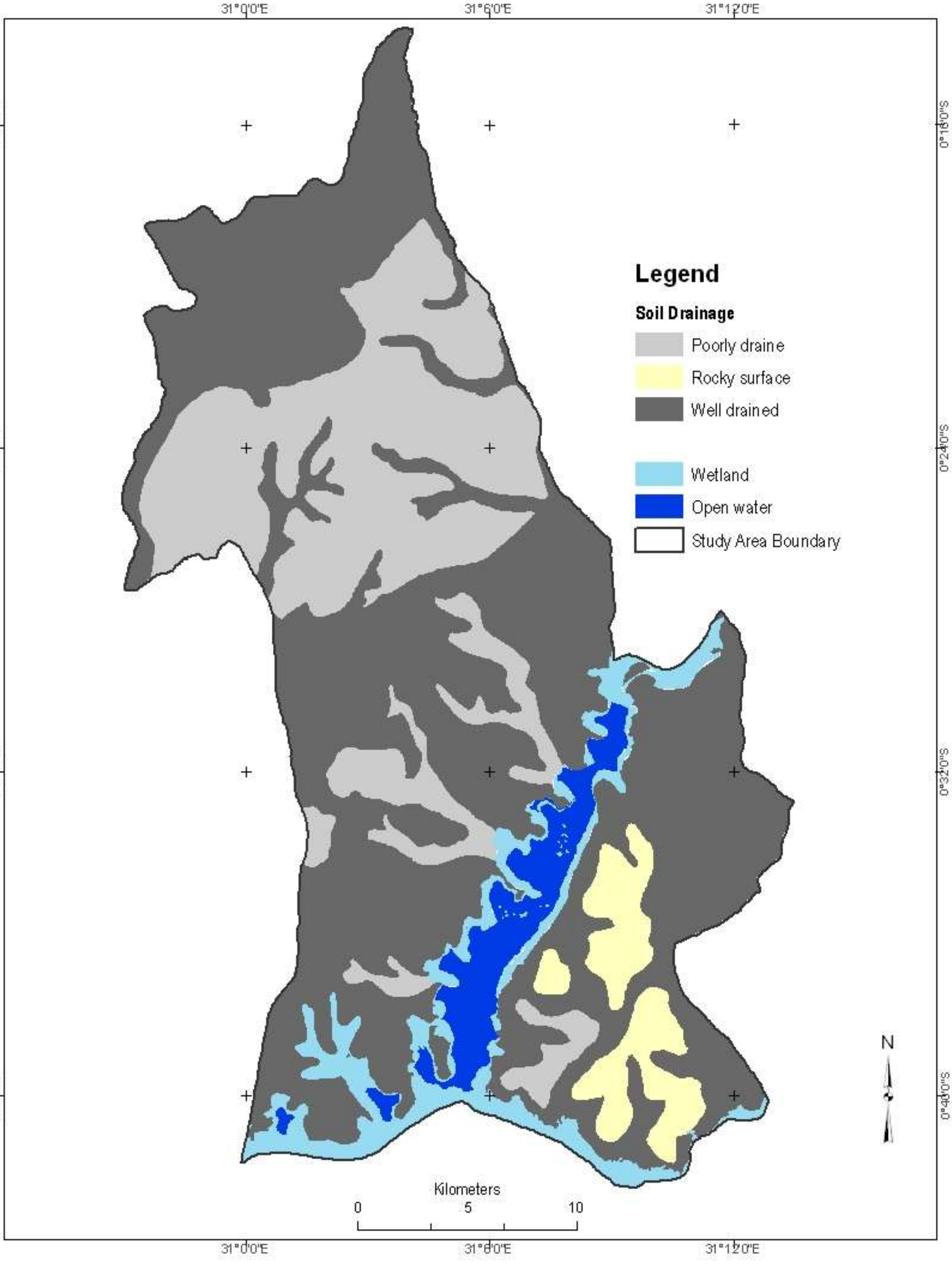
Appendix 8.1: The location of raingauges in the study area



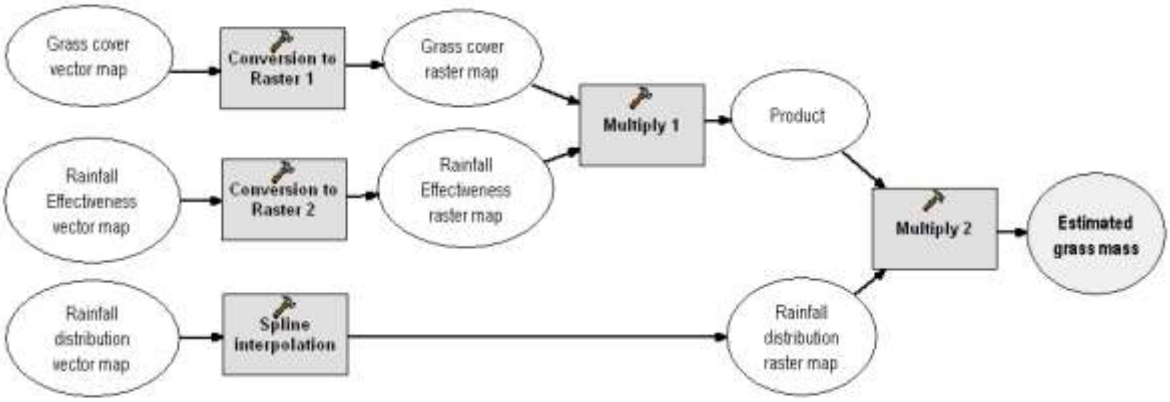
Appendix 8.2: Soil data used for determining rainfall effectiveness

Parish	X	Y	Depth	BD (gcm^{-3})	HC ($cmhr^{-1}$)	Textural class
Bijubwe	284083	9966754	Shallow	1.560	0.67	Sandy clay loam
Bijubwe	282540	9967800	Deep	1.330	3.54	Sandy clay loam
Bijubwe	283347	9964678	Shallow	1.486	0.1	Sandy loam
Bijubwe	284986	9969186	Deep	1.407	0.19	Sandy clay loam
Bijubwe	284506	9969250	Deep	1.575	0.24	Sandy clay loam
Bijubwe	286170	9962950	Deep	1.560	0.18	Sandy loam
Gwabunyankole	274087	9959624	Deep	1.330	0.42	Sandy clay loam
Kyakabunga	285198	9961394	Deep	1.539	0.19	Sandy clay loam
Kyakabunga	287881	9958654	Deep	1.136	2.58	Sandy loam
Kyakabunga	287931	9959454	Shallow	1.464	0.96	Sandy loam
Kyakabunga	277469	9963990	Deep	1.231	0.29	Sandy loam
Kyakabunga	277606	9964028	Very shallow	1.189	0.21	Sandy clay loam
Kyakabunga	278739	9961030	Deep	1.525	0.16	Sandy loam
Nyanga	283922	9930076	Deep	1.252	0.19	Sandy clay loam
Nyanga	284834	9931974	Shallow	1.352	0.26	Sandy loam
Nyakahita	288120	9942712	Deep	1.283	0.47	Sandy loam
Nyakahita	287723	9944554	Deep	1.100	0.21	Sandy loam
Nyakahita	282882	9949796	Deep	0.000	0.96	Sandy loam
Rurambira	284264	9936596	Deep	1.316	0.54	Sandy loam
Rurambira	284314	9937720	Deep	1.298	0.06	Sandy loam
Rurambira	288728	9938182	Deep	1.436	0.24	Sandy clay loam
Kaju	295261	9939926	Shallow	1.545	0.35	Sandy clay loam
Kayonza	299571	9926484	Deep	1.610	0.27	Sandy clay loam
Kayonza	296740	9934134	Shallow	1.065	6.69	Sandy clay loam

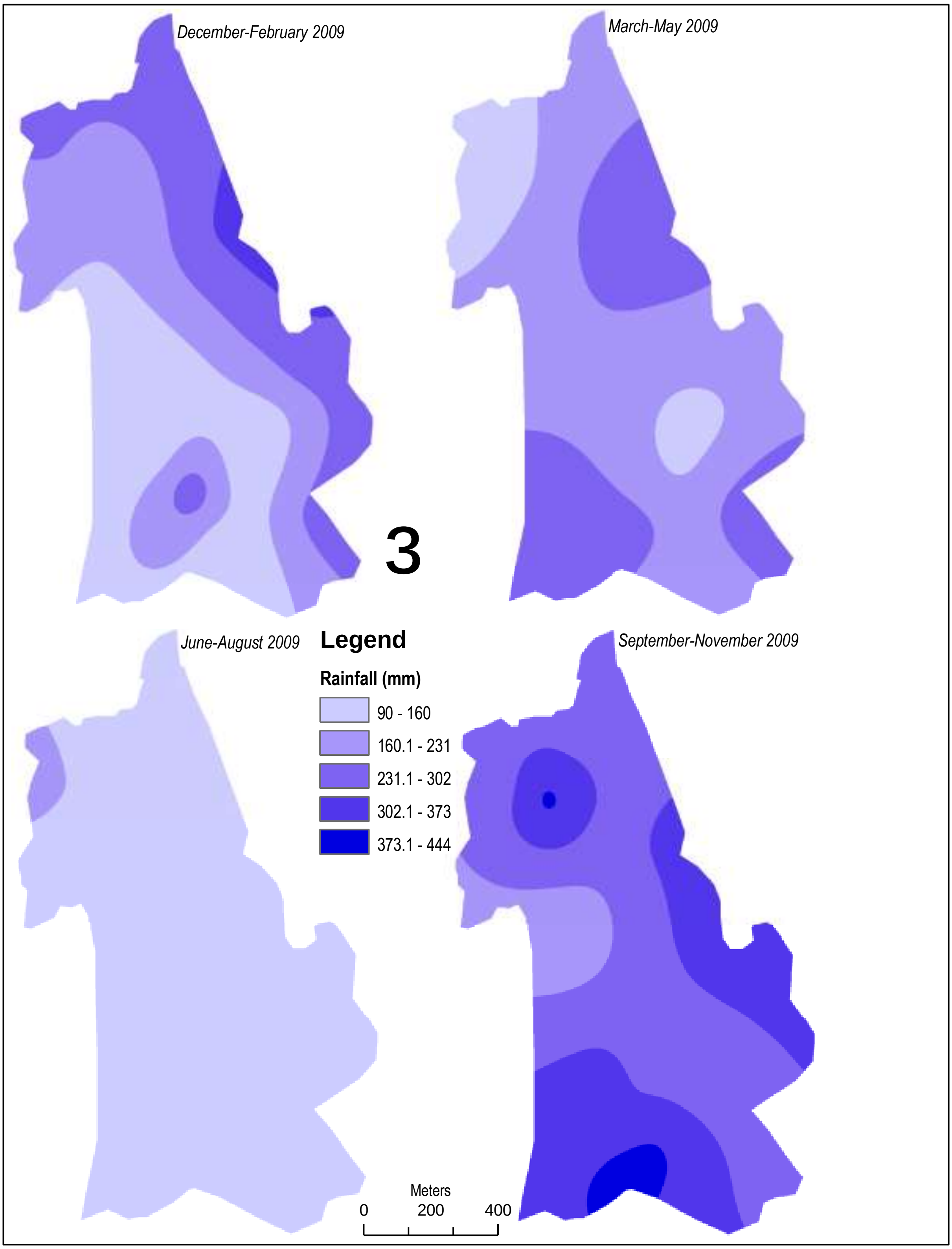
Appendix 8.3: Soil drainage classes based on FAO map units



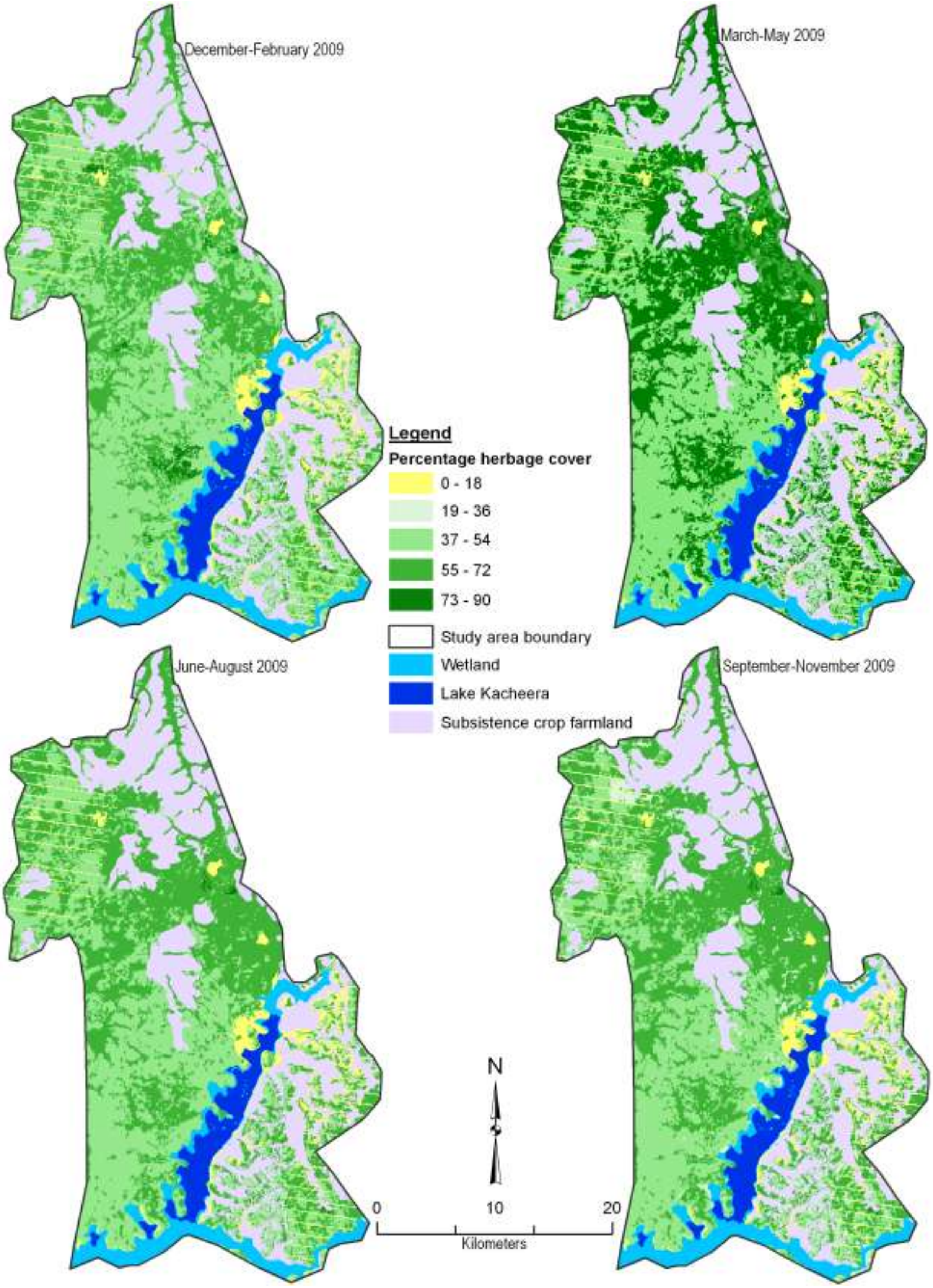
Appendix 8.4: ArcGIS model arrangement for Herbage mass estimation



Appendix 8.5: Spatial and seasonal rainfall distribution patterns during 2009



Appendix 8.6. Spatial and seasonal patterns of herbage cover during 2009



Appendix8.7. Summary out for regression analysis of harvested dry matter yield with rainfall, grass cover and rainfall effectiveness

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.8713368
R Square	0.7592278
Adjusted R Square	0.7212111
Standard Error	0.3630881
Observations	23

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	7.89847743	2.632826	19.970921	0.000004263
Residual	19	2.50482644	0.131833		
Total	22	10.4033039			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	5.2607581	4.03716196	1.303083	0.208118	-3.18911901	13.71063516	-3.18912	13.710635
Rainfall	-0.788446	0.57239574	-1.37745	0.1843843	-1.98648449	0.409591625	-1.98648	0.4095916
Grass cover	1.4353947	0.20475846	7.010185	1.124E-06	1.00683032	1.863959097	1.00683	1.8639591
Effectiveness	0.3938159	0.27201895	1.447752	0.1639869	-0.17552627	0.963158125	-0.17553	0.9631581