IMPACT OF UNDESIRABLE PLANT COMMUNITIES ON THE CARRYING CAPACITY AND LIVESTOCK PERFORMANCE IN PASTORAL SYSTEMS OF SOUTH-WESTERN UGANDA

A Dissertation

by

GILBERT STEVEN BYENKYA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2004

Major Subject: Rangeland Ecology and Management

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ABSTRACT

Impact of Undesirable Plant Communities on the Carrying Capacity and Livestock Performance in Pastoral Systems of South-Western Uganda.
(May 2004)

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The impact of undesirable plant communities (*Cymbopogon afronardus* and woody species dominated by *Acacia* species) on livestock carrying capacity and performance was investigated on 15 farms in an *Acacia*/*Cymbopogon* dominated pastoral system of south-western Uganda. Species prevalence based on basal cover for grasses, frequency for forbs and effective canopy cover for trees/shrubs were determined on farms. The PHYGROW model was used to predict forage productivity for computation of carrying capacity. The NIRS/NUTBAL nutritional management system was used to determine cattle dietary CP and DOM through fecal scans and to estimate animal performance.

Brachiaria spp. (33.57%), *Sporobolus pyramidalis* (20.35%), *Hyparrhenia spp.* (12.29%) and *Cymbopogon afronardus* (10.29%) were the most prevalent grasses while *Acacia gerrardii* (34.37%) and *Acacia hockii* (33.66%) were the most prevalent woody species. Forage productivity differed significantly among the farms with a mean long-term annual forage yield of 4560(SE$\pm$41) kg/ha. Farms with mixed high *Cymbopogon* and high woody species and the

Cymbopogon dominated farms produced 27% and 25% less forage, respectively and had the lowest carrying capacity estimates (0.38 and 0.39 AU/ha, respectively). Improved farms (devoid of the undesirable species) and farms with a moderate woody species component had higher forage yields with higher carrying capacity estimates (0.49 and 0.52 AU/ha, respectively). Carrying capacity for the system was estimated at 0.44 AU/ha using a 25% harvest efficiency for ANPP. All the farms were overstocked, on average by 3.2 times.

Livestock BCS, diet CP and DOM were significantly different ($P<0.0001$) among the farm types. BCS were highest on improved farms and lowest on *Cymbopogon* infested farms. However, dietary CP and DOM values were lowest on improved farms and highest on farms with a high woody component. High woody component farms exhibited intermediate BCS despite the high dietary CP. Cattle on *Cymbopogon* infested farms had consistently lower body weights although there were no significant differences in daily live weight gains among farms.

These findings suggest that the undesirable plant communities have a negative influence on the grazing potential of south-western Uganda rangelands. Research into appropriate control measures, improvement of forage quality on improved farms including feed supplementation for improved breeds and farmer sensitization about overstocking are recommended. Integration of NIRS / NUTBAL and PHYGROW models into the research and management systems was desirable. The observed increase in *Sporobolus spp*. required investigation.

ACKNOWLEDGMENTS

Many people and organizations have in many ways contributed to my being able to accomplish this undertaking. I will only mention a few.

Special thanks go to Dr. Jerry W. Stuth, my committee chair. Dr. Stuth supported and guided me from the time we met under the Livestock Early Warning in East Africa through my enrollment and up to completion of my studies at Texas A&M University. He has been very helpful in all respects. I sincerely thank my committee members Dr. Urs P. Kreuter, Dr. Fred Smeins and Dr. William Grant, for accepting to be on my committee and on many occasions for giving their valuable time and expertise that have enabled me to successfully complete this program. Many thanks to Dr. Whisenant, the head of the department, the faculty and staff of the Department of Rangeland Ecology and Management for making my life here enjoyable.

I am grateful for the financial support by DANIDA extended to the National Agricultural Research Organization (NARO), Uganda, through the Livestock Systems Research Project (LSRP) that enabled me to undertake this training. I am equally grateful to the Director General NARO and Director of Research, Namulonge Agricultural and Animal Production Research Institute (NAARI) for their support and permission to undertake the training. My appreciation goes to the National Coordinator, LSRP and Head, Animal Production Program, Dr. Cyprian Ebong for his support and encouragement from the start to the end. I thank the LSRP Research Advisory Committee

(RAC) for the support and advise that guided this research. For colleagues at NAARI, I thank you all for the many various ways you assisted me.

I appreciate the contribution of USAID funded GL-CRSP, Grant No. PCE-G-00-98-000-36-00 to Livestock Early Warning Systems (LEWS) project under which this study was conceived and immensely supported. Thank you.

I extend many thanks to Jay Angerer, Dr. Abdi Jama, Dr. Robert Kaitho, Clint Heath and Jim Bucher for the work on PHYGROW, Doug Tolleson for help with NIRS/NUTBAL, and Colin Shackelford for very willingly walking me through PC-ord software. Dr. Robert Blaisdell was always ready to help when I ran into a software problem. Fellow graduate students Laban Macopiyo, Negusse Kidane and Dr. Kosi Awuma were helpful in many ways.

Data collection in the field was no easy task, but with the help of Charles Sudhe, John Kigongo, Henry Sempagala, Constantine Mwesige, Hannington Kajja and many others we were able to manage. I am grateful to all of you. I am indebted to the many farmers and extension officers of Nyabushozi County who willingly allowed me to work with them on their farms. Extension officers John P. Kitimbo and Wilson Bagatuzayo were particularly very helpful.

Lastly, but not least, I appreciate the patience and daily prayers by my loving wife and children who have had to endure my long absence from home. Your prayers were not in vain.

Surely, this is yet another good work of the almighty God.

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CHAPTER I

INTRODUCTION

Rangeland ecosystems of Uganda are estimated to cover an area of about 84,000 km^2, which is equivalent to 43% of the landmass of the country, in a stretch of land across the country commonly known as the ‘cattle corridor’. The human population is about 6.6 million people (derived from Uganda Population Census 2001), mainly pastoralists and agro-pastoralists supporting about 90% of all the cattle in the country and producing about 85% of all marketed milk and beef. Livestock population in Uganda is estimated at 5.5 million cattle, 3.5 million goats and 1.3 million sheep (MAAIF 1998).

Management of the rangelands for sustainable production of goods and services for society continues to be a major challenge in Uganda. One such management challenge especially in the rangelands of south-western Uganda is the spread of undesirable plants in the natural grazing lands. The primary noxious species are *Cymbopogon afronardus, Acacia hockii* and an assortment of species associated with thicketized woody mottes. Infestation by these species causes reduction in land available to grazing in addition to suppression of the production of palatable grasses. In many areas where native rangeland is used for animal production, the encroachment of woody plants has hindered animal grazing capacity (Scifres et al. 1985).

This dissertation follows the style and format of the Journal of Range Management.

Pastoralists in the cattle corridor use manual labor with simple hand tools as a management strategy to control these undesirable species, but only with limited success. The species have proved not only difficult to manage but also economically constraining. Mugasi (1998) in an economic assessment of shrub encroachment on Ankole (Kazo County) rangeland productivity observed reduced financial gross margins on shrub-infested farms. Cost of shrub control considerably reduces profitability. More studies are required to evaluate the impact of these species on livestock productivity to support informed advisory and adoption of economically viable control strategies (Schwartz et al. 1996, Mugasi 1998). This study was undertaken to evaluate the impact of invasion of *Cymbopogon afronardus* and woody species as the major noxious species on the productivity of the pastoral system of south-western Uganda with emphasis on carrying capacity, forage availability, livestock nutrition and productivity.

Objectives

The overall objective of the study is to evaluate the impact of *Cymbopogon afronardus, Acacia hockii* and some assorted woody species on livestock carrying capacity, nutrition and productivity.

Specific objectives

- To determine how toposequence influences encroachment patterns of these noxious species on the landscape.
- To determine forage availability patterns as impacted by *Cymbopogon afronardus* and woody species.

- To determine the carrying capacity, nutrition and productivity under varying levels of ecosite infestation by *Cymbopogon afronardus* and woody species.
- To determine if NIRS fecal profiling technology and biophysical modeling of forage production can be a viable method for explaining landscape level effect of *Cymbopogon afronardus* and woody species expansion.

Hypotheses

- *Cymbopogon afronardus* and woody species reduce usable forage for cattle.
- Cattle performance and nutrition in the pastoral system decline as infestation by *Cymbopogon afronardus* and woody species increases.
- *Cymbopogon afronardus* and woody species have a negative influence on the carrying capacity of cattle.

The study area

Location

This study was carried out in Mbarara District of south-western Uganda, (Figure 1.1 and 1.2) specifically in the sub-counties of Kanyaryeru, Kikaatsi, Nyakashashara and Sanga of Nyabushozi County. Three study sites were in Kashari County but bordering Nyabushozi. Nyabushozi County is one of the six counties that form Mbarara District. Most of the study sites / farms are within or in close proximity to the former Ankole Ranching Scheme (Sacker 1968).

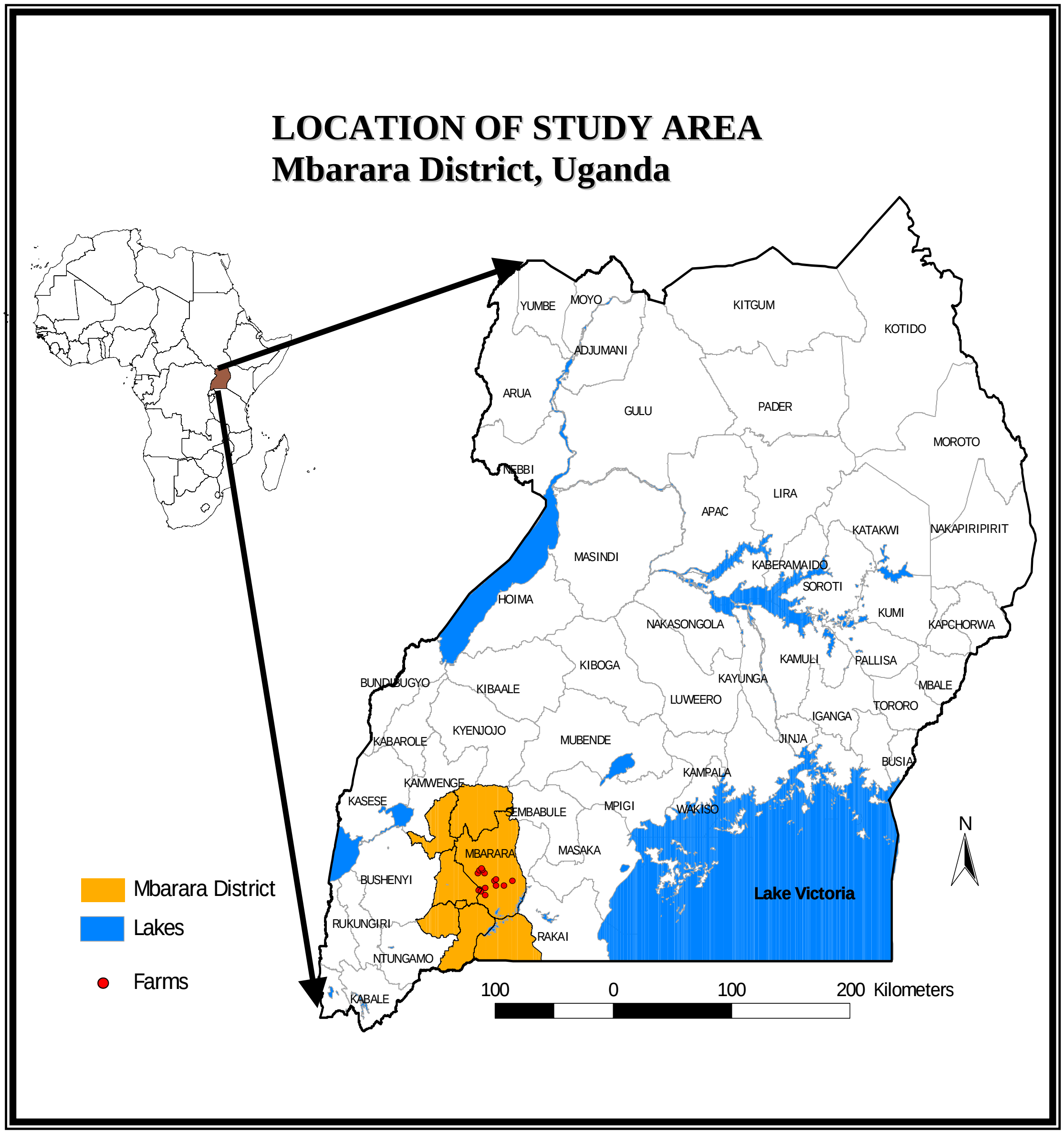

Figure 1.1. Location of study area: Mbarara district, Uganda

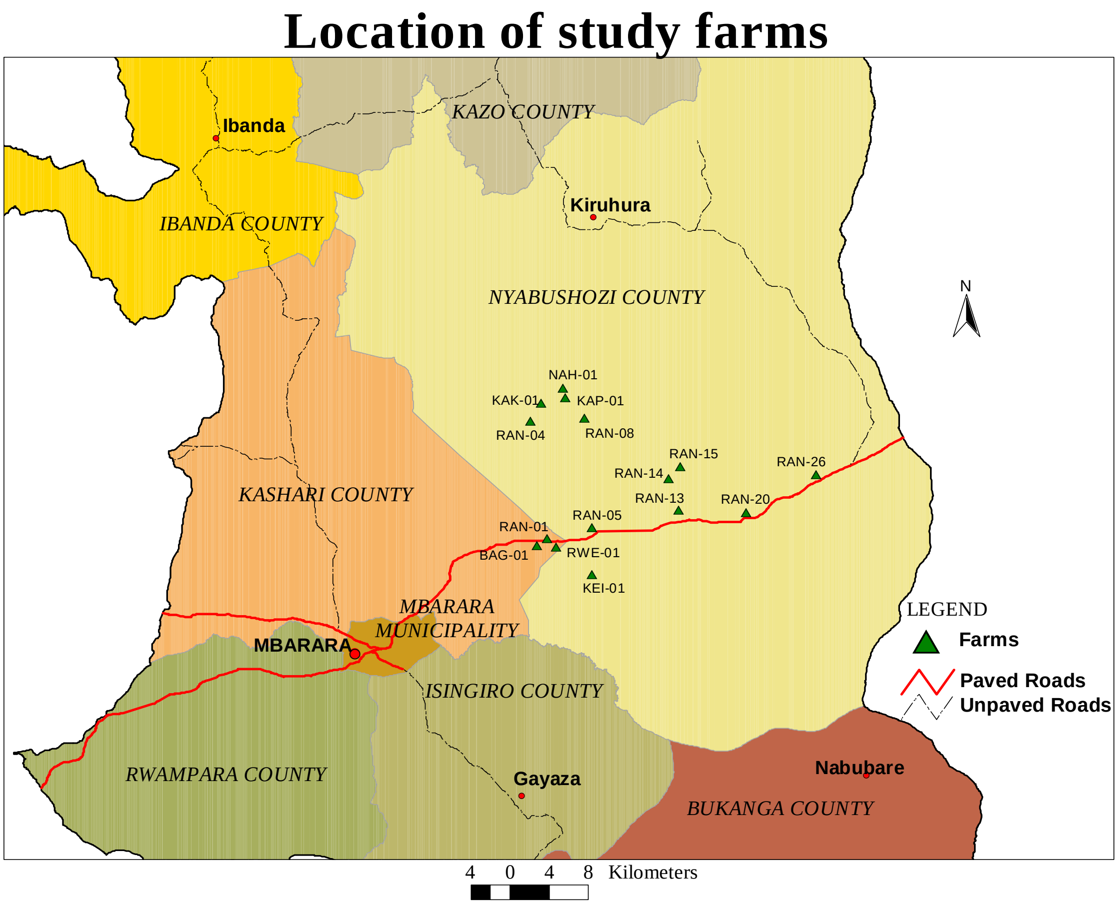

Figure 1.2. Location of study farms

Topography and climate

The topography consists of undulating hills and valleys. The hills rise about 100 – 200m above the flat valley bottoms. The area lies between 1250 - 1525m above sea level. Rainfall has in the past been reliable but recent trends in rainfall patterns indicate more erratic behavior. Mean annual rainfall is estimated to be between 760 – 1270mm and occurs in a bimodal pattern, peaking in the months of April to May and September to November. The months of June, July and August normally constitute a dry season with no rainfall. Schwartz et al. (1996) have computed the mean annual rainfall for the Mbarara Meteorological site at Kakoba for the period 1980-1994 and obtained a figure of 882mm with a coefficient of variation of 20%. The long-term event corrected Collaborative Historical African Rainfall Model (CHARM) (Funk et al. 2003) data for 1961 to 1996 derived for the various study sites for this study indicated a mean annual rainfall of 848mm. Positive moisture balance therefore usually occurs in April, May, October, November and December. Mean maximum temperature is about 26^{o}C and mean minimum around 14^{o}C. Rainfall data for the Mbarara weather station at Kakoba in Mbarara town for the year 2002 (Source: Meteorological Department, Kampala) is compared in Figure 1.3 with the long-term CHARM rainfall data and National Oceanic and Atmospheric Administration rainfall estimates (NOAA RFE) for the study sites in Nyabushozi county. Both CHARM rainfall data and NOAA RFE data were derived by input of the latitude/longitude for the selected farms and the means used to represent the study area. The Kakoba Meteorological station is in Mbarara Municipality, a distance of between 20 – 60 km from the different experimental farms.

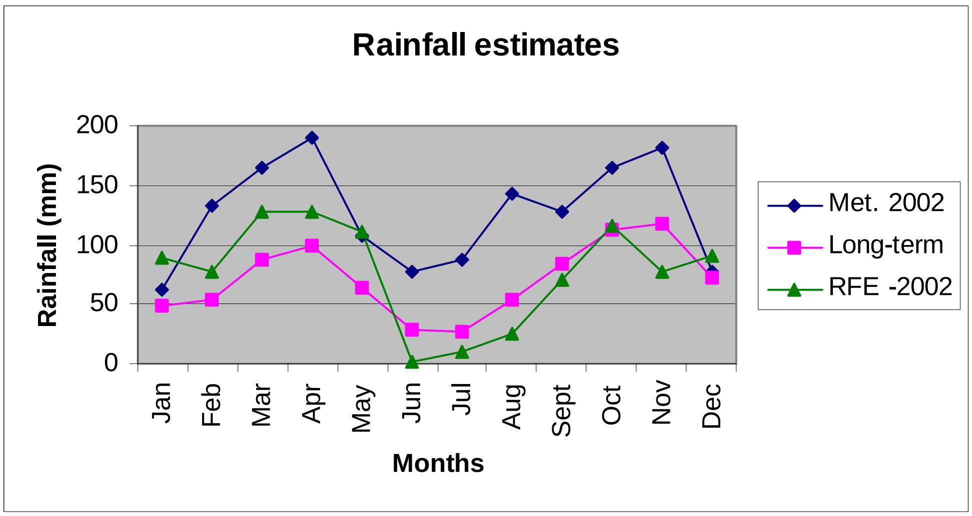

Figure 1.3: Mean long-term (CHARM) rainfall and NOAA rainfall estimates (RFE) for the study sites and Kakoba (Mbarara town) meteorological station rainfall data

Vegetation

The vegetation of Uganda was mapped and described by Langdale-Brown et al. (1964). The dominant vegetation type for this region was described as being dry *Acacia* savanna comprised of an *Acacia / Cymbopogon / Themeda* complex. The woody vegetation varies from 5 to 20 percent canopy cover consisting mainly of *Acacia* species. *A. gerrardii* was considered to be the dominant species derived from a thicket climax by burning and grazing. Other

Acacia species included *A. hockii* and *A. sieberiana.* The grass layer was described as being dominated by *Cymbopogon afronardus* with abundant *Brachiaria decumbens, B. platynota, Themeda triandra, Panicum maximum, Hyparrhenia filipendula, Chloris gayana* and *Loudentia kagerensis. Cymbopogon afronardus, Themeda triandra, Hyparrhenia filipendula* and *Loudentia kagerensis* are all known to be poor for livestock productivity. There are no reported recent studies undertaken to determine if any significant changes have taken place in species distribution and abundance. With changes in fire regimes (lower frequency) and increased grazing pressure, the likelihood of change in species distribution/composition and abundance would be high.

Land use

The area was traditionally inhabited by pastoralists who communally grazed their herds on the range. The ranching scheme established in the 1960s saw most of the area subdivided to create commercial ranches under the Ankole –Masaka Ranching Scheme, and displacing many of the indigenous pastoralists (Doornbos and Lofcie 1967). Another part of the region was also later gazetted as the Lake Mburo National Park. With the restructuring of the ranches in the late 1980s, many pastoralists acquired pieces of land for settlement and grazing. Pastoralism has therefore been the main land use activity in the system. Communal grazing or common property rangeland tenure system is being phased out in favor of individualization (privatization) of land ownership (Kisamba-Mugerwa 1995) as observed in many other pastoral areas of East

Africa (Graham 1988). Local development initiatives in Nyabushozi have emphasized land registration as a priority project. Today most pastoralists have become agro-pastoralists due to the changing social economic conditions in addition to deliberate government policies promoting sedentarization and land privatization. The cropping aspect is however still poorly developed. Banana growing is currently the main crop enterprise, occupying the most productive rangelands in the toposequence.

Livestock production

The pastoral production system in the Ankole cattle corridor is characterized by extensive grazing but differs from other pastoral systems elsewhere in that there is no communal grazing. Land is owned individually, in most cases under leasehold for 49 years. Resources allowing, most of the boundaries would be fenced. The production system can be described as comprised of large, medium and small scale ranching / farm enterprises, in terms of both land acreage and animal numbers. The large-property ranchers, mostly the beneficiaries in the former ranching scheme have large ranch sizes (500 – 1050 ha). Sub-division of the ranches during restructuring created more of the medium and small-scale producers. Land holdings among the participating farms/ranches varied from about 30 ha to about 1000 ha. Number of cattle on the farms also varied from about 30 head of cattle to about 1000 head of cattle.

Goat production is becoming increasingly important. The potential is high but has not yet adequately been exploited. Currently there are a few farms with large flocks up to 300 goats comprised of local and crossbreds with introduced breeds, especially the Boer goat from South Africa. Observation of typical farms appears to indicate that about 20% of landholders are serious goat producers.

Milk is the main product of the pastoral households in Nyabushozi (Kisamba-Mugerwa 1992) but cattle are also kept for prestige, social and other cultural functions. In terms of production objectives, there is an on-going shift from traditional subsistence to commercial enterprises. Due to the limitation of resources required for the transformation to commercial operations, many of these pastoralists can be described as ‘traditional in transition’ to commercial. While the traditional beliefs of prestigious large herds, minimum input and respect for the various roles performed by cattle are still pertinent, there is increasingly a strong desire to produce higher quality and more productive animals for the market. The love for the local breed (the long horned Ankole cattle) not withstanding, there is a steady increase in crossbred cattle in the system. Most individual households long-term plans have an aspect of upgrading the herd for increased milk yields and improvement of the rangeland on which to graze the improved stock. Improvement of the rangeland explicitly infers the removal of *Cymbopogon afronardus* and the various woody species especially *Acacia hockii* prevalent on the landscape. The sale of milk and live animals are the major sources of income for these households. When there is an emergency need of money, pastoralists will sell adult female animals, because the males are usually sold off as yearlings to meet routine family financial needs. The demands of a settled life as opposed to a pastoral one dictate increased productivity, increase efficiency and lower production costs to develop a product valued in the market.

Production constraints

The major constraints to production commonly expressed by the community include inadequate water for livestock especially during the dry season, lack of good markets for milk and live animals and high occurrence of weeds especially *Cymbopogon afronardus, Acacia hockii* and other woody species on the landscape. Cost of disease control especially for ticks and tick-born diseases continues to be an important constraint. There is generally inadequate capital for improvement in both livestock and crop farming practices.

General materials and methods

Fifteen (15) farms / ranches were selected in the study area for this research. The selection criteria were farmers' willingness to participate and accessibility of the farm. The farms selected were visually observed to represent occurrences of different levels of weed infestation i.e. from absent to high levels for either *Cymbopogon afronardus* or woody species or both. The 15 farms were assigned identification names and were geo-referenced as indicated in Table 1.1.

Table 1.1: Participating farms and their geographical positions

Farm	Location	Latitude	Longitude
BAG-01	Kanyaryeru	-0.5141	30.8097
KAK-01	Kikaatsi	-0.3762	30.7959
KAP-01	Kikaatsi	-0.3708	30.8176
KEI-01	Kanyaryeru	-0.3719	30.8427
NAH-01	Kikaatsi	-0.3614	30.8159
RAN-01	Kanyaryeru	-0.5069	30.8009
RAN-04	Kikaatsi	-0.3935	30.7856
RAN-05	Kanyaryeru	-0.4965	30.8427
RAN-08	Kikaatsi	-0.3708	30.8354
RAN-13	Sanga	-0.4797	30.9216
RAN-14	Sanga	-0.4489	30.9121
RAN-15	Sanga	-0.4375	30.9234
RAN-20	Sanga	-0.4816	30.9831
RAN-26	Nyakashashara	-0.4451	31.0476
RWE-01	Kanyaryeru	-0.5150	30.8097

Plant species characterization to establish types and levels of plant species on the landscape was carried out on each farm by ecosite (hilltop, slopes and valley bottoms). Grasses, forbs and woody shrubs and trees were characterized for percent basal cover, percent frequency and effective canopy cover, respectively. There are several methods used to determine species distribution on the range. They are based on the determination of canopy cover of the different species on the landscape, basal cover of the individual species and frequency counts of the different species, usually along a transect or within some prescribed area.

The PHYGROW model (Ranching Systems Group 1995), which is a hydrologic based plant growth model was used to predict forage production on the farms by ecosite. Plant growth attributes, grazing animal attributes, soil attributes and weather data are primary components of the model.

NIRS (near infrared reflectance spectroscopy) was used to estimate dietary crude protein (CP) and digestible organic matter (DOM) through cattle fecal scans on each farm while NUTBAL PRO model was used to estimate animal nutrition and productivity. Body condition scoring was used to assess animal performance on each of the farms.

CHAPTER II

LITERATURE REVIEW

Weeds in grazing systems

Weeds in grazing systems can simply be defined as those noxious plant species found growing together with more desirable forage species. They are unwanted because they do not contribute to the well being of the target grazing animal. Instead they are detrimental either to the forage plant or to the animal that grazes on the rangeland. Noxious plant species compete with forage species for scarce resources like water and nutrients and sometimes even light resulting in lower yields and lower quality of the more desired species. A number of weeds are poisonous to cattle when ingested during grazing. Some weeds may cause bad flavors in milk when ingested. Under good management therefore, a considerable amount of resources are spent on weed control.

Highlights of past research in the pastoral system of south-western Uganda

The planned development of the grasslands in south-western Uganda into a modern large-scale beef ranching scheme (Sacker, 1968) in the early 1960s provided a good impetus for concurrent pasture management investigations aimed at maximum production within the social economic limitations of pastoral systems (Harrington and Pratchett 1974a). Hence, a number of studies/ investigations were undertaken in the system to meet the challenge of increased production. Considerable effort was expended to understand the nutritional qualities of the indigenous grasses and their potential role in improving livestock production. Investigations into the problems of noxious plants, notably *Cymbopogon afronardus* and *Acacia hockii*, grazing systems and stocking rates were initiated. Unfortunately the political instability that followed disrupted these investigations before they could be adequately packaged for the benefit of the farming community.

Cymbopogon afronardus

Synonym: *Cymbopogon nardus* (L.) Rendle

Common names: False citronella, citronella grass, blue citronella grass, naid grass (India).

One of the most dreaded noxious grasses on Uganda's grazing lands is *Cymbopogon afronardus.* The species is distributed throughout eastern Africa from Sudan to South Africa, extending through southern India and Sri Lanka to Burma. It is found in Uganda, Kenya and Tanzania. It is believed to be native in Uganda (Clayton and Renvoize 1982). While many people in Uganda also believe that it is a native species, a few others, especially the older generation thinks that it is an introduced species during the colonial era. Harrington (1974) citing Ford and Clifford (1968) reports that the presence of tsetse flies in the area led to the movement of many pastoralists out of many parts of Ankole area between 1907 – 1960. When the pastoralists returned in the 1960s, they found that *Cymbopogon afronardus* had increased to cover an estimated 40% of the ground cover and yet those who could remember back to 1920 claimed that *C.*

afronardus was so uncommon at that time that they could walk many kilometers to collect the plant for medicinal purposes. According to Harrington (1974), it seems probable that a change in the grazing and or fire patterns induced by the depopulation of the area could be responsible for the increase in the species.

Cymbopogon afronardus has been well described by Harrington and Thornton (1969), essentially a tussock grass that establishes naturally from seed with leaves that contain aromatic oils, which impart a bitter taste. Foliage has a rough texture, grows fast and quickly builds up thick coarse vegetation where both humans and cattle find difficulty traversing areas dominated by the grass. The canopy of one plant can cover an area of up to 2 m in diameter. Because of its high competitiveness, the species establishes quickly in overgrazed places. After a fire, *Cymbopogon* will quickly form new shoots earlier than the other plants allowing it to maintain dominance over the others, in terms of light, water and nutrient resources. Although the species is most abundant in south-western Uganda rangelands, it is quickly spreading to other parts of the country.

Literature on *Cymbopogon afronardus* outside Uganda is scanty. Thornton (1968) reports that *Cymbopogon afronardus* was extremely prevalent in the Ankole - Masaka ranching scheme and that it was increasing in density in the preferred mid-slope habitats of western Uganda. It is one of the least palatable rangeland constituents, for both domestic and wild game except at the very young leaf stage (Thornton 1968). Cattle have been reported to starve to death when green *Cymbopogon* is in plenty (Harrington 1974). Buffalo will eat

C. afronardus sparingly (Field et al.1973) while elephants will accept it during the dry season (Field 1971). *C. afronardus* is unpalatable and may be regarded as an undesirable component in grazing land (Marshall et al. 1969).

Experiments with fire indicate that the species is resistant to fire, increasing with increased burning frequencies. However, burning in late August (towards the end of the dry season) every three years reduces the species prevalence while encouraging the growth of *Brachiaria decumbens*, *Themeda triandra* and *Hyparrhenia filipendula* (Harrington 1974). Manipulation of grazing pressures that kept the grass at the stable height together with an application of 120 lb of nitrogen fertilizer annually gave rise to a high increase of *Brachiaria jubata*, a more palatable species after two years (Thornton 1968). Control of *Cymbopogon* by hand hoeing was found to be the most effective treatment in small areas but was deemed impractical over large areas due to high labor costs (Thornton 1968). Thornton 1968 without indicating the types of herbicides used reported that the use of herbicides was found to be less effective as the killed aerial parts continued to regenerate from the roots while the cost of herbicides made it almost impractical. The search for a suitable herbicide to control *Cymbopogon afronardus* on the rangeland has been recently renewed and a number of new chemicals are being tested.

Forage species nutritive values, cattle diet selection and diet quality

Cattle have been found to select more nutritious diets than cut samples of the forage in the field (Bredon et al. 1967). Harrington and Pratchett (1973) reported that palatability of some forage species on the Ankole rangeland varied among seasons, being less palatable in the dry season. Dicotyledonous plants were generally avoided. They observed no relationship between palatability of the grasses and their published crude protein, crude fiber and digestibility. *Brachiaria decumbens* and *Setaria aequalis* were found to be the most desirable grasses in the system. Unfortunately *Setaria aequalis* was observed to be of limited distribution, being largely confined to heavy shade from woody plants. Other generally acceptable species were *Chloris gayana, Cynodon dactylon, Digitaria melanochilla, Hyparrhenia lintonii, Setaria sphacelata* and *Themeda triandra. Brachiaria platynota, B. brizantha, C. afronardus, Loudentia kagerensis* and *Sporobolus pyramidalis* were generally unpalatable while *Panicum maximum* and *Digitaria scalarum* were acceptable in the wet season but not in the dry season.

Dradu and Harrington (1972) investigated seasonal crude protein content of Ankole rangeland pasture at Muko Range Experimental Station using oesophageal fistulated steers. CP content of fistula extrusa (both solid and liquid) collected in different months of the year were significantly different and followed a bimodal pattern in phase with live weight of cattle and rainfall patterns. There were no differences in diet quality with time of the day of sampling and among different oesophageal fistulated steers. Marshall et al. (1969) reported in vitro dry matter digestibility of between 34.7 to 59.3% (mean 45.6 %) for clipped whole plants for various common species on the Ankole rangeland with *Brachiaria spp.* scoring highest while *Themeda triandra* and *Hyparrhenia filipendula* exhibited low digestibility. *Chloris gayana* was below average despite its importance in the dairy systems.

Stocking rates, grazing systems and animal performance

Thornton and Harrington (1971) while comparing stocking rates of 1.2 ha, 2.4 ha and 3.6 ha per Ankole steer (2 to 3 years, 300 kg) observed that 1.2 ha per steer gave significantly lower live weight gains but there was little difference between 2.4 and 3.6 ha over a 6-year period. However, the short-term financial returns on the 1.2 ha were greater by 66% and 152% over the 2.4 and 3.6 ha, respectively. Thornton and Harrington (1971) further observed that there was no difference in weight gains between a 2 paddock/1herd grazing system and continuous grazing despite the heavier investment with the former.

Harrington and Pratchett (1974a) reported on a series of stocking rate trials between 1961 and 1972 consisting of young 2-3 year Ankole longhorn steers grazed at 2.4, 1.2, 0.8 and 0.6 ha/300kg animal on *Cymbopogon/Hyparrhenia/Themeda* under continuous grazing, rotational grazing and presence or absence of *Cymbopogon*. Weight gains were higher at 0.6 ha/300 kg body weight, which was associated with an increase in *Brachiaria decumbens* in the pasture. Annual production levels were 143 kg/ha/annum for the 0.6 stocking rate, 131 kg/ha/annum for 0.8 stocking rate and 53 kg/ha/annum for the 2.4 ha/ stocking rate. Rotational grazing was less productive than continuous grazing because it promoted a rapid increase in

Cymbopogon afronardus. Removal of *Cymbopogon* increased cattle growth rates and gains/ha by over 40% at 0.6 ha/animal. However, a grazing pressure of ca. 0.8 ha/animal was expected to maximize long-term profits on *Cymbopogon* free rangeland where average gains of 0.29 kg/day/animal were achieved in a 3 year trial with no supplementation. Harrington and Thornton (1969) in earlier grazing trials concluded that heavy stocking rates resulted in a radical alteration in species composition. Harrington and Pratchett (1974b) contrasted five stocking rates (3.6, 2.4, 1.2, 0.8 and 0.6 ha/300kg steer) and supported their observations with fistula sampling. They observed a significantly lower CP and higher crude fibre (CF) on the lower stocking rates than the more heavily stocked treatments leading to the conclusion that cattle growth rates at the different stocking rates were due to differences in dry matter intake rather than observed diet quality. The high CP was attributed to an increase in *Brachiaria decumbens* both in the field and in the diet. Ankole cattle were reported to show only marginal improvements in growth rates with a ceiling of 0.5kg/day (Trail et al. 1971).

Acacia hockii and other woody species

Acacia hockii De Wild synonyms: *Acacia chariensis* A. Chev., *Acacia oerfota* Brenan, *Acacia seyal* var.multijuga, *Acacia stencarpa* sensu auctt.

Encroachment of the natural grazing areas by woody species is a recognized problem on Uganda grasslands and has been widely reported. *Acacia hockii* has been noted as being the most troublesome. Other Acacia species include *Acacia gerrardii* and *Acacia sieberiana*. Other non *Acacia* shrubs include *Capparis spp*., *Carrisa spp*., *Grewia spp., Rhus natalensis* and many others. The tendency has been for these species to coalescence to form bush motts. Sabiiti and Mugasi (1997) and Mugasi (1998) reported that shrub encroachment in neighboring pastoral rangelands of Kazo was the major factor affecting livestock production through reduction in grazable land and suppression of palatable grasses like *Brachiaria brizantha, Setaria anceps* and *Cynodon dactylon.*

Acacia hockii has been well described by Harker (1959) and Harrington (1973). The species will continue to coppice from basal meristems located below ground even when burned or cut back several times in a year, making it difficult to control. While the tall stage of the tree may be desirable because of its association with the *Brachiaria brizantha* (Harker 1959), a preferred forage species, the shorter bushy form is responsible for reduction in potential grazing area due to interlocking thorny branches that prevent grazing in close proximity to the trees. The species however is palatable to goats. The role of fire in controlling *Acacia hockii* has been documented (Harker 1959, Sabiiti 1985). While fire might have been effective in the past, the reduced fine fuels associated with higher grazing pressures reduced the effectiveness. Increased herbivory and to some extent high frequency of fires in the past have tended to reduce the fine fuel loads essential for an effective fire.

Herbicides have also been used with varying successes to control *A.*

hockii. Harker (1959) reported the use of 2,4-D, 2,4,5-T and mixtures of the two in proportions of two parts 2,4-D and one part 2,4,5-T at various concentrations diluted with water or dieseline and applied to uncut boles or cut stems using a knapsack spray or a paintbrush. Though no detailed reports of plants killed by different applications were given, the use of a paintbrush though economical on the herbicide gave low tree kills where a 3% concentration of the chemicals only had 25% tree stems killed after 6 months. The reported tree kill using a knapsack spray on cut stems was 88% kill after 6 and 12 months with a 2 % mixed chemical concentration. Harrington (1973) reported of experiments using commercial picloram formulations (Tordon 22K containing 240 g picloram a.e./l and Tordon 101 containing 65 g picloram a.e. and 240 g 2,4-D a.e./l) and 2,4,5-T + 2,4-D on cut stems of *A. hockii* during different seasons of the year. Tordon 22K at 0.4 g picloram a.e. gave 90 -100% kill at all seasons of the year except June. 2,4,5-T – 2,4-D mixture diluted at 40:1 in dieseline gave less than 50% kill at all seasons except August. Else where, goats have reportedly been used to suppress woody species (Donaldson 1979).

Cause and extent of shrub expansion

The shift from C_4 grassland and savanna ecosystems to one increasingly dominated by subtropical thorn woodland species has been observed worldwide. Carbon isotope analysis of soils, aerial photography and tree ring data suggest the change from grasses to woody rangeland cover has primarily occurred over the past 200 years in the subtropics of south Texas after introduction of

European cattle and restriction of fire regimes (Archer 1995). In Texas rangelands for example, honey mesquite (*Prosopis glandulosa*) and Juniper (*Juniperus sp.*) are the two important shrubs that have expanded over rangelands since the last century. They are now adapted to a wide range of environmental conditions and inhabit a variety of arid and semi-arid environments of south-western USA. Populations of redberry juniper (*Juniperus pinchotii*) which were previously restricted to buttes and escarpments appear to have expanded into grasslands since the 1860's (Ellis and Schuster 1968). In Africa and Uganda in particular, *Acacia* species have been the leaders in the encroachment process. Pratt et al. (1966) have classified East African rangelands indicating the extent of wooded/bushed savannas in the region. Kibet (1984), Kamau (1985) and Mnene (1985) have reported various levels of bush dominated by *Acacia senegal*, *Commiphora* sp. and other *Acacia* sp. in southern central Kenya. A number of factors that might be causing or contributing to the increase in shrub cover have been advanced. Many of these factors seem relevant to many parts of the world affected by the phenomenon. Some of the factors highlighted include:

Increase in herbivory

The increased domestic grazing is generally accepted as a driving force behind shrub invasion (Van Auken 2000, Brown and Archer 1999). Increases in domestic grazing have put unnatural stress on native grassland species, which has been exacerbated by the expansion of cropping systems into higher producing land pushing grazing pressure up on remaining rangelands. The result is a competitive imbalance between grass and woody species, especially in terms of below ground biomass growth in both vegetation types (Van Auken and Bush 1997). Increased domestic grazing is also partly responsible for increased seed dispersal for woody species (Brown and Archer 1999). The seeds have a long life with high germination rates over a wide range of temperature and moisture conditions (Glendening and Paulsen 1955, Mooney et al. 1977).

Changes in fire regimes

A change in the fire regime to less periodic fire is thought to be partially responsible for the expansion of shrubs. The removal of abundant grass biomass from the rangelands through herbivory has reduced fuel for frequent fires which were responsible for woody vegetation mortality, promoting re-colonization by grass species (Van Auken 2000). The expansion of woody species into grasslands may also be due in part to relatively recent species adaptation to fire (Van Auken 2000). Location of the buds (above or below the soil surface) affects the ability of fire treatments to kill the species. Factors that favor the burial of the bud zone such as plant size, slope, and soil surface stability will favor regeneration of the shrubs after fire treatments. Acacia hockii, one of the troublesome species on Ugandan rangelands has its buds below ground and therefore regenerates fast after a fire.

Patch coalescence and reduction of rangeland rodents and insects

Patches of woody vegetation, once established, modify the soil and microclimate that promote further colonization. Increased herbivory makes conditions favorable for woody patch expansion. Eventually, neighboring patches coalesce into larger and more stable patches (Archer 1995) such as thicketized mottes.

As regards reduction of rangeland rodent and insect communities, a good example given is the prairie dog colonies on the western USA rangeland that have disappeared. Eradicating prairie dogs was a common practice to increase livestock productivity because they competed with livestock by eating and clipping grass. Weltzin et al. (1997) showed that the presence of prairie dogs and ants commonly associated with prairie dog colonies suppressed mesquite seed and pod dispersal by eating them.

Changes in climate, drought and drought tolerance

Carbon dioxide (CO_2) has increased its atmospheric concentration since the 19th century. Carbon dioxide concentrations in the atmosphere have increased from as low as 265 ppm about 135 years ago to about 350 ppm in 1991 (Mayeux et al.1991) and currently about 372.9 ppm (Landscheidt 2003). Increased atmospheric CO_2 can give C_3 woody vegetation a boost in metabolic efficiency (Polley et al. 1994). However, while CO_2 enrichment of the atmosphere can explain acceleration of woody vegetation encroachment, it remains a background factor in light of the aggressive expansion over the recent past (Polley et al. 1994, Archer et al. 1995). Likewise, variability in precipitation remains secondary in ability to explain the rapid change in rangeland vegetation communities (Brown and Archer 1999, Weltzin and McPherson 1997).

Increasing aridity and the frequency of droughts favor shrub establishment compared to herbaceous plant growth. Shrubs utilize deep ground water via extensive taproots (Mooney et al. 1977, Thomas and Sosebee 1978, Levitt 1980) and also exhibit mechanisms of drought tolerance, responding rapidly to precipitation (Ansley et al. 1990). Many woody species have the ability to withstand high negative water potentials, have high water use efficiency and have the ability to regenerate from underground dormant buds (Glendening and Paulsen, 1955, Mooney et al 1977).

Influence of woody species on rangeland hydrological processes

Availability of water is one of the key factors that influence rangeland productivity. Justification for controlling woody species on grazing lands has been traditionally related to enhanced livestock production as a result of increased herbage production. In Texas, the control of honey mesquite has been associated with increased forage production (Scifres and Polk 1974, Dahl et al. 1978, Jacoby et al. 1982). A more recent hypothesis is that controlling woody species may result in increased off-site water yield (Griffin and McCarl 1989), mainly through increased subsurface flow. There is a well-established relationship between range vegetation and potential water yield (Hamilton and Ueckert 2000), with increases in woody cover negatively affecting stream flow and ground water recharge. There is currently an on-going debate and increased research efforts in Texas regarding the potential to increase water yield through reduction of the prevalent woody species such as honey mesquite (*Prosopis glandulosa*) and juniper (*Juniperus spp.)* on Texas rangelands. Heitschmidt and Dowhower (1991) observed that control of honey mesquite would not enhance water yields dramatically in the absence of livestock grazing that would utilize the increased herbaceous growth. Lemberg (2000) observed an increase in water yield with brush control on 35% of the land area in the Frio River Basin of Texas but the cost of brush control was more than the increase in the returns. Generally, shrubs are known to influence the hydrological cycle in a number of ways.

Woody species and interception

Interception is part of the precipitation, which does not reach the soil but is caught by vegetation cover and is evaporated back to the atmosphere. Interception therefore can substantially influence the water budget of an area. Interception losses are influenced by the vegetation type, density, form and surface texture of the plant surfaces. The denser the foliage, the greater the interception. Some tree species intercept a greater percentage of rainfall than others (Muoghalu and Johnson 2000). Conifers have been found to have higher interception rates than hardwoods to the magnitude of 30% and 13%, respectively (Thurow et al. 1987). Working with curleymesquite (*Hilaria belangeri*), a stoloniferous grass species, sideoats grama (*Bouteloua* *curtipendula*) a bunch grass and live oak (*Quercus virginiana*) trees, Thurow et al. (1987) reported interception losses of 10.8%, 18.1% and 46% for curleymesquite, sideoats grama and live oak dominated sites, respectively. Generally, increases in density and aerial coverage by woody species would seem to cause changes in community leaf area that could impact the ecosystem water balance through increased transpiration and interception of precipitation with a possible decrease in soil water.

Litter and organic matter water holding capacity are important in rangeland hydrologic assessments (Naeth et al. 1991). Litter interception has been found to be important especially in forested areas or evergreen gymnosperm stands. Litter and organic matter accumulations can reduce soil water through interception of precipitation and subsequent evaporation of the absorbed water.

Although interception might be an important water loss process, Dunne and Leopold (1978) argue that interception loss is balanced by reduced transpiration although Thorud (1967) reported that 90% of the intercepted water was evaporated from the foliage without reducing the transpiration rate and that the rate of evapotranspiration of intercepted water was on the average, about four times as great as the transpiration rate (Rutter 1967).

Woody species and evapotranspiration

In semi-arid rangelands, evapotranspiration (ET) can account for 80-95% of the water loss (Thurow 1991). Most woody plants generally have higher transpiration rates than do grasses and forbs due to larger transpiration area (leaf area), longer transpiration period (length of growing period), and deeper rooting structures that access deep soil moisture. Therefore, removal of woody plants is believed to reduce ET and result in increased water yield. Dugas and Mayeux (1991) have however concluded that the removal of mesquite from Texas rangelands for purely hydrological purposes was not justified due to a small reduction in ET (7 %) with the removal of the species. Similar observations have been reported by Richardson et al. (1979) and Weltz and Blackburn (1995). Dugas and Hicks (1998) further observed that the removal of brush did not have significant effect on ET and no consistent effect on runoff, with the removal of shrubs resulting in increased herbaceous growth with a comparable evapotranspiration rate.

Woody species, infiltration and runoff

Infiltration is the process by which water enters and moves through the soil surface to deeper soil layers. Excess water runs off when the soil surface is saturated. Soil and soil surface characteristics together with the rainfall event are important for infiltration. Shrubs and trees influence infiltration through their effects on the soil. Trees tend to accumulate litter beneath their canopies. Addition of decomposing litter / soil organic matter to the soil improves soil structure that favors infiltration. However, undecomposed litter may impede infiltration. Plant roots facilitate infiltration through formation of fractures and macropores in the soil. Studies in the bushed grassland of Kenya at Kiboko

(Cheruiyot 1984) and at Bucuma (Mbakaya 1985) indicated that vegetation foliar cover, litter cover, standing crop, litter accumulation and soil aggregate stability were the most important in influencing infiltration. Mbakaya (1985) observed higher (by 11%) infiltration rates under *Grewia bicolor* shrub than under *Chloris roxburghiana* grass but observed no significant differences in infiltration rates and sediment production under different livestock grazing systems (high intensity low frequency, rotation grazing, moderate continuous grazing and livestock exclosure).

Shading by trees causes reduced understorey growth that may create bare ground, which is easily compacted by raindrops under the trees, hence promoting runoff. Absence of trees is expected to result in increased water yield in the form of runoff due to absence of evapotranspiration and interception losses. However, vegetation generally including trees and litter creates resistance and impediment to surface runoff by friction and tends to reduce overland flow. Vegetation also improves infiltration capacity, which may exceed any precipitation rate hence reducing surface runoff. As more water is infiltrated, this may result in subsurface flow when infiltration exceeds permeability creating a saturated layer that results in lateral flow.

Soil water balance

Soil moisture relative to the holding capacity of the soil influences the rate and amount of evapotranspiration and drainage. The movement and storage of water is influenced by the nature of the soil. Trees and shrubs influence the redistribution of precipitation reaching the ground. Stem flow from precipitation may concentrate water at the base of the plant. Concentration of water at the base may be as much as seven times the amount of a precipitation event. Such concentrations of soil water may enhance movement through soils to stream channels or shallow aquifers. In forests, snow catch is least at the base of the stem. Branches carrying snow load may bend over and snow slides off and gets concentrated at the crown periphery, a phenomena common in conifers. Shrubs and trees utilize ground water via extensive taproots (Mooney et al. 1977). Through transpiration, deep and shallow water is returned to the atmosphere.

Rangeland shrub and weed management

Management of weeds and especially shrubs has been a long-standing issue in rangeland environments. Various methods have been used to control weeds and shrubs on rangelands involving mechanical, chemical, biological, prescribed fire and more recently the integrated brush management systems (Hamilton and Ueckert 2000). The level of use of the different methods has varied from country to country.

Mechanical control of shrubs

The use of mechanical means in the management of shrubs has been widely reviewed by Hamilton and Hanselka (2000), Wiedemann (2000) and Burroughs et al. (2000). The methods range from the use of simple hand tools (hoe, panga) to state of the art heavy machinery (crawler tractors) performing heavy-duty operations. Use and performance of different methods have been highlighted (Fisher et al. 1973, Herbel et al. 1958, McKenzie et al. 1984, Scifres et al. 1976). Hamilton and Hanselka (2000) have given a chronological overview of development and application of mechanical brush/shrub control practices and equipment. Grubbing (hand or power tools), blading (bulldozing), shredding, cabling/chaining, roller chopping, disking/plowing, mechanical shears, root plowing and railing/dragging control practices using different machinery have all been and most of them are still being used. The famous bulldozer is one of the earliest machines to be used but has since undergone many improvements over the years (Hamilton and Hanselka 2000). Potential limitations, advantages and disadvantages with mechanical control methods have been described (Welch 1991, Welch et al. 1985).

Chemical control of shrubs and weeds

Although herbicides have been a major tool for the management and control of weeds and brush on rangeland, McGinty (2000) noted that few, if any, new herbicides will be added to the present arsenal of range herbicides over the next 20 years. The problem is that rangeland is a small market for chemical companies to devote resources for new products and that products available today were developed for other markets first (McGinty 2000). Bovey (2000) has reviewed the history and development of herbicides used in weed and woody plant management as well as their residual activities in soil, plant and water resources while Klaassen et al. (1986) and Ware (1989), have elaborated on the toxicology and safety of the agricultural chemicals.

Herbicides commonly used for weed and brush control include foliar applied amitrole, clopyralid, 2.4-D, dicamba, dichlororprop, diquat, fosamine, glyphosate, picloram, trichlopyr, paraquat, tebuthiuron and diesel oil and kerosene (Bovey 2000). Amitrole, 2.4-D, dichlororprop, diquat, fosamine, glyphosate and paraquat enter the plant mainly through the foliage while clopyralid, dicamba, picloram and trichlopyr have both foliar and root activity. Diesel oil and kerosene enter plants primarily through foliage and stems and are also used as herbicide diluents in addition to basal pours on woody plants. Diquat and paraquat are contact herbicides applied to foliage only. Tebuthiuron is soil applied as a granule or pellet. Some of the herbicides can also be applied in mixtures for weed and brush control.

Biological control of shrubs and weeds

Biological control is defined as the deliberate use of natural enemies (such as parasites, predators and pathogens) to suppress the growth or reduce the population of their host plant (Ueckert 2000). Wapshere et al. (1989) outlines the advantages associated with biological control over other methods of weed control. Ueckert (2000) reaffirms that from ecological and environmental perspective, biological control is an ideal solution to weed and brush problems, but like all methods of control, there are advantages, limitations and specific applications. Biological control, by itself, has rarely been a total solution to any rangeland weed and brush problem and should be considered only as one component in an integrated weed or brush management system. Insects, mites, nematodes, plant pathogens and herbivores have been used as biotic agents in classical biological weed control programs. Ueckert (2000) has outlined the procedures for biological control programs, biological control candidates, successful biological weed control projects, plant diseases for biological control and biological control of weeds and brush with vertebrates. Goeden (1977), Huffaker (1957, 1959, 1964), Scifres (1980) and Quimby et al. (1991) have provided good reviews on biological control.

The role of prescribed burning in the control of shrubs and weeds

"Prescribed burning" is the methodical application of burning to achieve specified natural resource management and ecological goals (Scifres 2000). Shrub control has been the over-riding expected outcome from burning. Vallentine (1971) gives 18 purposes of burning in addition to shrub control. Due to its relatively low cost and environmental friendliness, fire is viewed as an extremely viable tool (Ansley and Tailor 2000). For the future more efficient execution of prescribed fires is anticipated, with a greater ability to manipulate fire behavior and effects, increase use of fire within integrated treatment plans, increase use of summer or dry season fires, greater understanding of when to apply and not apply fire and an increased use of fire to manage seeds and seedlings.

Global climate change and the carbon sequestration view

In contrast to removing woody species, there are organizations in parts of the world that are proposing contracts to landowners who will plant or keep vegetation on their land that will sequester carbon (Hamilton and Ueckert 2000) as a means of mediating global climate change. In some areas, woody plants may provide greater carbon sequestration than other forms of rangeland vegetation (Archer et al. 2000).

While land managers and scientists were optimistic about herbaceous and woody plant control in the 1950s to the 1980s when costs were reasonable and new herbicides and non-chemical methods were coming on line, time has proven that wholesale eradication of weeds and brush was not possible or desirable (Bovey 2001). Today land managers can use brush management to attain multiple benefits for society, including wildlife habitat management, watershed enhancement, aesthetics, and improved livestock carrying capacity (Hanselka 1997). Sculpting brush allows the landowner or manager to optimize the value of his resource for livestock, wildlife, aesthetics, recreation, water, and real estate, while providing the desired products and services (Bovey 2001).

Stocking rate and carrying capacity

One of the keys to a successful livestock operation is the proper use of pasture, whether planted or natural rangeland. To properly manage the land, the manager must know how much dry matter the land is capable of producing and the amount of forage required by the animals for the grazing period. The optimum number of animals on the pasture makes efficient use of the forage without waste but also leaves enough forage to allow quick recovery and maintain ecological integrity of the system. Stocking rate is defined as “the amount of land allocated to each animal unit for the grazable period of the year", with an animal unit (AU) making an average daily consumption of 26 lb or 12 kg on dry matter basis (Society for Range Management 1989). Carrying or grazing capacity refer to the maximum stocking rate possible year after year without causing damage to vegetation or related resources (Holechek et al. 2001). While stocking rates may vary with time due to fluctuating forage conditions, carrying capacity is considered to be the average number of animals that a particular range will sustain over time (Holechek et al. 2001).

In determining stocking rates, the level of use of the range by the grazing animal must be considered. Reports based on research findings indicate that under normal grazing, livestock will consume only 25 % of the forage produced in a year (Galt et al. 2000, Hanselka et al. 2001, Johnston et al. 1996) usually referred to as a 25% harvest efficiency. The remainder of above ground biomass senesces and is turned over into the ecosystem as litter or left on the site and trampled, ending up in the detritus food chain. Adjustment of stocking rates for distances to water and for slope is important. Non-herded cattle make little use of areas further than 3.2 km (2 miles) from water (Valentine 1947, Martin and Ward 1970, 1973). Holechek (1988) suggests percent reductions in cattle grazing capacity of none, 50 and 100% associated with distance from water of 0-1.6, 1.6-3.2 and over 3.2 km, respectively. In herded grazing systems where cattle movement is directed by the herder, adjustment for water may not be justified. Sheep and goats can use areas that are more than 3.2 km from water (McDaniel and Tiedeman 1981). Areas on steep slopes of over 60% receive little or no use by cattle (Mueggler 1965, Cook 1966) and should therefore not be part of grazable area. Holechek (1988) suggests that percent reduction in grazing capacity of none, 30, 60 and 100% should be effected for percent slopes of 0-10, 11-30, 31-60 and over 60%, respectively. Sheep and goats make better use of ragged terrain (Holechek 2001).

Body condition scoring as a useful range livestock management tool

Body condition scoring is a valuable tool in the management of beef cattle nutrition (Lyons and Machen 2000). For those doing research, body condition scoring provides a quick, cheap and easy method of comparing herds of cattle or individual animals under different management systems, experimental treatments, seasons or environments (Nicholson and Butterworth 1986). Body condition scoring is an estimation of the relative fatness or body composition of cows and reflects the past nutritional history of the animal. There are many different systems for body condition scoring. The most commonly used is the 1-9 system (Nicholson and Butterworth 1986). Scores range from 1, for a very thin body condition, to 9, indicating extreme fatness. A cow that is average- neither thin nor fat – would have a score of 5. The 1-3 and 1-5 condition scoring systems are also in use. The 1-5 system is more common in dairy cattle condition scoring.

Lyons and Machen (2000) and Nicholson and Butterworth (1986) indicate that as an evaluation tool, body condition scoring offers several advantages over weighing animals or use of heart girth measurements. Body condition score does not require scales that have been found to be expensive and cumbersome. Even then, weights never reflect the condition of the animal since weight can be affected by digestive tract fill (digesta + water), defecation and urination. Restraining of animals for weighing or heart girth measurement is not a simple task, especially if many animals of varied temperament are involved. Generally weight is a poor indicator of condition. A small frame fleshy cow and a large frame, thin cow may weigh the same but differ greatly in body condition (Lyons and Machen 2000). If a frame index of the animal, which is a reflection of the height and weight relationships, is known, body condition score (BCS) can be used to compute the weight of the animal if the age and the sex of the animal are known, otherwise the heart girth and hip height are the best indicators of weight. The most sensitive time to condition score animals in relation to reproductive performance is at calving, followed by scoring at breeding (Stuth and Maraschin 2000). While body condition scoring has been criticized for being a subjective assessment, the prerequisite for accurate body condition scoring is only practice (Croxton and Stollard 1976).

Biophysical modeling and the PHYGROW model

Increased understanding of ecological systems physical processes and the ability to relate these processes through computer simulation modeling is an important breakthrough for environmental resource management. Further breakthroughs in geographical information systems (GIS) and satellite imagery technologies have contributed to a more understanding and management of natural resources.

Joyce and Kickert (1987) have observed 6 different categories of models used for grazing lands. These are (1) empirical models with simple expressions used to predict forage production as a function of one or two environmental factors; (2) use of agronomic models; (3) hydrologic models detailing soil water dynamics acting on aboveground biomass as a group; (4) models that focus on aboveground production; (5) models that combine plant growth and livestock production; and (6) models that highlight the dynamics of plant species interactions over time on grazing lands. The PHYGROW used in this research program incorporates all the six categories at some point in the landscape - scale modeling of rangeland ecosystems (Ranching Systems Group 1995).

A number of models with relevance to rangelands have been developed in recent times. These include SPUR (Simulation of production and utilization of rangelands) (Wight and Skiles 2000) composed of climate, hydrology, plant, animal (domestic and wildlife, and economic components and is oriented towards rangeland management and research; ERHYM (Ekalaka rangeland hydrology and yield model) (Wight and Neff 1983) a climate, water balance model initially developed to predict runoff and herbage production; ELM (Innis 1978) developed to simulate biomass dynamics and responses to management for a variety of grassland types; EDYS (ecological dynamics simulation) developed by US Army corps of engineers and MWH is designed to mechanistically simulate complex ecological dynamics across varying spatial scales; EPIC (erosion productivity impact calculator) (Williams et al. 1984), a mathematical model developed to determine the relationship between soil erosion and soil productivity; SPAW (soil-plant-air-water model) (Saxton et al. 1974) estimates daily soil water on cultivated cropland; SAVANNA model (Coughenour 1992), a spatial model for grassland, shrub land and forested ecosystems, with hydrologic, plant production, animal and population sub-models.

PHYGROW (phytomass growth simulator) model (Ranching Systems Group 1995), which is a hydrologic based biophysical model with plant growth attributes, grazing animal attributes, soil attributes and weather data as primary components is used to simulate daily forage growth under grazing. Lee (1999) integrated PHYGROW with an economic model FLIPSIM to study the economic impact of brush on ranches while Lemberg (2000) has used PHYGROW integrated with hydrologic and economic models to analyze the viability of brush control for water yield in the Frio River basin. Schumann (1999) used PHYGROW in the analysis of cost effectiveness of long-term brush management systems for the Welder Wildlife Refuge, a cattle and wildlife ranch in South Texas. In East Africa, PHYGROW has been used since 1999 to predict forage production for Livestock Early Warning Systems in pastoral areas (LEWS 1999).

CHAPTER III

PASTORAL SYSTEMS OF SOUTH-WESTERN UGANDA: SPECIES ABUNDANCE AND DISTRIBUTION

Introduction

One of the basic requirements for good rangeland management is the knowledge of the plant communities on the land relative to the ecological sites they occupy. Plant communities reflect on the grazing potential in terms of both quantity and quality of desirable species, which is directly linked to carrying capacity of the range. Monitoring of plant communities supports the determination of range condition and trend.

There are no studies in literature that have provided a broad scale characterization of plant communities along the toposequence of the Ankole pastoral system of south-western Uganda. The few studies reported on species characterization in the system have been on a small scale, usually covering a few paddocks on a hillside as part of or prior to a grazing trial and were mainly carried out on an experimental station. Harrington and Thornton (1969) carried out species botanical composition on a hillside on one-acre (0.4 ha) paddocks used in a study on the management of *Cymbopogon afronardus* using controlled grazing and manual hoeing. Harrington and Pratchett (1973) carried out a botanical analysis at the former Muko Range Experimental Station as part of a study to evaluate cattle diet on Ankole rangeland at different seasons. Similarly

Harrington and Pratchett (1974a) reported of botanical analysis in a set of paddocks used for stocking rate trials. More recently the Livestock Early Warning Systems (LEWS) project (LEWS 1999) carried out species basal and canopy cover determinations on some households in the system but without topographical considerations.

This study was undertaken to determine species abundance and distribution in the land use system. As a follow up to this study, a hydrologically driven biophysical model (PHYGROW) was used to explore relationships and productivity of plant components in these vegetation types. Hence the methodology used in the determination of species abundance and distribution was in a form usable by the PHYGROW model, as presented in the methodology section of this chapter. This chapter seeks to use these attributes to contrast differences in plant community across the farms and toposequences.

Objectives

- To determine plant species abundance in the land use system.
- To determine how toposequence influences encroachment patterns of *Cymbopogon afronardus* and woody species.
- To evaluate factors associated with the observed species abundance and distribution on the different farms.
- To relate current to past observations and evaluate species prevalence and distribution dynamics.

- To evaluate the plant species contribution to forage biomass production and herbivory (discussed in Chapters 1V and V).

Methodology

The study was undertaken on the 15 farms / ranches described in Chapter 1. Plant species characterization to establish types and distribution on the landscape was carried out on each farm by ecosite along a toposequence i.e. hilltop, slope and valley bottom positions. Grasses, forbs/herbs and woody shrubs and trees were characterized for basal cover, frequency and effective canopy cover, respectively. A 500-m transect was established on each ecosite and a 100-m tape laid end to end to cover the 500m to maintain direction of the transect and for accurate determination of the 5m interval sampling points. At every 5m along the transect, a 5-station sampling frame (Figure 3.1a and 3b) (Jama et al 2002) was laid perpendicular to the measuring tape. Each station of the sampling frame consisted of a 5x5 cm sub-frame with a metallic pointer in the center. The five sub-frames along the sampling frame are each separated by a 12.5-cm buffer zone.

The grass species was recorded if the central pointer of the sub-frame touched the base of the grass plant or the rooting point of a stolon for stoloniferous species. The presence of different forb species within each of the 5x5 cm sub-frames was also recorded for computation of forb percent frequencies. Effective canopy cover for trees and shrubs was measured using a small mirror with a marked central point and placed above each of the sub-frames (Figures 3c and 3d). If the point on the mirror was covered by wood or leaf material preventing light from passing through, a ‘hit’ for canopy cover for the species was recorded otherwise no hit.

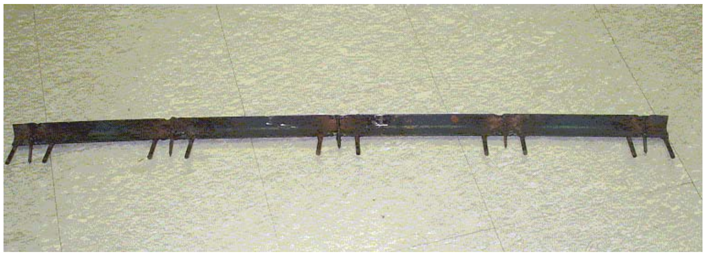

Figure 3.1a. PHYGROW sampling frame

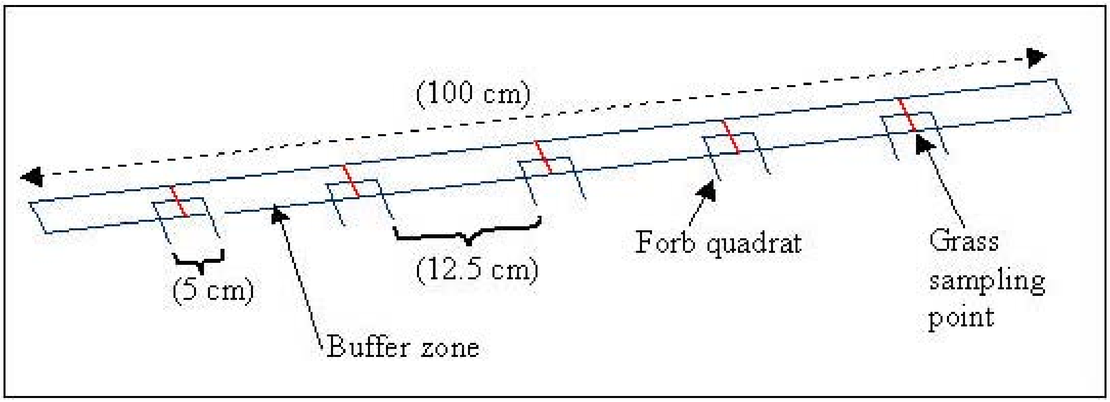

Figure 3.1b. Details of the PHYGROW sampling frame

Figure 3c. Mirror with a dot reflecting tree canopy

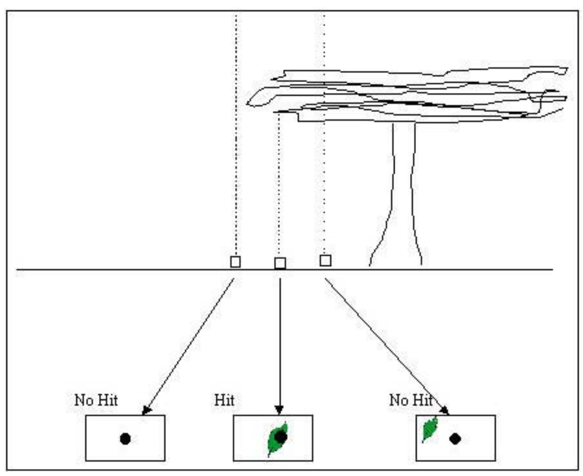

Figure 3d. Determining woody species effective cover based on mirror reflections

Field generated data was entered into Microsoft Excel (Microsoft Corporation, Redmond, WA) and analyzed using Statistical Analysis Systems (SAS) version 8.1 (SAS Institute Inc., Cary, NC). The SAS PROC FREQ procedure was used to generate percent frequencies of “hits” or occupancy for forbs, grasses and woody species while PROC GLM was used to determine differences in species distribution among the farms.

Detrended Correspondence Analysis (DCA: Hill and Gauch 1980) was conducted using PC-ORD Version 4.20 software with the program DECORANA based on default options to ordinate observed grass and woody species with the 15 farms used for the study with the aim of identifying species associations on the farms to facilitate identification and grouping of farms with common species. DCA is an eigenvector method which ordinates species and their sites and is considered one of the most powerful multivariate tools for analyzing community species with unimodal distributions along an environmental gradient (Hill and Gauch 1980, Kent and Ballard 1988). DCA is an indirect gradient analysis that extracts the dominant compositional gradients from a site by a species matrix and based upon species abundances, produces standardized axes that are actual ecological distances and not forced to be equal in length (Hill 1979, Hill and Gauch 1980, Fuhlendorf 1996). Indirect gradient analysis relies on correlation analysis to infer relationships with environmental variables that because of difficulty in measurement are less accurate than the underlying relationship with the ordination (Jongman et al. 1987, Fuhlendorf 1996).

Six rare species with a mean basal / canopy cover of less than 1.5 percent were eliminated from the species list prior to the ordination to remove their possible stochastic influence on the analysis (Hill and Gauch 1980, Fuhlendorf and Smeins 1997, McCune and Grace 2002). The woody species omitted were *Combretum molle, Euphorbia candelabrum, Hoslundia opposita, Lantana camara and Maytenus heterophylla* while *Digitaria thouarisiana* was the only grass species omitted. The woody species used in the analysis in order of their prevalence were *Acacia gerrardii, Acacia hockii, Grewia mollis, Rhus natalensis, Capparis erythrocarpos, Capparis spp, Dichrostachys cinerea, Carissa edulis, Ocimum suave, Flueggea virosa* and *Acacia sieberiana.* The grass species used in the analysis in order of their prevalence were *Brachiaria spp, Sporobolus pyramidalis, Hyparrhenia spp., Cymbopogon afronardus, Loudentia kagerensis, Panicum maximum, Cynodon dactylon, Setaria spp, Digitaria scalarum, Setaria homonyma, Chloris gayana Andropogon schirensis, Eragrostis tenuifolia, Themeda triandra and Brachiaria platynota.*

After ordination, attempts were made to identify potential driving forces to observed species ordinations. Correlation analysis based on Spearman’s rank correlations between DCA derived farm scores for different ordination axes and ranked scores of potential driving factors influencing species abundance and distribution on the different farms were performed to evaluate the factors influence.

Results

A combined total of 77 different plant species or species categories were identified on the 15 experimental farms. All the farms with the exception of one (KAK-01) did not differ significantly in terms of total cover by grasses, woody species and forbs. The overall mean percent coverage by the species on the farms ranged from 3.34 to 7.10. Species mean coverage on hilltops, slopes and valley bottoms was not significantly different in terms of mean percent basal and canopy coverage of 4.14, 3.91 and 4.36, respectively. Ecosite did not have any influence on the general coverage of grasses, trees and forbs combined. Similarly, the habit of the plants (grass, tree or forb) did not significantly influence the mean coverage of the plants on the farms. Individual plant species showed highly significant differences ($P<0.0001$) in their coverage on the farms. *Kyllinga alba* (forb), *Brachiaria spp*. (grass) and *Acacia gerrardii* and *Acacia hockii* trees were the most prevalent species in the three plant categories.

Grasses prevalence

Sixteen (16) grass species were observed on the landscape on the 15 farms (Table 3.1). Mean percent coverage (for hilltop, slope and valley) by individual grass species was computed for each farm to derive total percent basal coverage for grasses on each farm (Table 3.1). Total basal grass cover on the farms ranged from 29.9% (RAN-13) to 63.9% (RAN-05). Based on these results, the mean percent basal cover for grasses on the farms was 39.2 %. Although the differences in total grass basal cover on the farms were not significantly different, “improved” farms (those that had undesirable plant communities removed) had higher basal cover (> 50%) coverage than unimproved farms. Basal cover for individual grass species on the farms was significantly different ($P<0.0001$) (Table 3.1).

Table 3.1: Mean grass species percent basal cover on the 15 experimental farms across ecosites

FARM SPECIES***	BAG01	KAK01	KAP01	KEI01	NAH01	RAN01	RAN04	RAN05
Andropogon schirensis	0.2	2.1	0.3	-	-	-	0.7	1.8
Brachiaria platynota	-	0.6	0.4	0.6	-	1.4	-	-
Brachiaria spp.	12.8	18.3	13.1	8.8	4.3	14.0	7.9	13.3
Chloris gayana	1.6	1.2	0.2	0.6	-	0.4	0.2	0.6
Cymbopogon afronardus	0.4	0.2	0.2	0.2	9.9	0.2	14.3	2.7
Cynodon dactylon	0.9	2.2	2.1	0.7	1.0	0.6	0.9	3.8
Digitaria scalarum	0.8	-	-	3.4	-	0.2	0.4	6.3
Digitaria thouarisiana	-	-	-	-	-	-	2.0	-
Eragrostis tenuifolia	-	-	-	1.1	0.4	0.8	-	-
Hyparrhenia spp.	7.6	11.4	14.1	0.9	13.9	1.1	5.3	2.6
Loudentia kagerensis	4.9	9.1	8.1	4.4	-	0.2	2.8	0.6
Panicum maximum	2.6	0.2	0.6	1.5	0.5	7.9	0.4	7.0
Setaria homonyma	-	-	0.2	1.0	-	1.2	0.8	1.0
Setaria sphacelata	4.4	0.5	5.7	4.4	-	-	2.7	1.0
Sporobolus pyramidalis	14.1	7.1	5.7	10.6	0.7	8.9	8.1	17.8
Themeda triandra	0.2	-	0.3	-	-	-	0.2	5.4
Total mean cover % - ns	50.5	52.9	51	38.2	30.7	36.9	46.7	63.9

*** Significant differences (P<0.0001); ns = Not significantly different

Table 3.1: Continued

FARM SPECIES***	RAN08	RAN13	RAN14	RAN15	RAN20	RAN26	RWE01	MEAN
Andropogon schirensis	0.4	-	0.6	1.2	-	-	0.2	0.32
Brachiaria platynota	0.2	-	-	-	-	0.4	-	0.08
Brachiaria spp.	14.1	11.7	16.4	19.3	16.5	9.3	15.9	13.16
Chloris gayana	1.4	-	-	-	0.4	-	1.0	0.35
Cymbopogon afronardus	9.6	5.2	7.6	0.2	3.6	10.0	0.2	4.03
Cynodon dactylon	0.9	0.6	0.6	5.4	1.2	1.3	1.0	1.12
Digitaria scalarum	0.4	0.7	1.0	0.2	-	0.7	0.3	0.73
Digitaria thouarisiana	-	-	-	-	-	1.6	-	0.08
Eragrostis tenuifolia	0.8	0.2	-	-	-	1.6	-	0.17
Hyparrhenia spp.	10.3	0.4	0.3	0.8	2.6	3.0	2.3	4.82
Loudentia kagerensis	2.8	1.8	2.5	0.4	0.2	3.7	2.7	2.56
Panicum maximum	0.2	3.5	0.9	0.2	3.0	1.9	4.1	2.25
Setaria homonyma	-	2.0	0.6	1.0	-	0.6	1.0	0.36
Setaria sphacelata	1.7	-	1.0	-	-	0.5	1.6	1.02
Sporobolus pyramidalis	4.2	3.8	2.8	4.3	5.0	8.0	15.5	7.98
Themeda triandra	0.2	-	-	-	-	-	-	0.15
Total basal cover % - ns	47.2	29.9	34.3	33.0	32.5	42.6	45.8	39.2

*** Significant differences (P<0.0001);   ns = Not significantly different

The percent basal cover by ecosite for each individual grass species was calculated against the total cover of all the grass species on the different farms to estimate the percentage coverage of the individual species. The individual grass species relative percent basal cover as a percentage of the total basal cover for the grasses on each ecosite is given in Table 3.2. There were significant differences ($P<0.0001$) in basal cover for the different species on the landscape. There were no significant differences in species prevalence attributable to ecosite. *Brachiaria spp*. were the most prevalent accounting for 33.57% of basal cover of all the grasses on the landscape. The other important species in terms of prevalence were *Sporobolus pyramidalis* (20.35%), *Hyparrhenia spp.* (12.29%), *Cymbopogon afronardus* (10.29%), *Loudentia kagerensis* (6.53%) and *Panicum maximum* (5.75%). *Cymbopogon afronardus* is one of the species that is most undesirable in the study area. Visual observation in the land use tends to draw closer prevalence relationships between *Brachiaria spp.* and *Acacia spp*. These results indicated a high correlation coefficient ($r = 0.82$) between *Brachiaria spp*. cover and total woody species but this was reduced to a correlation coefficient of $r = 0.50$ when associated with only *Acacia* spp. There was also a high correlation coefficient

Table 3.2. Grass species, their prevalence and distribution by ecosite.

Species***	Relative basal cover (%) by ecosite Hilltop	Slope	Valley	Mean
Brachiaria spp.	37.45	38.01	24.90	33.57 [a]
Sporobolus pyramidalis	15.07	13.14	33.38	20.35 [b]
Hyparrhenia spp.	11.27	13.54	12.03	12.29 [c]
Cymbopogon afronardus	14.11	13.02	3.47	10.29 [cd]
Loudentia kagerensis	7.03	7.58	4.90	6.53 [cde]
Panicum maximum	6.64	8.88	1.54	5.75 [dce]
Cynodon dactylon	2.91	1.36	4.39	2.86 [de]
Setaria sphacelata	0.32	0.73	6.95	2.61 [e]
Digitaria scalarum	2.48	1.25	1.90	1.87 [e]
Setaria homonyma	0.53	0.49	1.79	0.93 [e]
Chloris gayana	0.46	0.63	1.61	0.89 [e]
Andropogon schirensis	0.82	0.73	0.88	0.81 [e]
Eragrostis tenuifolia	0.62	0.19	0.51	0.44 [e]
Themeda triandra	0.11	0.07	1.02	0.40 [e]
Brachiaria platynota	0.18	0.10	0.37	0.21 [e]
Digitaria thouarisiana	0.00	0.28	0.37	0.21 [e]
TOTAL	100.00	100.00	100.00	100.00

*** P<0.0001. Means with the same letter in a column are not significantly different.

(r = 0.88) between *Cymbopogon afronardus* and woody species. A correlation coefficient matrix for the prominent species is given in Appendix A.

The leading most prevalent species were further evaluated to determine how they differed individually on the different farms and ecosites. The species were *Brachiaria spp., Sporobolus pyramidalis, Cymbopogon afronardus, Hyparrhenia spp., Loudentia kagerensis* and *Panicum maximum* (Table 3.3). A significant reduction in prevalence of both *Brachiaria spp* and *Cymbopogon afronardus* occurred in the valleys compared to the hilltops and slopes. *Sporobolus pyramidalis* was overwhelmingly more prevalent in the valleys compared to the hilltops and slopes. All the six species showed significant farm-to-farm differences as well as significant ecosite differences with the exception of *Hyparrhenia spp.* and *Loudentia kagerensis* that tended to show a more even distribution on all the farms and ecosites.

Table 3.3. Farm and ecosite mean basal cover differences of the six most prevalent grass species.

			Ecosite		
Species	Farm means	Ecosite means	Hilltop	Slope	Valley
Brachiaria spp.	P=0.0014	P=0.0034	14.07^{a}	14.58^{a}	10.48^{b}
Sporobolus pyramidalis	P=0.0004	P<0.0001	5.66^{b}	5.04^{b}	14.06^{a}
Hyparrhenia spp.	P<0.0001	NS	4.23	5.19	5.06
Cymbopogon afronardus	P=0.0008	P=0.06	5.30^{a}	4.99^{a}	1.66^{b}
Loudentia kagerensis	P=0.0002	NS	2.64	2.91	2.51
Panicum maximum	P=0.0099	P=0.0204	2.49^{ab}	3.41^{a}	0.65^{b}

Means with the same letter in a row are not significantly different. NS = Not significantly different

Trees and shrubs prevalence

Twenty-seven (27) different woody species were encountered on the transects. The different species and the percent effective canopy cover of each species as a percentage of the total effective canopy cover of all the species by ecosite are presented in Table 3.4. *Acacia gerrardii* (34.37 %) and *Acacia hockii* (33.66 %) were the most prevalent tree species on the landscape. There were significant differences (P=0.017) in the prevalence of the different tree species on the farms. No ecosite differences were observed.

Percent effective canopy cover of woody species on each farm and ecosite is presented in Table 3.5. The woody species effective cover on the farms ranged from 0.25 % (NAH-01) to 21.47 % (RAN-14) implying that some of the farms had little woody species on the landscape. There were significant differences between farms (P<0.001) in tree species effective canopy cover but no ecosite differences were observed. Management efforts by some farmers had reduced the prevalence of woody species on such farms. Management efforts were usually aimed at controlling both woody species and *Cymbopogon afronardus.* Of the two undesirable plant communities, only two farms (RAN-14, RAN-26) could be referred to as having high levels of both *Cymbopogon afronardus* and woody species.

Table 3.4. Woody species percent effective canopy cover by ecosite

	Relative effective canopy cover (%) by ecosite (NS)			
Species**	Hilltop	Slope	Valley	Mean
Acacia gerrardii	30.10	24.52	48.49	34.37
Acacia hockii	42.08	38.85	20.06	33.66
Acacia senegal	0.14	0	0	0.05
Acacia sieberiana	0.57	2.30	4.62	2.50
Asparagus flagellaris	0	0.15	0	0.05
Carissa edulis	1.00	0.92	2.71	1.27
Capparis erythrocarpos	3.28	3.52	5.89	4.23
Combretum molle	1.14	0	0	0.38
Capparis edulis	4.42	2.61	2.07	3.03
Dichrostachys cinerea	1.85	5.36	1.27	2.83
Dissotis trothae	0	0.46	0	0.15
Euphorbia candelabrum	0	0.61	0.64	0.42
Flueggea virosa	1.28	0.92	3.50	1.90
Grewia mollis	5.14	7.36	3.18	5.23
Hoslundia opposita	0.43	0.77	0.16	0.45
Lantana camara	1.14	1.38	0.32	0.95
Maytenus heterophylla	0.29	0.15	0	0.15
Ximenia americana	0	0.77	0	0.26
Ocimum suave	2.14	1.99	0.32	1.48
Canarium schweinfurthii	0.29	0	0	0.10
Entada abyssinica	0	0	1.59	0.53
Techlea nobilis	0.57	0	0	0.19
Phytolacca dodecandra	0	0.31	0	0.10
Rhus natalensis	3.42	6.13	5.57	5.04
Sida cuneifolia	0.14	0	0	0.05
Sena didymobotrya	0	0.31	0	0.10
Solanum incanum	0.57	0.61	0	0.39
	100.00	100.00	100.00	99.86

** P=0.0168. NS= Not significant

Table 3.5. Woody species effective canopy cover (%) by farm and ecosite

Farm	Effective canopy cover (%) by ecosite (NS)			
	Hilltop	Slope	Valley	Mean (**)
BAG-01	2.4	3.8	13.2	6.47
KAK-01	0	2.0	0	0.70
KAP-01	0	0	0.8	0.27
KEI-01	25.8	22.0	5.6	17.80
NAH-01	0	0.5	-	0.25
RAN-01	16.2	18.4	18.4	17.67
RAN-04	6.4	2.6	0	3.00
RAN-05	10.8	15.0	5.0	10.27
RAN-08	5.2	8.0	0.8	4.67
RAN-13	3.4	12.0	19.2	11.53
RAN-14	24.6	13.6	26.2	21.47
RAN-15	10.2	8.0	14.4	10.87
RAN-20	7.0	10.0	-	8.50
RAN-26	20.2	5.6	6.4	10.73
RWE-01	8.0	9.0	15.8	10.93

**P = 0.001)		NS = Not significant

Forbs / herbs prevalence

There were many forbs on the landscape. Forbs frequency in a 5x5 cm frame by farm and ecosite is given in Table 3.6. Mean forbs frequency of between 24.13 % (RAN-05) and 45.67 % (KAK-01) was observed on the farms. The differences in forbs frequencies by farm and ecosite were not significant. A list of the forbs and herbs observed on the farms is presented in Table 3.7. *Kyllinga alba*, a small Cyperaceae forb of no significant importance to range condition, was ubiquitous in distribution, growing almost everywhere between and underneath other vegetation and was therefore the most prevalent (67.67 %), and was the only species responsible for significant differences ($P<0.0001$) in forbs frequencies on the different farms and ecosites. Categories of annual forbs and leguminous forbs were created due to difficulties in identification of many of the small forbs species. Separation of forbs components into leguminous and non-leguminous revealed a low proportion of the legume component in the system of only 6.29%. *Neonotonia wightii* was the most prevalent among the leguminous herbs.

Table 3.6. Forbs frequency by farm and ecosite

Farm	Forb frequency (%) (NS) Hilltop	Slope	Valley	Mean (NS)
BAG-01	27.0	33.0	15.6	25.33
KAK-01	47.6	45.8	43.6	45.67
KAP-01	30.2	33.0	33.2	32.13
KEI-01	38.2	36.4	26.6	33.73
NAH-01	30.9	16.5	-	23.70
RAN-01	39.8	30.2	30.6	33.53
RAN-04	38.4	33.8	51.3	41.17
RAN-05	25.2	35.2	12.0	24.13
RAN-08	17.4	23.2	59.4	33.33
RAN-13	45.9	32.4	24.0	34.10
RAN-14	29.2	25.4	21.2	25.27
RAN-15	58.6	44.0	60.0	54.20
RAN-20	25.6	31.4	-	28.50
RAN-26	25.4	35.2	40.6	33.73
RWE-01	41.8	36.2	20.8	32.93

NS = Not significantly different

Table 3.7. Forbs and their percent frequency on sampled farms

Species	Frequency (%)
Aloe volkensii	0.04
Asparagus flagellaris (seedlings)	0.01
Cyphostemma adenocaule	0.03
Centella asiatica	0.10
Cyperus cyperoides	0.15
Cassia hildebrandtii	0.03
Centrosema pubescens	0.01
Clitoria ternatea	0.01
Commelina benghalensis	3.93
Crotalaria aculeate	0.01
Datura stramonium	0.38
Dissotis trothae	0.03
Desmodium tortuosum	0.06
Dolichos sp.	0.09
Eriosema laurentii	0.06
Galinsonga parviflora	0.02
Hoslundia opposita (seedlings)	0.18
Hypoestes verticillaris	0.33
Indigofera spp.	0.48
Kyllinga alba	67.97
Laggera alata	0.02
Leguminous forbs	4.61
Monechma subsessile	2.43
Neonotonia wightii	0.72
Solanum nigrum	0.03
Oxalis corniculata	0.69
Pentas zanzibarica	0.03
Portulaca quadrifida	0.01
Ruellia patula	0.07
Solanum incanum	0.16
Scenecio vulgaris	0.10
Macroptilium artropurpureum	0.07
Stylosanthes spp.	0.06
Triumfetta rhomboidea	0.11
Wynn cassia	0.08
Other annual forbs	16.88
	100.00

Results of Detrended Correspondence Analysis (DCA)

The farms and species percent basal and canopy cover matrix as used in ordination is presented in Appendix B. DCA ordination presented 3 axes from the 26 species offered. DCA analysis showed successful ordinations of the plant species, farms and species / farm combinations as showed in the ordination overlays (Figures 3.2, 3.3 and 3.4, respectively). Species clearly separated themselves along some driving variable with woody species being segregated on the upper left side of axis 1 and the grasses on the right and lower side of axis 1 (Figure 3.2). Separation of the farms followed the species trend where farms with many woody species segregated themselves on the left side and those with grasses on the right side of axis 1 (Figure 3.3). Farms high in *C. afronardus* appeared on the extreme upper side of axis 1. Ordination of farm ecosites showed no clear pattern of separation of hilltop and slope positions while most valleys tended to separate out on the lower side of Axis 1 (Appendix C). This agrees with an earlier observation that ecosite positions did not significantly influence species distributions on the landscape. Ordination results of the species along the different axes indicated that Axes 1 and 2 of the DCA ordination accounted for 48.07 % of the species data (Table 3.8). McCune and Grace (2002) report that investigators are often pleased to explain more than 50% of the variation with two axes, though perfectly useful and interpretable ordinations commonly have 30-50% of the variation represented in two axes.

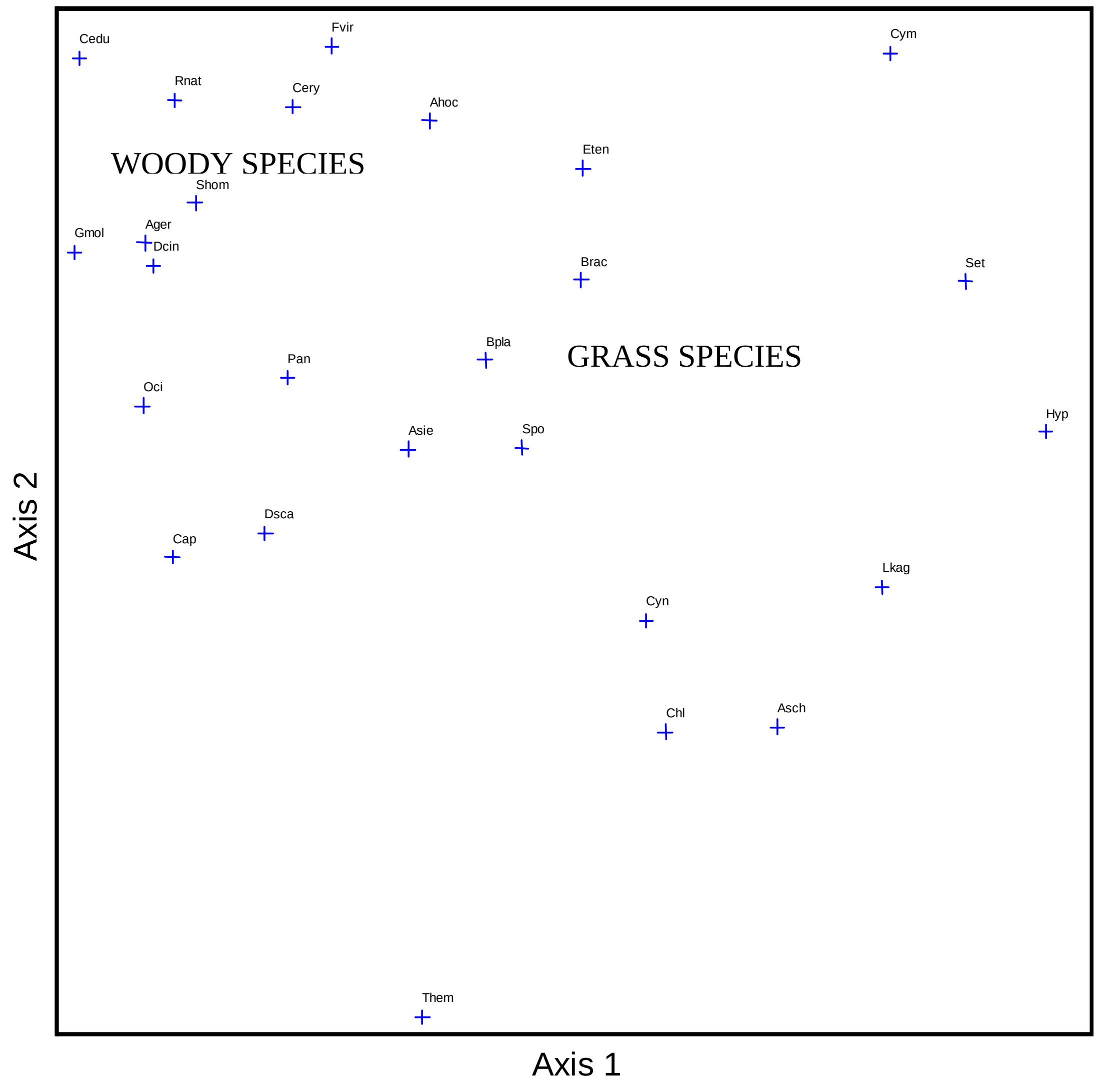

Figure 3.2. DCA overlay of plant species ordination on farms.

The different species are represented as:

Woody species
Ager - *Acacia gerrardii*
Ahoc - *Acacia hockii*
Asie - *Acacia sieberiana*
Cedu - *Carissa edulis*
Cery - *Capparis erythrocarpos*
Cap - *Capparis spp*
Dcin - *Dichrostachys cinerea*
Fvir - *Flueggea virosa*
Gmol- *Grewia mollis*
Oci - *Ocimum suave*
Rnat- *Rhus natalensis*

Grass species
Asch - *Andropogon schirensis*
Bpla - *Brachiaria platynota*
Brac - *Brachiaria spp.*
Chl - *Chloris gayana*
Cym - *Cymbopogon afronardus*
Cyn - *Cynodon dactylon*
Dsca- *Digitaria scalarum*Set
Eten - *Eragrostis tenuifolia*
Hyp - *Hyparrhenia spp*
Lkag - *Loudentia kagerensis*
Pan - *Panicum maximum*
Shom- *Setaria homonyma*
Set - *Setaria spp.*
Spo - *Sporobolus pyramidalis*
Them- *Themeda triandra*

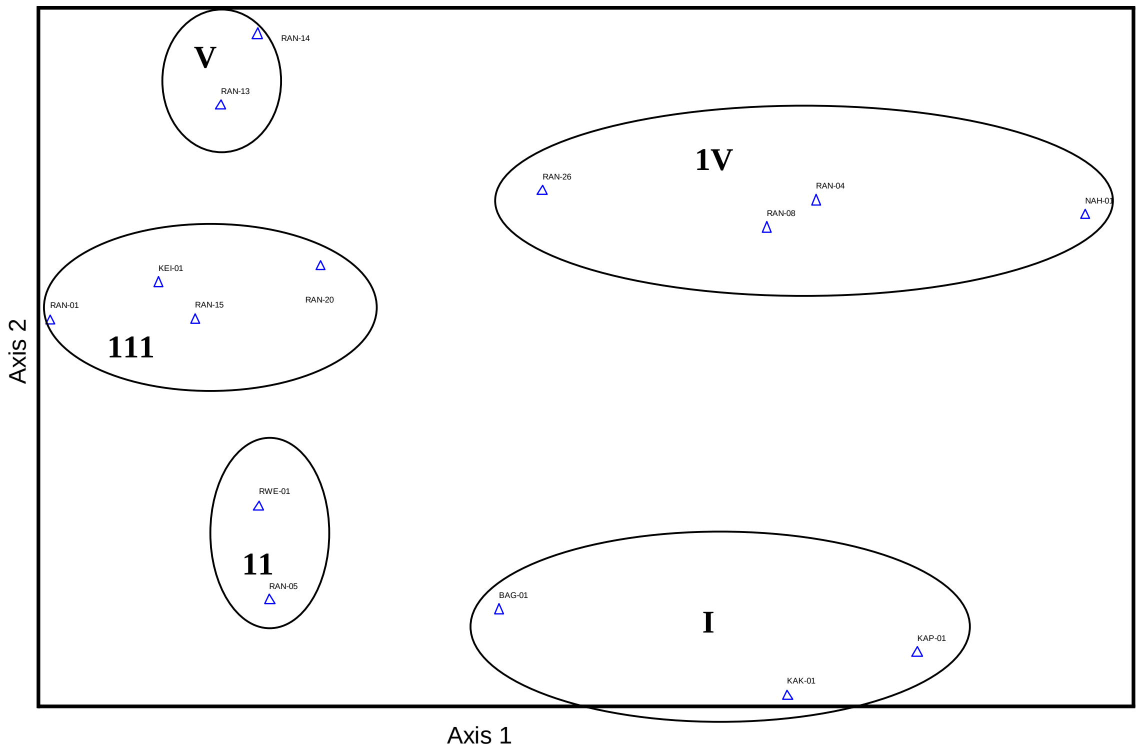

Figure 3.3: DCA overlay of farms ordination and farm groups based on plant species on the farms (triangles represent the different farms).

Farm group characteristics:
I - Herbaceous species dominated farms ('improved' farms)
II - Herbaceous species dominated but with a moderate woody component
III - Woody species dominated farms with minimal or no *Cymbopogon*.
IV - *Cymbopogon* dominated farms with minimal or no woody species
V - High *Cymbopogon* and high woody components farms

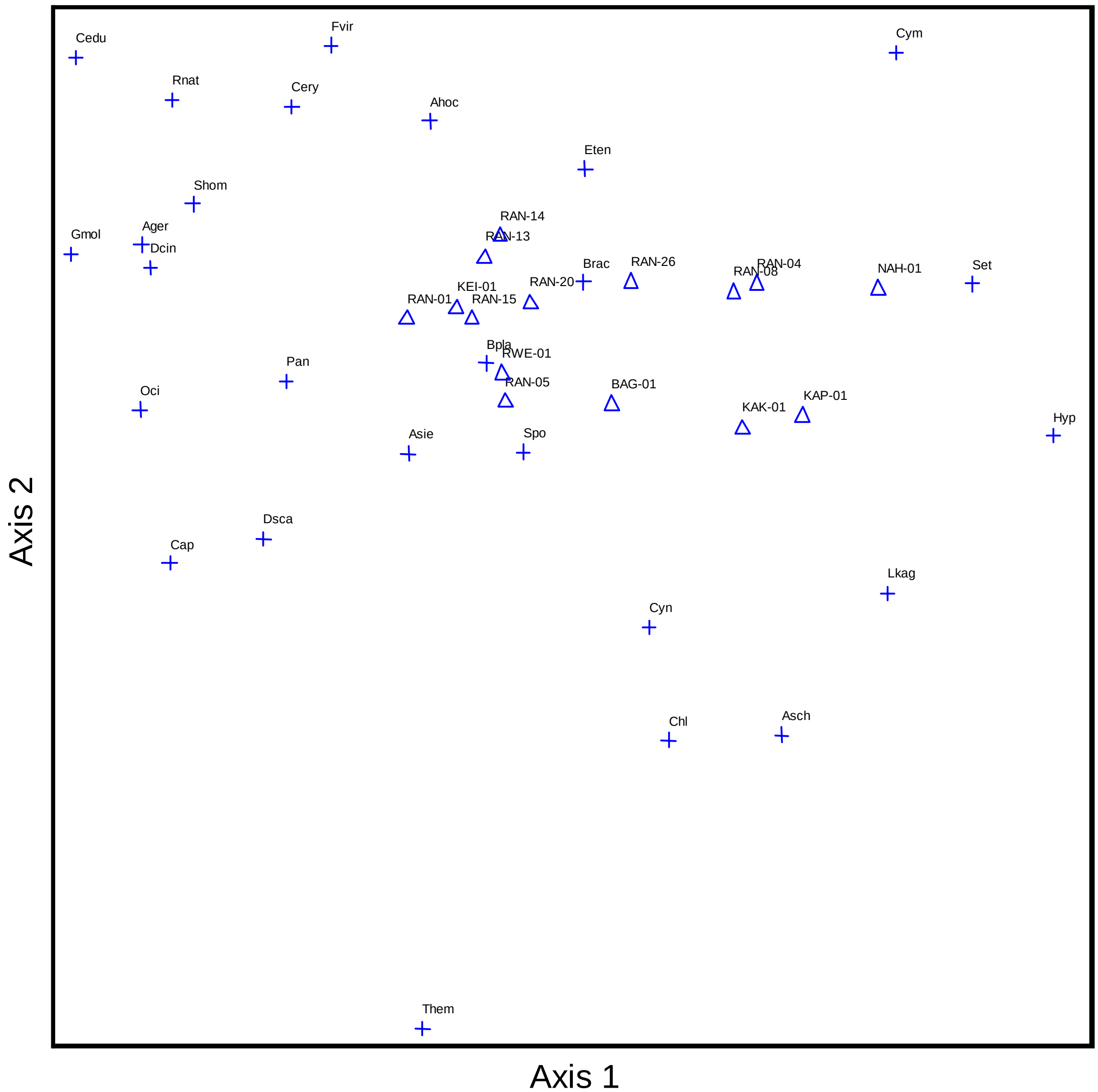

Figure 3.4: DCA overlay of farms and plant species ordination (triangles represent farms and crosses represent species).

Correlation coefficients of species with different ordination axes showed that most of the woody species were negatively correlated with Axis 1 (Appendix D).

Analysis of species ordination driving variables

Based on prior knowledge of the land use system and the farms, seven variables were evaluated to determine their potential role in influencing the observed species distribution and composition. The role of the dominant plant communities, ecosite / topography, grasses basal cover, species removal (physical removal of undesirable species), soil depth, stocking density / grazing intensity and woody species effective canopy cover were investigated. Fire has been an important component of this system, however fire effects could not be evaluated due to insufficient knowledge about fire history on the different farms. The factors evaluated were assigned ranked scores that were correlated to the different farm ordination scores for the different axes. The factors were ranked as follows:

- Dominant plant community (Cymbopogon = 1, other grasses = 2, woody species = 3)
- Ecosite / topography (hilltop = 1, slope = 2, valley = 3)
- Grasses basal cover (low < 40% =1, moderate 40-50% =2, high >50% = 3)
- Species removal (low /none = 1, moderate = 2, high = 3)
- Soil depth (< 100 cm = 1, 101 – 120 cm = 2, 121 – 140 cm = 3, > 140 = 4)
- Stocking density / grazing intensity (light < 0.7 AU/ha =1, moderate 0.7- 1.2 AU/ha =2, heavy > 1.2 AU/ha =3)

- Woody species effective canopy cover (low < 7% =1, moderate 7-14% =2, high >14 = 3)

Spearman's rank correlations between scores of the investigated variables and the different farm ordination scores for the different axes indicated significantly high negative correlations between woody species effective canopy cover (r = -0.866), dominant plant community (r = -0.772) and soil depth (r= -0.866) associated with axis 1 (Table 3.8.). The only significant positive driving variable of axis 1 was grasses basal cover (r = 0.524). Most of the grasses exhibited high positive ordination scores while most woody species had negative scores. Therefore, environmental variation associated with axis I can be partly explained by the four interlinked variables. The negative influence of woody species appears to be stronger in determining species distribution and composition. Correlations between ecosite, species removal and stocking density with DCA axis 1 scores were not significant.

In ordination axis 2, the removal of species (r = -0.903) that is associated with grasses basal cover (r = -0.634) explain the environmental variation that negatively influenced species distribution and composition. In ordination axis 3, stocking density was highly positively correlated with the axis (r = 0.719) while the removal of species had a significant but negative correlation (-0.541) (Table 3.8.). Therefore at the level of axis 3, species distribution and composition to a greater extent was explained by the influence of grazing intensity on the farms.

Table 3.8. DCA for species composition and Spearman's rank correlation between potential influential factors and farm ordination scores for the 3 axes

	DCA axis		
	1	2	3
Eigenvalue	0.274	0.126	0.046
Length of gradient (SD)	1.856	1.180	1.226
Cumulative percentage variance	32.93	48.07	53.60
Driving variable *c*orrelations with axes			
Dominant plant community	-0.772**	-0.053	-0.389
Ecosite (hilltop, slope, valley)	-0.170	-0.334*	0.175
Grasses basal cover	0.524*	-0.634*	0.143
Species removal	0.066	-0.903**	-0.541*
Soil depth	-0.778**	0.244	-0.315
Stocking density/grazing intensity	0.180	0.091	0.719**
Woody species effective canopy cover	-0.866**	0.302	-0.193

* P = 0.05 level
** P = 0.01 level

Grouping of farms

Based on the species and farm ordinations, potential driving variables and prior knowledge of the different farms, the 15 farms were categorized into 5 different groups (Figure 3.3 and Table 3.9). The group naming was based on the level of the dominant plant community on the farm i.e. herbaceous species, woody species and *Cymbopogon afronardus* which are also indicators of the level of species removal / management of the farms. Farms with high levels of *C. afronardus* or woody species or both belong to the unimproved farms where human disturbance on existing species has been minimal while the absence of *C. afronardus* and woody species indicates high level of human disturbance in the form of improvement / management for livestock production and hence such farms are sometimes referred to as “improved farms”. In the farm ordination overlay (Figure 3.3), improved farms (KAP-01, KAK-01, BAG-01) appear closer to Axis 1 while the unimproved (with many woody species and *C. afronardus*) appear on the upper side of axis 1 of the ordination.

Table 3.9: Farm categorization identified by the dominant plant community.

Group	Level of indicator species	Farms
1	Herbaceous species dominated farms ('improved' farms)	BAG-01, KAK-01, KAP-01
11	Herbaceous species dominated but with a moderate woody component	RAN-05, RWE-01
111	Woody species dominated farms with minimal or no *Cymbopogon*	RAN-01, KEI-01, RAN-15, RAN-20
1V	*Cymbopogon* dominated farms with minimal or no woody species	NAH-01,RAN-04,RAN-08, RAN-26
V	High *Cymbopogon* and high woody components farms	RAN-13, RAN-14

Ecological implications of species distribution

Many factors are suspected to be at play to influence species distribution and composition in the pastoral system of south-western Uganda. Long history of fire and or its absence on some farms, long grazing history of both livestock and wild animals, human disturbance characterized by physical removal of dominant species, species competition as influenced by the presence or removal of dominant species, topographical differences and effects of weather may all at varying degrees influence species distribution, composition and diversity in this system. Belsky (1992) observed that protection from grazing and physical disturbance had greater impacts on species cover and diversity than the removal of dominant species or fire. General ecological theory holds that plant communities, following a disturbance such as fire, overgrazing, or drought, move toward a climax community that is relatively stable with the prevailing climate (Clements 1916, Dyksterhuis 1949). The Clementian succession has had some challenges. Gleason (1926) while challenging the Clementian succession described plant species behavior as being individualistic but with overlapping distributions. More recent concepts of multiple / alternate steady states (Westoby et al. 1989) that include the state and transition models (Westoby et al. 1989) with recognized ecological thresholds (Archer 1989, Fuhlendorf and Smeins 1997) have been proposed. Therefore having more than one stable state on an ecological site is presumed.

Ordination results of this study seem to support the existence of multiple steady states in this ecological setting. Figure 3.3 and translated to Table 3.9 seem to suggest the existence of several steady states in this vegetation type associated with the different farms that lie on a spatial scale of approximately 30 x 30 km (Figure 1.2). A management disturbance that eliminated all the woody species and *Cymbopogon afronardus* occurred in Group I farms (herbaceous species dominated farms) (Figure 3.3, Table 3.9) in more recent times (about 5 - 8 years ago). The same treatment was applied to some of Group III farms (woody species dominated farms with minimal or no *Cymbopogon)* over 20 years back while those in Group II farms (herbaceous species dominated but with a moderate woody component farms) had the treatment about 10 years ago. There is no evidence that Group IV (*Cymbopogon* dominated farms with minimal or no woody species) and Group V (high *Cymbopogon* and high woody components farms) farms have had any management intervention in recent times, only before the establishment of the ranches, about 40 years ago when the area was cleared of woody species in the fight against tsetse flies / trypanosomiasis. The climax vegetation of the area has been described as *Acacia-Cymbopogon /Themeda* complex (Langdale-Brown et al. 1964), which is closely represented by Group V farms (high *Cymbopogon* and high woody components farms) although *Themeda triandra* is greatly reduced. Group I – IV farms appear to be steady states that are in transition to a climax state in Group V, with likely thresholds between some states due to observed changes in physiognomy exemplified by increased woody species (Archer 1989). The different states move through transitions 1, 2, 3, 4, 5,6,7 and 8 as influenced by the prevailing driving factor. However for the *Cymbopogon* dominated state (IV) to change to the mainly herbaceous state, energy will have to be expended to cross the threshold (Figure 3.5). Similarly energy will be required to change the woody states (II, III and V) back to the mainly herbaceous state (I). Overall, the dynamics of the vegetation observed on these farms with a tendency to move towards the climax seem to support the Clementian linear model of succession.

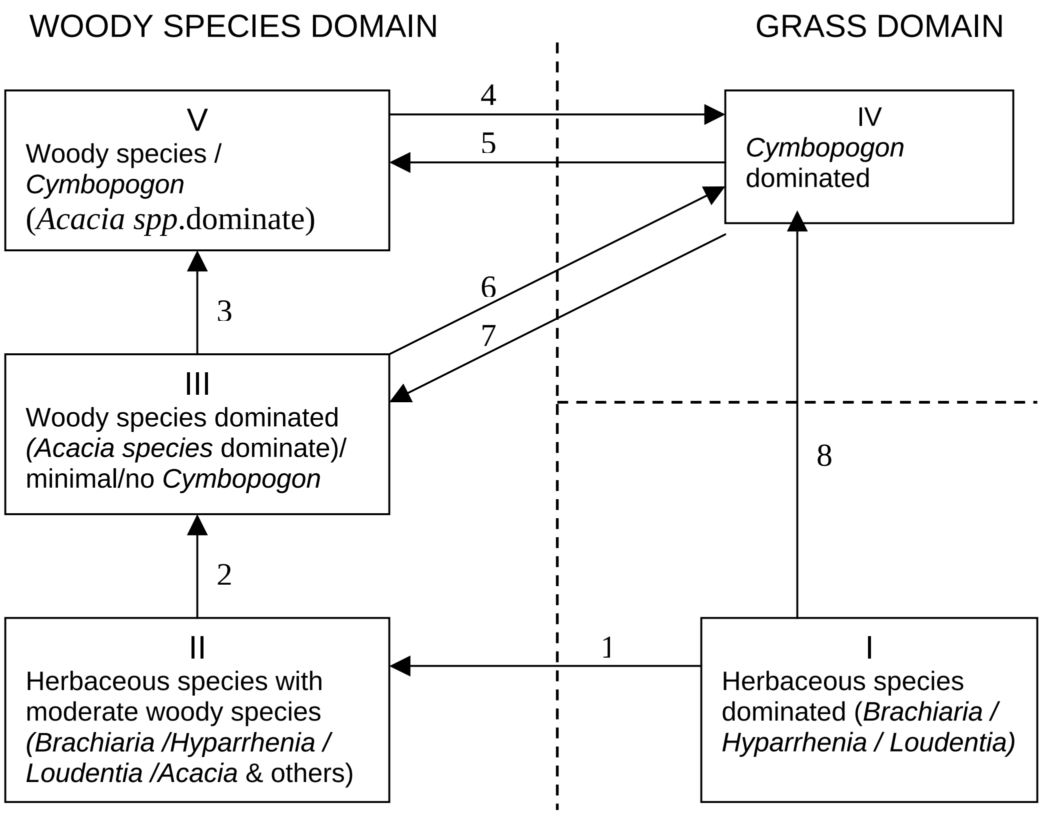

Figure 3.5: Species distribution represented in a 1st order landscape scale State-and- Transition model. I –V represent the different states. Dotted lines represent thresholds. Arrows represent transitions between states.

Discussion

Species distribution and composition were evaluated on 15 farms / ranches in the pastoral system of south-western Uganda. The farms were distributed in four sub-counties of Nyabushozi county, Mbarara district. Species basal cover for grasses, effective canopy cover for trees and shrubs and forb frequency were used in the evaluations. Species differences and similarities in coverage on the different farms were observed. Due to very high grazing intensities on some farms, grass species like *Brachiaria spp*. and *Hyparrhenia spp*. rarely developed floral parts that made it difficult for identification to species level.

The grass species with high frequencies of occurrence on the landscape were *Brachiaria spp (*34%)*, Sporobolus pyramidalis* (20%)*, Hyparrhenia spp* (12%), *Cymbopogon afronardus* (10%)*, Loudentia kagerensis* (7%) and *Panicum maximum* (6%). The stoloniferous growth nature of *Brachiaria spp* and the large bunch form of *Cymbopogon afronardus,* respectively make the two species appear to have a much larger coverage of the landscape. Of the grass species, *Brachiaria spp* particularly *B. decumbens* and *Panicum maximum* are regarded as being of high nutritional quality (Marshall et al 1969). The co-dominant tree species are *Acacia gerrardii* (34%) and *Acacia hockii* (34%). *Acacia hockii* is of high consequence to grazing as compared to *Acacia gerrardii*, which tends to grow into a tall tree.

Earlier reports (Langdale-Brown et al. 1964, Harrington and Thornton 1969, Harrington 1974) indicate dominant species at the time as being *Themeda triandra* (in the valleys), *Cymbopogon afronardus* and *Loudentia kagerensis* on the slopes, *Brachiaria decumbens* (under heavy grazing or reduced fire regimes), *Digitaria maitlandii, Hyparrhenia filipendula* and *Panicum maximum,* which to a greater extent agrees with current study observations. However, from the sites sampled in this study, *T. triandra* was among the least prevalent species while *Sporobolus pyramidalis* became one of the most prevalent species especially in the valleys. The vegetation in this system is generally described as *Acacia-Cymbopogon /Themeda* complex (Langdale-Brown et al. 1964), emphasizing the importance of *T. triandra*. Botanical analysis by Harrington and Pratchett (1973) on hillside and valley positions observed a frequency presence of 80% for *T. triandra* and was the most frequently observed species while analysis for the valley bottoms indicated a frequency of 62% and was also the most frequently observed. *Themeda triandra* was reported to be favored by regular fire regimes (Harrington and Thornton 1969, Harrington 1974) and best suited to light grazing under drier conditions (Edward and Bogdan 1961). All these conditions have considerably changed to less regular fires and increased grazing pressure. Because of the close similarities in growth form with *Hyparrhenia spp*. at the growing stage, there is some possibility that there could have been some botanical sampling errors but still that does not explain the large gap in its current prevalence. Visual evaluation of the landscape also does not support the presence of significant levels of *T. triandra*. In terms of livestock production, reduction in *T. triandra* prevalence may not be that detrimental as it has been described as being of low palatability (Dougall et al. 1964, Thornton 1968) and having low CP and DM digestibility (Marshall and Bredon 1967, Marshall et al. 1969). Harrington and Pratchett (1973) blamed *T. triandra* for its role in holding cattle live weight gains at about 0.3 kg/day and favored its elimination but however pointed out that *T. triandra* was more desirable than *Hyparrhenia filipendula*.

Brachiaria spp. especially Brachiaria decumbens had been reported to be more prevalent in heavily grazed sites, sites protected from fire and in areas lower in *Cymbopogon afronardus* (Harrington and Thornton 1969, Harrington and Pratchett 1974a). It is evident from this study that *Brachiaria spp* have become more prevalent and are the commonest species in the system and appear to be the primary forage species to support livestock grazing in the system and is reported to be of very high nutritional quality in all respects (Marshall et al. 1969, Harrington and Pratchett 1974b). Increased grazing pressure and reduction in fire frequency appear to have favored the expansion of *Brachiaria spp. Brachiaria spp* appear to be increaser species in this system.

The increase in *Sporobolus pyramidalis* on the farms has also been noted. Harrington and Pratchett (1973) observed a frequency presence for *S. pyramidalis* of only 7% in a valley bottom paddock and was among the least prevalent species out of the19 species encountered. There is no record indicating that *S. pyramidalis* was among the prominent species in the system. The species is unpalatable and an aggressive grass that can reduce animal production from pastures by up to 50%, out compete other pasture grasses and threaten biodiversity (Bray et al. 1998). Heavy infestation with *S. pyramidalis* can reduce carrying capacity, decrease stock weight gains, with stock taking an extra 12 months to finish and can half stocking rates (NRM facts 2003). *S. pyramidalis* can quickly dominate a pasture, especially following overgrazing and soil disturbance and produces many seeds (up 20,000 seeds/m^2) that can remain viable for a long time, even up to 10 years (NRM facts 2003). Seed dispersal in dung is big with *Sporobolus*. Application of fire for a very short time has been found to destroy *Sporobolus* seed (Vogler et al. 1998). The increase in this species can possibly be explained by overstocking on the farms and reduction or elimination of fire on these farms. There was a high correlation coefficient (r = 0.9082) between *S. pyramidalis* and woody species on the farms, both of which are by-products of overgrazing and thrive best in the absence of fire. As more land is encroached by woody species, available grazing land is reduced and this results in increased grazing pressures.

Cymbopogon afronardus and woody species as the dominant plant communities on the landscape influenced species distribution and composition (Table 3.9). High correlation coefficients were observed between *Brachiaria spp*., *C. afronardus, S. pyramidalis* and woody species (r = 0.82; 0.88; 0.91 respectively). In natural ecosystems, some grasses have been found to grow exclusively in close association with tree canopy cover. The influence of woody species on the seasonal production of the understorey pasture could be beneficial, detrimental or may have a variable influence (Kennard and Walker 1973). Hence the level of management / disturbance of *C. afronardus* and woody species is bound to have an effect on species composition on such farms. Grazing intensity on the farms was also observed to influence species composition on the farms. Harrington and Thornton (1969) reported that pasture composition altered radically under heavy stocking rates.

Cymbopogon afronardus is unpalatable and tends to out compete and dominate other species. Hence farmers spend large sums of money to control *C. afronardus.* Trees reduce on grazeable forage through their impediment to grazing and competition for resources. *Acacia gerrardii*, unlike *Acacia hockii,* is usually tall (basically an upperstorey up 13 m tall), offering less impediment to grazing. The tendency of woody species to form thickets is a much bigger problem that takes a lot of land out of grazing.

The importance of forbs/herbs for livestock production in the Ankole pastoral system has not received adequate attention. Harrington and Pratchett (1973) reported that herbs and browse were usually highly unacceptable although cattle demonstrated a requirement for some food of this category, where for a few minutes after several hours of grazing they were eaten to the exclusion of others. Field (1972) however reported that annuals were present in stomachs of wild ungulates in large proportions during the rain season.

Leguminous forbs/herbs are importance in livestock nutrition. Only 6.29 % of the forbs in this system were leguminous. *Neonotonia wightii* was the most prevalent legume. Harrington and Pratchett (1973) reported a failure in attempts to increase artificially the legume population of Ankole rangelands. However more recent attempts to introduce the legume component in the pastoral rangelands of neighboring Kazo County by the Dryland Husbandry project looked promising (personal observation). Legumes are known to increase pasture quality and quantity, animal productivity in addition to improved soil fertility (Musangi 1965, Horrell 1965, Otim 1973).

CHAPTER 1V

PASTORAL SYSTEMS OF SOUTH-WESTERN UGANDA: SEASONAL FORAGE AVAILABILITY AND CARRYING CAPACITY ESTIMATES

Introduction

One of the major problems of extensive grazing on rangelands is the seasonal fluctuation in available forage for livestock. The usually severe dry seasons result in low forage biomass on the landscape. Under some forage conditions, animals are subject to standing crops (kg/ha) that restrict forage intake (Stuth et al. 1995). In subtropical shrub lands, total herbaceous grazed standing crop below 900 kg/ha can result in a dietary shift to browse by cattle attempting to meet their indigestible dry matter fill constraint (Hanson 1987, Launchbaugh et al 1990, Stuth and Lyons 1994). The success of any grazing management strategy will depend on the ability to track availability of forage on a property and being able to relate it to the number of animals that can be grazed on the property. The amount of available forage and the number of animals grazing on the area will affect intake and therefore animal nutritional performance and productivity per unit area.

Estimating forage availability especially in the more extensive grazing systems has been one of the major problems when trying to adjust carrying capacity on rangelands. In recent years, new weather and modeling tools, coupled with geographical information systems (GIS) capabilities have allowed near real-time predictions of forage supply for livestock in a spatially explicit manner (Stuth et al. 2003). A biophysical model PHYGROW that links with the Collaborative Historical African Rainfall Model (CHARM) data and near real time weather data from National Oceanic and Atmospheric Administration – Rainfall Estimates (NOAA – RFE) is used to estimate forage production.

Objectives

- To determine forage availability on farms using the PHYGROW model and to compute the carrying capacity / stocking rates of the system/ farms.
- To determine the impact of *Cymbopogon afronardus* and woody species on carrying capacity / stocking rates.
- To determine if biophysical modeling of forage production can be a viable method for explaining landscape level effect of *Cymbopogon afronardus* and woody species expansion.

Methodology

Prediction of forage productivity on the farms was performed using the PHYGROW model. The PHYGROW model, which is a hydrologic based plant growth model, is composed of four primary components, namely soil attributes, plant growth attributes, grazing animal attributes and weather information. The four attributes are used in model parameterization before model runs to generate multiple outputs. Therefore, parameterization for PHYGROW was performed for each of the farms selected for the study. Separate PHYGROW files were created for hilltop, slope and valley aspects of the farm. Data for each of the four attributes was generated through direct field measurement, interaction with various stakeholders while other data was generated from other web-based sites as follows:

Soil attributes

Soil attributes required for PHYGROW represented in a data set generated for one of the sites are presented in Appendix E. Determination of soil attributes was mainly through soil pits dug on the farms in collaboration with a Soil Scientist from Kawanda Agricultural Research Institute in Kampala. Four sites/farms in the land use system were selected, each representing farms around it. On each site, a soil pit was dug, the different soil layers and depth determined and a soil sample from each layer obtained for laboratory analysis at Kawanda Agricultural Research Institute.

The sand and clay proportions in the soil layers were used to estimate soil hydraulic properties (saturated hydraulic conductivity, moist bulk density, dry bulk density, volumetric water content (at 0 Bar, -1/3 Bar, -15 Bar representing saturation, field capacity and wilting point respectively) based on hydraulic properties calculator of the soil texture triangle (Saxton et al. 1986). The soil parameters used in PHYGROW for the four sites representing hilltop, slope and valley positions and the respective farms for which they are parameterized are given in Appendices E, F, G and H. The four sites are represented by their sub-county names i.e. Kikastsi, Kanyaryeru, Sanga and Nyakashashara.

The Kikaatsi soil sampling site representing KAP-01, KAK-01, NAH-01, RAN-04 and RAN-08 farms has dark reddish brown, sandy clay loam soils on upper layers and dark red, moist sandy clay soils in the lower layers on hilltops. The soils turn to black on upper layers to very dark gray to gray further down the soil profile in the valley bottoms. The soils are well drained and are moderately permeable on hilltops and slopes but poorly drained with very slow permeability in the valleys. FAO classification (WRBS) classifies the hilltop and slope soil type as Endopetric Plinthosols and valley soil type as Mollic Gleysols.

The Kanyaryeru soil-sampling site was used to represent the surrounding farms namely BAG-01, KEI-01, RAN-01, RAN-05 and RWE-01. The soils are dark reddish brown on the upper layer becoming reddish brown to yellowish red further down the profile on the hilltop and slope sites. In the valley bottoms the soils become black and dark gray. On the hilltop and slope, the soils are moist sandy clay loams across the profile. In the valleys, soils contain more clay in the lower horizons and are also poorly drained with very slow permeability. FAO classification is Lixic Ferralsols for hilltop, Acric Ferralsols for slopes and Mollic Gleysols for valley soil type.

The Sanga sampling site was used to represent four farms that are in close proximity namely RAN-13, RAN-14, RAN-15 and RAN-20. The soils are sandy loams and dark brown in color in the upper horizons on hilltops but become brown in color and sandy clay in texture deeper in the horizon. The soils are also well drained with a moderately rapid permeability. The dark brown and brown colors for upper and lower horizons are also observed on the slope with texture being sandy clay loam on the upper layer and becoming sandy clay lower down. In the valley, brown black, dark reddish brown, grayish brown, dark brown and brown soil colors are observed down the soil pit. The soils are imperfectly drained with slow to very slow permeability. The soils are classified (FAO) as Haplic Acrisols on hilltop and slopes and Stagnic Luvisols in valleys.

The soils for the Nyakashashara area were taken from RAN-26 as the only participating farm in the area. The soil color for the hilltop, slope and valley sites were similar to those observed on other sites. The soil texture was also similar, being mostly sandy clay loam with slightly more clay in the lower horizons. The soils are classified as Aremic Acrisols on hilltop, Acric Ferrasols on slopes and Mollic gleysols in the valley bottoms.

Plant species attributes

Each of the 15 farms was characterized for its plant species for hilltop, slope and valley bottom.   The methodology and materials used have been described in Chapter III. Therefore, the plant species data observed in Chapter III was used in the construction of PHYGROW files. Grass species percent basal cover, forb species frequency and percent effective canopy cover for tree species were computed for each toposequence on each farm. A sample list of the plant species and categories identified on farm RAN-14 (slope position) for use in PHYGROW is provided in Appendix I.

The different plant species observed were further characterized using 32 attributes (Appendix J) that affect plant growth dynamics with respect to the influence of weather, soils, vegetation characteristics and the grazing livestock.

Grazing decision rules

PHYGROW requires an understanding and setting of those dates in the year when farmers were likely to destock and restock by a certain magnitude or percentage. Destocking and restocking influence grazing pressure on the existing forage and affect the amount of forage available. Arriving at these destock and restock decisions involved discussions with each pastoralist and determined when such decisions were taken and numbers of livestock involved. However, these discussions revealed that the pastoralists did not have clearly defined destock/restock rules. Sales were made when there was an impending problem. The problems ranged from need for school fees, addressing a household problem to some small to medium scale investment. Usually very few (1-5) animals were involved in a period of one to six months. It is usually young bulls that are sold. Reasonable agreed dates to accommodate the few sales made were arrived at and were translated to specific decision dates for PHYGROW for a 365 days planning horizon. Each decision date is accompanied by a maximum and minimum stocking density and a maximum and minimum forage available for the date. PHYGROW adjusts stocking density accordingly on the dates indicated, matching the stocking density with the forage available. Decision days are determined for each grazer species (cattle, goats and sheep). PHYGROW also requires an input of a daily forage demand (kg/head/d) by the grazer animal. The average daily demand was computed using fecal NIRS profiling each month and then NUTBAL model (see Chapter V). Grazing decision rules used in PHYGROW for the different farms are given in Appendix K.

Under the grazing component of PHYGROW, all the plant species observed on the farm were assigned a preference rating for each grazer. The preference rating classes are: preferred, desirable, undesirable, emergency, toxic and non-consumable (Stuth et al. 1999). The ratings were identified in the field through interaction with the farmers, extension officers and personal experience and observation. A species list for each farm was drawn and a preference rating assigned according to each grazer involved by growth phase. A list of all the species encountered on the 15 farms and preference ratings for cattle and goats are presented in Appendices L and M, respectively.

Within the grazing component, a daily forage demand by the livestock type kept on the farm is required so as to compute what is consumed and what remains. The daily demand can easily be computed using NUTBAL (Chapter V). When the daily demand is put at zero (0), PHYGROW allows the forage to grow without consumption from the livestock, allowing for estimation of total forage production from the site in the absence of grazing. This was used in the estimation of carrying capacity of the farms/system, mimicking a grazing exclosure with the model.

Weather data

Event corrected Collaborative Historical African Rainfall Model (CHARM) (Funk et al.) data and near real time weather data from National Oceanic and Atmospheric Administration – Rainfall Estimates (NOAA – RFE) were used to run the PHYGROW model. The event corrected CHARM data provided long-term historical weather data for the sites and was used to stabilize the model. Daily rainfall, maximum and minimum temperature and solar radiation (Langleys) data were acquired from the NOAA's Climate Prediction Center that is supporting Africa as part of the Famine Early Warning System Network (FEWS NET) (Stuth et al. 2003). Under the NOAA program, rainfall and temperature data are mapped for the entire continent of Africa on an 11 km grid. The weather data was downloaded for every farm from http://cnrit.tamu.edu/rsg/rainfall/rainfall.cgi after input of the longitude and latitude in decimal degrees of the farm.

Validation of PHYGROW outputs

In validating model performance, some farms were randomly selected where forage was physically clipped for the determination of available forage per hectare at the time for comparison with model outputs. On an identified clipping site, fifteen 1-m^2 quadrats were clipped along a transect after being scored using a1-5 scoring system for dry weight ranking (Jama et al. 2002). The quadrat with most biomass got a score of 5. The quadrats were clipped, the biomass weighed and a weighed sub sample taken to the laboratory for dry matter determination. Another 10 quadrats were estimated using the scores and their biomass determined based on the 15 harvested quadrats using regression analysis. In all, 25 quadrats were sampled at a site to determine grazed forage standing crop in kg/ha. The coefficients of determination (R^2) between the 15 scored quadrats and their associated DM yields on the specified clipping dates are given in Appendix N, which indicates that most of the R^2 were above 0.9.

Carrying capacity / stocking rates estimations

Determination of long-term carrying capacity / stocking rates requires an estimation of forage production from a site in the absence of grazing. Annual forage production is usually estimated through repeated clipping on sites protected from grazing. Using the PHYGROW model, this was achieved by running PHYGROW for the different farms with animal demand set at zero such that plants grew without being grazed as would be expected in a grazing exclosure. Annual forage production was derived from PHYGROW outputs under ungrazed conditions by mimicking a sampling regime of 5 times in the year starting with the beginning of the growing season. The sampling was done on the 15th day of September, November and December and then in February and April of the following year to complete an annual growth cycle. Positive increments were summed for all the sampling dates to give the Above-ground Net Primary Production (ANPP). Long-term (1961-2003 April) annual forage productivity estimates were used to estimate carrying capacity for the system while forage dry matter yields for the year 2002/3 was used to compute stocking rates. Long-term carrying capacity was computed from mean yield for hilltops, slopes and valleys. Determination of stocking rates involved estimation of the proportions of hilltop, slope and valley on each farm based on visual observation and assessment. The proportions of hilltop, slope and valley were then translated into actual area in hectares based on the size of the farm. The yield for each ecosite was adjusted to the size of the ecosite to project the total dry matter yield for the ecosite. For both carrying capacity and stocking rate, dry matter yield was readjusted for a 25% harvest efficiency to determine the actual amount available to livestock. Animal demand of 7.1 kg/DM/day as computed in NUTBAL (see Chapter V) was used to estimate annual dry matter requirement by an animal (estimated to be 2592 kg/DM/year). The annual requirement divided by the forage DM/ha available determined the carrying capacity / stocking rate for the ecosite. The farm-stocking rate was computed based on total forage available on all the three ecosites.

Results

Observed and PHYGROW predicted forage availability under grazing

Forage dry matter (DM) available on the participating farms under grazing during the period of the study was an estimated mean of 2582 kg/ha (SE $\pm$ 364 kg). Significant differences ($P<0.0001$) in forage availability were observed among the different farms. The lowest amount was 1513 kg/ha on RAN 13, which was also the most densely stocked farm (2.1 AU/ha) while the highest was 3526 kg/ha (KAK 01), which was comparatively moderately stocked (0.71

AU/ha) and was one of the improved farms. The amount of herbage available was negatively correlated with stocking rate on the farm (r = -0.64). Ecosite differences were significant with slightly more forage standing crop on hilltops (2652 kg/ha) followed by valleys (2588 kg/ha) and slopes with 2507 kg/ha. Analysis of the nutritionally better grass species indicated that the more basal cover of such species on the landscape, the more forage and therefore the higher the stocking rates.

Observed forage availability on farms through clipping and PHYGROW predicted forage dry matter on the dates of clipping indicated that there were no significant differences between clipped values and PHYGROW predicted values. PHYGROW reasonably predicted available forage on the farms, with a coefficient of determination of R^2 = 0.69 and a standard error of prediction of SEP $\pm$ 352 (Figure 4.1, Figure 4.2 and Appendix N).

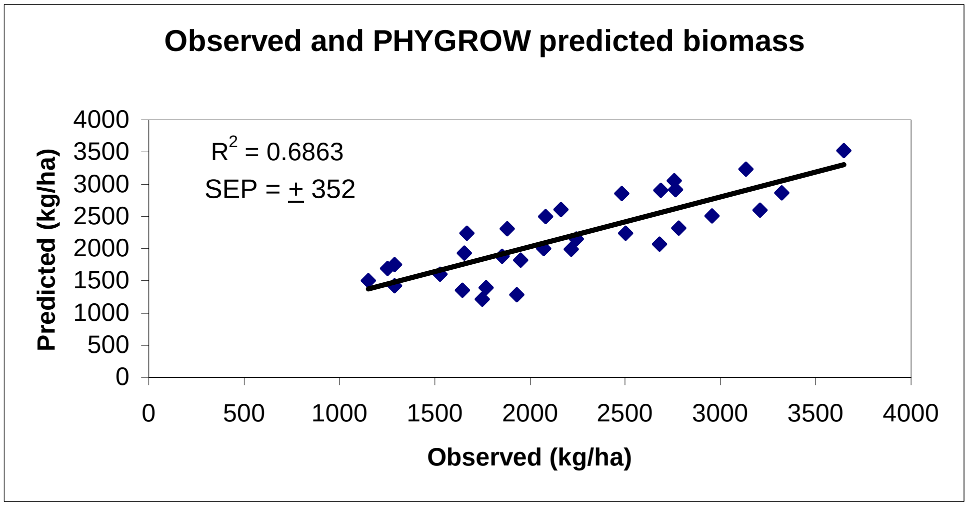

Figure 4.1. Hand clipped (observed) and PHYGROW predicted forage biomass (kg/ha)

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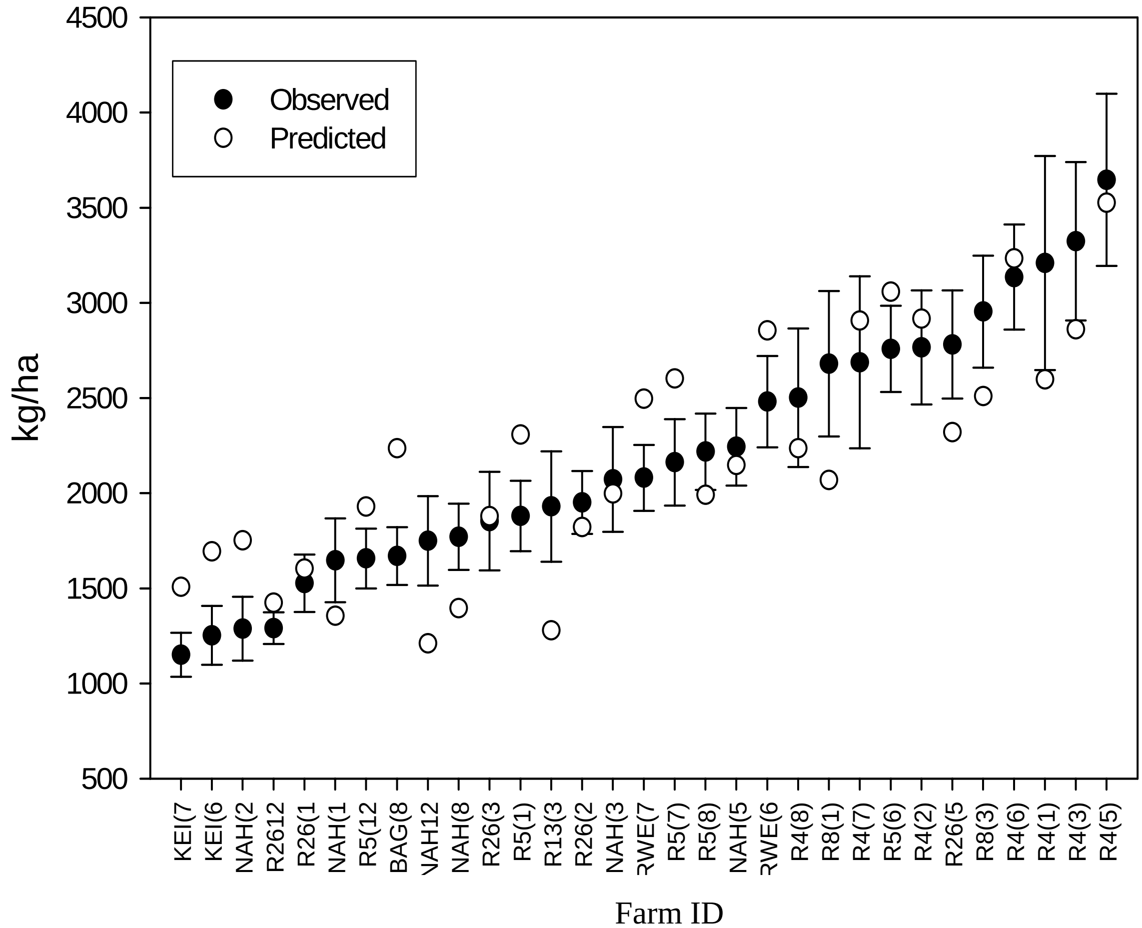

Figure 4.2: Hand clipped (observed) and PHYGROW predicted forage biomass (kg/ha) on different farms and dates.

Long-term forage productivity and carrying capacity estimates

Carrying capacity estimation was based on mean yield for hilltops, slopes and valleys. The mean long-term annual forage productivity was predicted to be 4560 kg/ha. There were significant differences (P<0.0001) in forage productivity among the farms, ecosites and farm groups. Yearly yields were also significantly different ($P<0.0001$). Long-term mean annual forage yield for hilltops, slopes and valleys were 4675 $\pm$ 35, 4381 $\pm$ 35 and 4634 $\pm$ 40 kg/ha respectively. Forage productivity was significantly lower on slopes ($P=0.05$) but there were no significant differences between hilltops and valleys. Group II (two) farms were predicted to produce the highest amount of forage (5360 kg/ha) while group V farms were predicted to produce the least amount at 3936 kg/ha. Productivity by farm groups were predicted to be:

Group I: 5107 $\pm$ 39; Group II: 5360 $\pm$ 49 kg/ha; Group III: 4548 $\pm$ 29

Group IV: 4028 $\pm$ 33; Group V: 3936 $\pm$ 55 kg/ha.

Long-term mean annual forage productivity for each ecosite (4675, 4381, 4634 kg/ha for hilltop, slope and valley respectively) were adjusted for harvest efficiency (25%) and forage demand of 7.1 kg/day for the computation of carrying capacity. Carrying capacities were estimated at 0.45, 0.42 and 0.45 AU/ha for hilltop, slope and valley positions, respectively. Carrying capacity estimates based on farm type in respect to the dominant vegetation were as follows:

- Farm group I - Herbaceous species dominated landscape (‘improved’ farms) = 0.49 AU/ha;
- Farm group II - Herbaceous species dominated but with a moderate woody component = 0.52 AU/ha;

- Farm group III - Woody species dominated landscape with minimal or no *Cymbopogon* = 0.44 AU/ha;
- Farm group IV - *Cymbopogon* dominated landscape with minimal or no woody species = 0.39 AU/ha;
- Farm group V - High *Cymbopogon* and high woody components landscape = 0.38 AU/ha.

A mean carrying capacity for this system would therefore be 0.44 AU/ha.

Stocking rate determination on farms

. The mean total forage yield (ungrazed) for 2002/3, the time when the study was conducted was estimated to be 3993 kg/ha, slightly lower than the long-term mean (4560 kg/ha). This was derived from PHYGROW outputs without grazers for the period of the study. There were significant differences (P> 0.05) in forage yield among the different farms, farm groups and ecosites. The highest production was 4772 kg/ha (RAN-05) while the lowest was 2862 kg/ha (NAH-01) (Figure 4.3 and Appendix O). The model predicted higher yields for hilltops (4184 kg/ha) followed by valleys (4085 kg/ha) and then slopes (3720 kg/ha), with hilltop yields being not significantly different from valley yields.

Analysis of forage productivity by farm group types in ungrazed conditions during 2002/3 indicated significant differences (P=0.05) among the group types with Group II and I farms (herbaceous species dominated farms but with a moderate woody component and improved farms, respectively) leading in available forage at 4509 and 4286 kg/ha, respectively while Group IV and V farms (*Cymbopogon* dominated farms and high *Cymbopogon* and high woody component farms respectively) had lower yields at 3691 and 3477 kg/ha, respectively (Figure 4.4)

The stocking rates computed for the farms based on the 2002/3 forage yields varied from 0.43 AU/ha to 0.25 AU/ha with a mean of 0.36 AU/ha (Figure 4.5). Slopes tended to have lower stocking rates compared to hilltops and valleys. When computed stocking rates are compared with the observed stocking on the farms (Figure 4.5), the farms were highly overstocked, on average 3.2 times the computed stocking. *Cymbopogon* infested farms had the lowest computed stocking rates (Figure 4.6).

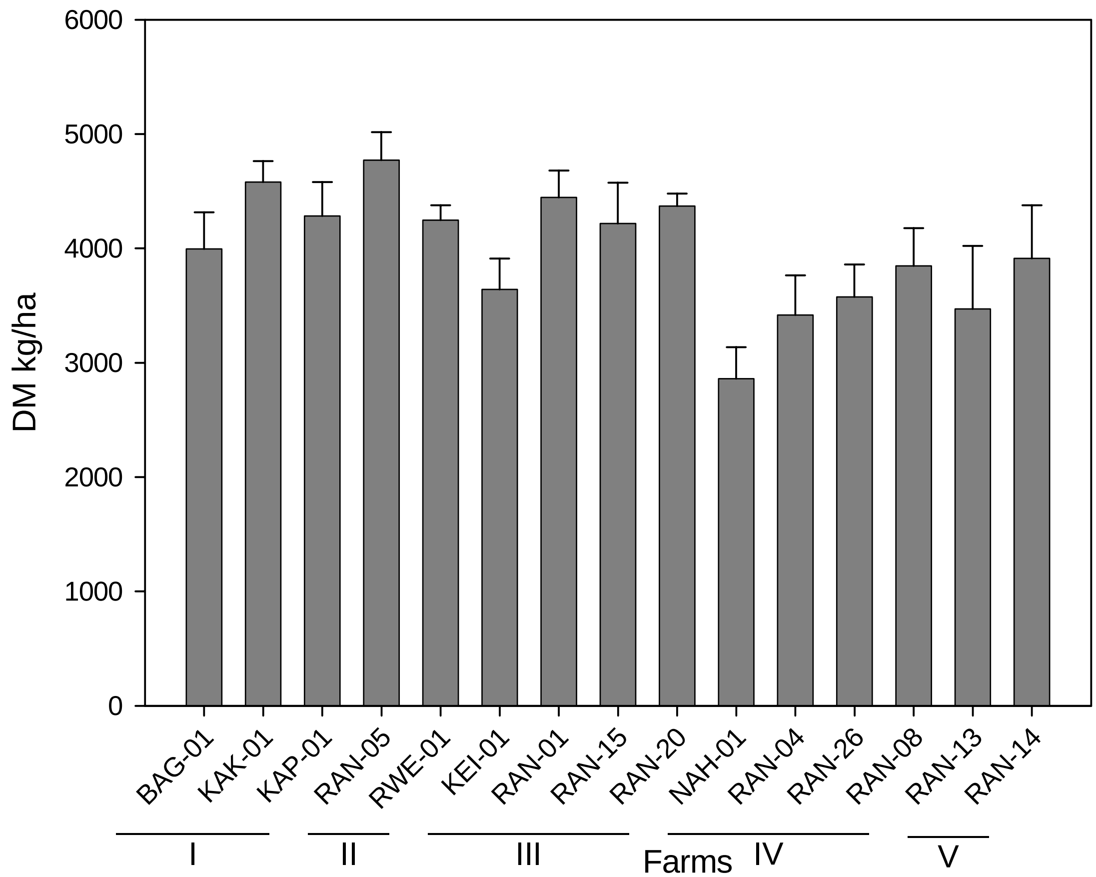

Figure 4.3. Forage DM ANPP productivity (kg/ha) on farms by group (underlined)

Farm group characteristics:
I - Herbaceous species dominated farms ('improved' farms)
II - Herbaceous species dominated but with a moderate woody component
III - Woody species dominated farms with minimal or no *Cymbopogon*.
IV - *Cymbopogon* dominated farms with minimal or no woody species
V - High *Cymbopogon* and high woody components farms

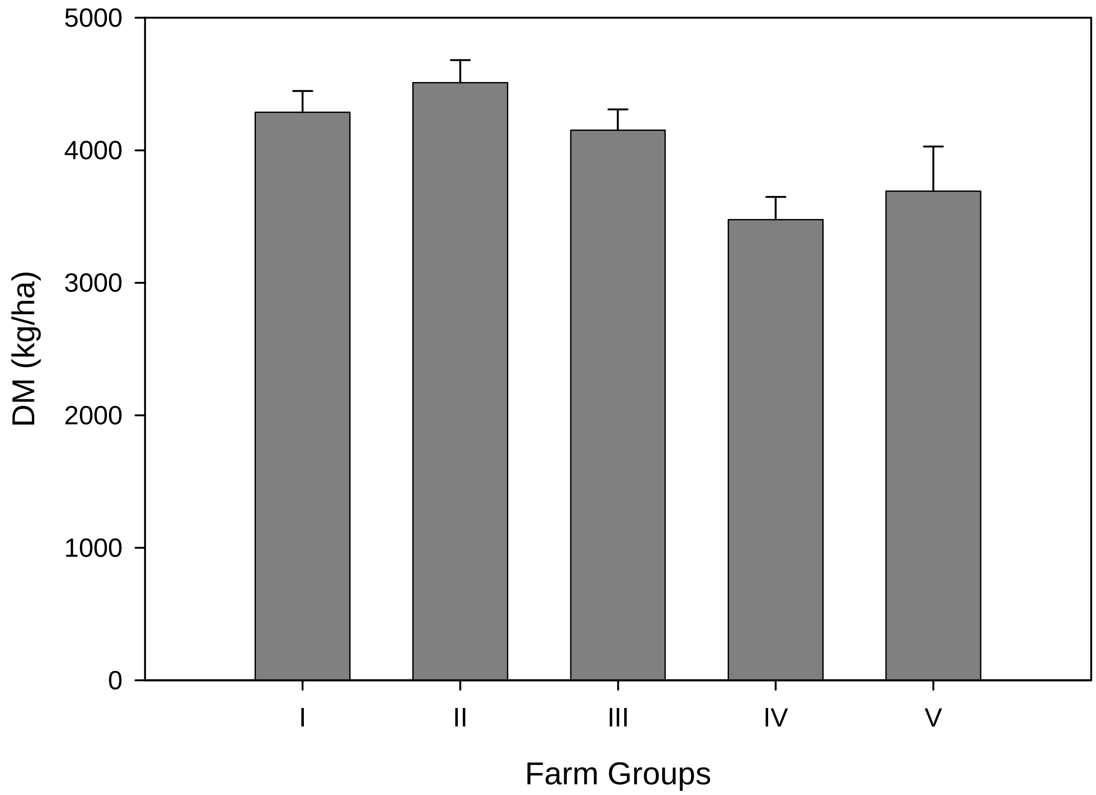

Figure 4.4. Mean forage DM ANPP productivity (kg/ha) by farm group

Farm group characteristics:
I - Herbaceous species dominated farms ('improved' farms) (4286 SE± 161).
II - Herbaceous species dominated but with a moderate woody component (4509 SE ± 171).
III - Woody species dominated farms with minimal or no *Cymbopogon* (4151 SE± 157).
IV - *Cymbopogon* dominated farms with minimal or no woody species (3477 SE ± 171).
V - High *Cymbopogon* and high woody components farms (3691 SE± 337).

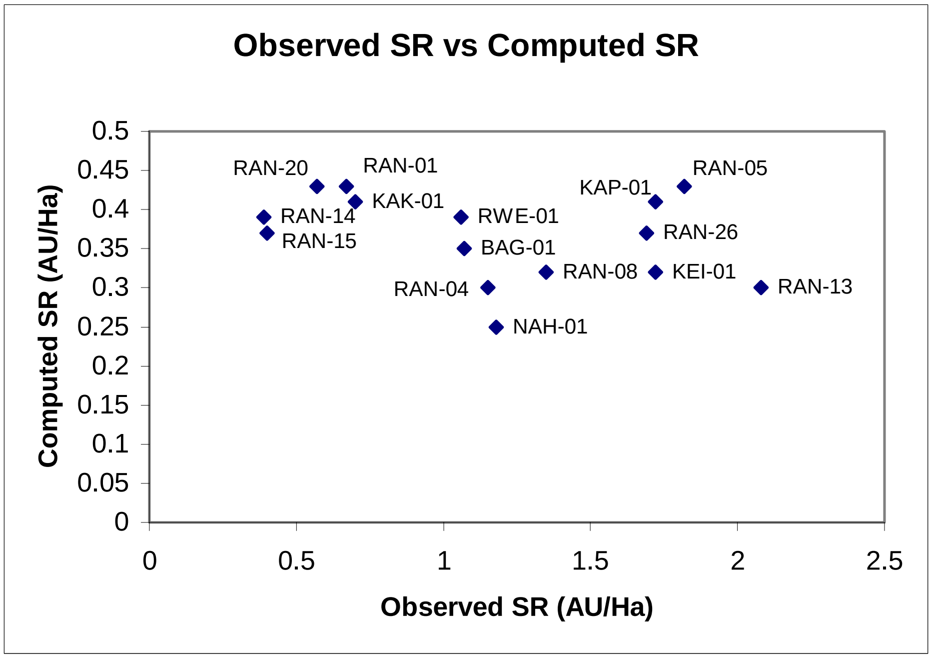

Figure 4.5. Computed (ANPP/25%) stocking rates and observed stocking on farms (AU/ha)

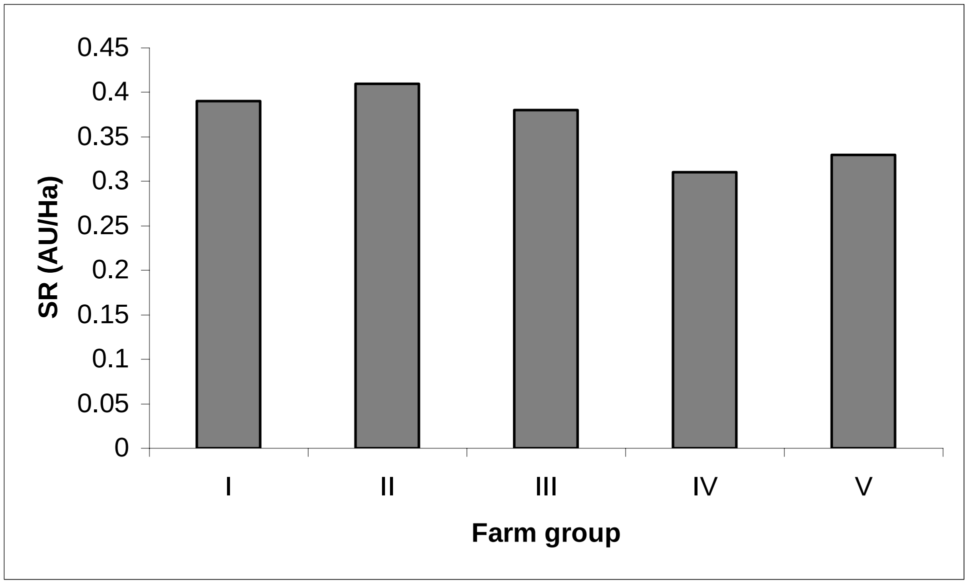

Figure 4.6. Computed stocking rate (AU/ha) by farm group

Farm group characteristics:
I - Herbaceous species dominated farms ('improved' farms) (0.39 AU/ha).
II - Herbaceous species dominated but with a moderate woody component (0.41 AU/ha).
III - Woody species dominated farms with minimal or no *Cymbopogon* (0.38 AU/ha).
IV - *Cymbopogon* dominated farms with minimal or no woody species (0.31 AU/ha).
V - High *Cymbopogon* and high woody components farms (0.33 AU/ha).

Discussion

PHYGROW prediction of 2582 kg/ha (SE $\pm$364 kg) mean forage productivity under grazing appears to be a reasonable estimate for this land use. This value is supported by thirty-one (31) forage clipping results that indicated that there was no significant difference between clipped values and PHYGROW predicted values. Sserunkuuma (1998) working in the same environment of Nyabushozi county reported an average standing crop of 2590 kg /ha (2.59 metric tons) under grazing conditions through clipped samples from 40 farms. Mugasi (1998) reported a dry matter standing crop of 2230 kg/ha as the highest dry matter yield on farms in the neighboring Kazo County also of Mbarara district. Slight differences in species composition between Nyabushozi and Kazo Counties are noted. These estimates are clearly comparable to PHYGROW predictions. It is therefore not entirely wrong to conclude that PHYGROW to a greater extent accurately predicted herbage production on the farms. Ryan (2004) and LEWS project (Stuth et al. 2003) have also concluded that PHYGROW accurately predicted forage production at Laikipia and at various LEWS sites in East Africa, respectively. Significant differences in forage availability observed among the different farms is due to the differences in factors such as soils, rainfall, plant species and grazing pressures on the farms as used in the parameterization process. Stocking rate is the one major factor that will determine the amount of forage on a farm and as observed, the amount of forage available was negatively correlated with stocking rate of the farms.

A moderate coefficient of determination of $R^2 = 0.69$ between clipped and PHYGROW predicted forage dry matter may not be due to inability of PHYGROW to accurately predict forage production but rather due to inability to obtain accurate data to input into PHYGROW or to compare with PHYGROW outputs during validation. Based on this experience, the two broad areas of major concern are:

1) Livestock data for PHYGROW parameterization including:

- Accuracy in the determination of the actual number of animals grazing on the farm (herd size). In this study area it appeared to be culturally inappropriate to disclose the number of animals one owned. Accuracy was particularly of concern in cases of large and multiple herds that are not easily verifiable. This also included monitoring of actual numbers leaving the farm for sales and other purposes.
- Wildlife as other grazers on the farms. These farms are not very far from the Lake Mburo National Park and therefore a number of wild animals (zebras and various antelopes) graze freely on some of the farms, hence rendering the stocking rate within PHYGROW less accurate which may create discrepancies between observed and predicted values. Parameterization for wildlife within PHYGROW is possible (Ryan 2004) but actual numbers and their movements have to be known.
- There is a lot of crossbreeding between the local breed and other exotic /

foreign breeds going on in this system. Accuracy in the determination of breed composition of the herd is not guaranteed and may therefore result in underestimation of the forage demand component of the animal attributes within PHYGROW.

2) Validation through clipping: The growth form of the vegetation on some of the farms with lots of woody components may reduce the accuracy of validation.

The mean total ungrazed forage productivity in the system during 2002/3 was 3992 kg/ha as predicted by PHYGROW, while a long-term mean (42 years) was predicted to be 4560 kg/ha. Mugerwa (1992b) cited in Mugasi (1998) reported mean dry matter productivity of 3900 kg/ha/year for southwest Uganda rangelands where this study was undertaken. Sserunkuuma (1998) reports an increase from 2650 kg/ha to 4500 kg/ha in a 90-day growing period under fenced exclosures without grazing.

Farms infested with *Cymbopogon* had lower available forage compared to farms with a moderate woody component or those devoid of the noxious species during both the year 2002/3 and in the long-term predictions (by about 23% and 25% respectively). Results indicated a probable beneficial effect for forage growth with some level of woody species presence. Farms with a moderate presence of woody species had the highest forage dry matter yields both in 2002/3 and in the long-term forage yield predictions. A high correlation between woody species and *Brachiaria* species was observed. A number of tree species including some *Acacia* species are nitrogen fixing and can therefore improve on the nitrogen status of the soil to the advantage of the associated grasses. In natural ecosystems, some grasses have been found to grow exclusively in close association with tree canopy cover. However, the influence of woody species on the seasonal production of the understorey pasture could be beneficial, detrimental or may have a variable influence (Kennard and Walker 1973).

The stocking rates computed for the different farm groups for the year 2002/3 varied from 0.25 AU/ha to 0.43 AU/ha with a mean of 0.36 AU/ha. Long-term carrying capacity estimates varied from 0.38 to 0.52 AU/ha among the different farm groups with a mean of 0.44 AU/ha. Mugerwa (1992b) cited by Mugasi (1998) however estimates carrying capacity for southwest rangelands at 1.63 Ha/AU (0.61 AU/ha). The major differences lie in the determination of the carrying capacity / stocking rate through the use of 50% safe grazing and dry matter consumption at 2.5 body weight (Mugerwa 1992b) while in this study, a 25% harvest efficiency and dry matter consumption of 7.1 kg (equivalent to 2.2 % of body weight as computed through NUTBAL-Chapter V) were used in the calculations. Thornton and Harrington (1971) while comparing stocking rates of 1.2 ha, 2.4 ha and 3.6 ha per Ankole steer (2 to 3 years old) (equivalent to 0.83, 0.42 and 0.28 AU/ha, respectively) observed that 1.2 ha per steer gave significantly lower live weight gains but there was little difference between 2.4 and 3.6 ha over a 6-year period but the financial returns at 1.2 ha/animal were greater by 66% and 152% over the other stocking rates respectively. In related studies Harrington and Pratchett (1974a) report of higher weight gains at

0.6 ha/300 kg animal stocking compared to 2.4, 1.2 and 0.8 ha/300kg animal. Both Thornton and Harrington (1971) and Harrington and Pratchett (1974a) however did not estimate dry matter productivity at the sites.

Based on computed stocking rates / carrying capacity in this study, overstocking is probably one of the biggest constraints to livestock productivity in the rangelands of south-western Uganda. Sserunkuuma (1998) reported that the majority of farmers that overgraze were aware that they overgrazed and were also aware of the consequences but continued to keep large herds in order to raise enough milk for family consumption and a surplus for sale. Schwartz et al. (1996), write, “Given the extremely high stocking rates currently imposed on the land, it is unlikely that cattle production in its current form will be sustainable”.

CHAPTER V

LIVESTOCK NUTRITION AND PRODUCTIVITY: IMPACT OF *Cymbopogon afronardus* AND WOODY SPECIES

Introduction

An understanding of seasonal nutritional trends of livestock in the pastoral system of south-western Uganda in relation to the dominant vegetation types has been desirable as a precursor to strategic improvement efforts. Knowledge of the nutritional status of the livestock is a major asset to a livestock manager. Nutritional status is primarily affected by forage quantity and forage quality, which are known to vary by season (Lyons and Machen 2000). Herbage quality and digestible energy intake are among the most important factors that limit production by foraging cattle (Musangi 1965, Hamilton et al 1970, Gartner and Hallam 1984) and are major determinants of the economies that can be achieved in forage based milk and beef production systems (Mugerwa 1992a). Diet quality indicators include crude protein (CP), digestible organic matter (DOM) and intake (Hobbs et al. 1983, Van Soest 1994). Under extensive grazing, intake is influenced by the amount of forage on offer relative to the grazing demand, the concentration of critical nutrients (energy, CP, minerals), ratios of nutrients and partitioning of components within these nutrients (Diarra et al. 1995). Deficiencies of energy, protein and phosphorus, which occur during the dry season result in a reduced intake and consequently in poor live weight gains and reproductive performance (Lamond 1970, Little 1970). Livestock productivity is influenced by the DOM/CP ratio of the diet, with production estimated to be between ratios of 4 and 8 (Stuth et al. 1999). Diets with DOM/CP ratio of below 4 indicate very high diet CP level that is associated with high production of ammonia and limits intake while DOM/CP ratios of above 8 are associated with diet energy level far exceeding CP that results in high production of methane and reduced intake. Different forages have differing nutritional values.

The rate of growth of cattle grazing natural grassland is subject to extreme variation between the wet and dry seasons at any one location and between locations depending upon the rainfall received and the vegetation available (Stobbs 1976). Studies (Smith 1962, Elliott 1967, Marshall and Bredon 1967) indicate that voluntary intake of energy of different *Bos indicus* breeds in the dry season was between 0.5 and 0.8 of their maintenance requirements. In many instances there is virtually a complete deficiency of protein (Topps 1976).

There has not been a rapid reliable method for determining diet quality of free ranging herbivores (Lyons and Stuth 1992, Stuth et al. 1999). Near Infrared Reflectance Spectroscopy (NIRS) scans of feces has been proved capable of predicting diet quality of free ranging livestock (Lyons 1990, Lyons and Stuth 1992, Lyons et al. 1995, Leite and Stuth 1995, Whitley 1996, Showers 1997, Coates 1998, Ossiya 1999, Gibbs et al. 2002, Awuma 2003). The physical and chemical principles of NIRS and its related advantages and disadvantages have been extensively reviewed (Lyons 1990). NIRS analysis is based on the principle that each major chemical component of a sample has near infrared absorption properties that can be used to differentiate components from each other (Norris 1989). The procedures and the various stages to developing a stable equation for use in the analysis of fecal samples have been well documented (Stuth et al. 1999). Fecal sample scan provides an estimate of percent CP and DOM of the diet of the animal. The CP and DOM values are then input in the metric version of NUTBAL PRO, a model for nutritional management system (Ranching Systems Group 1999, Stuth et al. 1999). The NIRS estimates dietary crude protein (CP) and digestible organic matter (DOM) through fecal scans of free-ranging animals while the NUTBAL PRO model allows the estimation of animal performance based on crude protein and net energy of maintenance/gain balance of cattle, goats and sheep.

Objectives

- To determine seasonal forage quality, livestock nutrition and productivity
- To determine the impact of *Cymbopogon afronardus* and woody species on livestock nutrition and productivity

Methodology

The fifteen (15) farms / ranches identified for the earlier studies (Chapter III & IV) were also used for this study. Each farm was visited once a month and a composite fecal sample collected from the herds for scanning with the NIRS machine in the laboratory. On each sample collection day, the farm was visited early in the morning, usually before 8 am when the cattle were still at their night holding ground. A composite sample of between 5-10 fecal sub samples picked from fresh fecal heaps was collected from each farm and stored in an icebox until when delivered to the NIRS laboratory at Namulonge Agricultural and Animal Production Research Institute.

On each farm 15 mature female animals were identified and ear tagged for easy identification for purposes of routine body condition scoring. At the time of selection, most of the animals were lactating. On the fecal collection morning, each of the 15 animals was assigned a body condition score based on the 1-9 system using a 0.5 incremental score. Body condition scoring was performed independently by 3 persons, all trained and experienced in the system in an effort to minimize subjectivity. An agreed upon average score was then recorded. Both the fecal collection and condition scoring were carried out for 13 months starting April 2002.

At the laboratory, the fecal samples were oven dried at 60^{o}C for 48 hours or slightly longer depending on the moisture content of the sample. The samples were then ground in Tecator cyclotec mill and passed through a 1- mm screen for uniform particle size, stored in coin envelopes and oven dried at 60^{o}C overnight before scanning with a Foss 5000 NIRS machine to predict the CP and DOM of the sample. The CP and DOM of the sample were predicted using the Global equation 2003.

CP and DOM values from NIRS scans were input in the NUTBAL PRO (nutritional balance analyzer) nutritional management support model to predict the nutritional parameters and productivity of the livestock. The body condition scores were used for performance evaluation of the farms and also for input into the NUTBAL system. Weather data i.e. maximum / minimum temperatures, mean daily humidity and wind speed for the Mbarara weather station at Kakoba, all required as input into the NUTBAL system because they influence livestock performance were obtained courtesy of the Meteorological Department, Kampala.

The impact of *Cymbopogon afronardus* and woody species on livestock nutrition and productivity was determined based on the prevalence of the species on the different farms (Chapter III) vis-à-vis the nutritional and production outputs from the different farms. These include BCS observed monthly on each farm, CP and DOM from NIRS fecal scans and NUTBAL reports.

Statistical analysis

Data analysis was performed using the SAS statistical package for analysis of variance using PROC GLM.

Results

Crude protein (CP) and digestible organic matter (DOM) intake and cattle body condition scores (BCS) on farms

Mean diet CP on the different farms ranged from 8.62% (KAP-01) to 12.62% (RAN-15) (Table 5.1) with an overall mean of 10.51%. Mean diet DOM ranged from 60.03% (NAH-01) to 64.26% (RAN-15) (Table 5.1) with an overall mean of 62.26%. The differences in both mean diet CP and DOM on the different farms were significant (P<0.0001). Similarly diet CP and DOM by months of the year on the farms were significantly different (P<0.0001) (Table 5.2). Monthly diet CP and DOM levels had a bi-modal distribution with highest peaks in the months of April / May and November / December, and lowest in the August / September period (Figure 5.1), from a CP mean low of 6.7% in August to a mean high of 12.7% in December. Diet DOM ranged from 59.07% in August to 64.67 in December (Table 5.2). Diet CP and DOM by farm and months are presented in Appendix P and Q, respectively. The DOM/CP ratio ranged from 5.08 in March and December to 8.79 in August (Table 5.2) implying potential for production in all the months except August when the protein levels fell much below the energy level affecting intake. A ratio of 4 should allow optimum performance and a ratio of greater than 8 indicates potential weight loss.

Table 5.1. Mean diet CP (%), DOM (%) and cattle body condition scores (BCS) by farms

	CP (%)		DOM (%)			BCS	
Farm	Mean	SE	Mean	SE	DOM/CP	Mean	SE
RAN-15	12.62[a]	0.17	64.26[a]	0.18	5.09	4.6[def]	0.05
RAN-20	11.70[b]	0.23	63.10[d]	0.27	5.39	4.4[g]	0.06
RAN-01	11.57[bc]	0.13	63.60[c]	0.13	5.50	4.9[abc]	0.06
RAN-05	11.56[bc]	0.16	62.41[ef]	0.16	5.40	4.7[cde]	0.07
RAN-14	11.46[c]	0.21	63.85[b]	0.19	5.57	4.8[bcd]	0.06
RAN-08	11.03[d]	0.13	62.31[fg]	0.14	5.65	4.4[g]	0.05
RAN-13	10.93[d]	0.19	62.62[e]	0.19	5.73	4.6[efg]	0.06
KEIJ-01	10.59[e]	0.13	62.12[gh]	0.17	5.87	4.6[ef]	0.06
RAN-26	10.47[e]	0.18	62.23[fg]	0.21	5.94	4.5[fg]	0.05
RWE-01	9.88[f]	0.12	61.87[hi]	0.11	6.26	4.8[cde]	0.05
RAN-04	9.55[g]	0.12	61.70[i]	0.16	6.46	4.0[h]	0.07
BAG-01	9.29[h]	0.09	61.97[h]	0.11	6.67	5.0[a]	0.07
KAK-01	9.21[h]	0.13	61.15[j]	0.12	6.64	4.6[ef]	0.06
NAH-01	9.21[h]	0.11	60.03[l]	0.11	6.52	3.7[i]	0.06
KAP-01	8.62[i]	0.13	60.74[k]	0.15	7.05	5.0[ab]	0.06

Means with the same letter in a column are not significantly different (P=0.05)

Table 5.2. Mean diet CP (%), DOM (%) and DOM/CP ratios and cattle body condition scores (BCS) by month

	CP (%)		DOM (%)			BCS	
Month	Mean	SE	Mean	SE	DOM/CP	Mean	SE
Dec-02	12.74[a]	0.13	64.67[a]	0.15	5.08	4.6[cd]	0.05
Nov-02	12.38[b]	0.11	64.65[a]	0.12	5.22	4.5[ef]	0.06
May-02	11.92[c]	0.11	64.18[b]	0.10	5.38	4.5[de]	0.07
Mar-03	11.91[c]	0.10	60.55[g]	0.12	5.08	4.8[ab]	0.04
Oct-02	11.60[d]	0.15	63.91[c]	0.11	5.51	4.4[fg]	0.06
Apr-03	11.05[e]	0.10	61.83[c]	0.08	5.59	4.8[abc]	0.04
Apr-02	10.93[e]	0.13	63.18[d]	0.16	5.78	4.3[g]	0.10
Jan-03	10.89[e]	0.09	63.30[e]	0.09	5.81	4.9[a]	0.04
Jun-02	10.15[f]	0.11	61.39[f]	0.14	6.05	4.4[efg]	0.07
Feb-03	9.45[g]	0.09	61.63[e]	0.11	6.52	4.8[ab]	0.04
Sep-02	8.67[h]	0.05	61.39[f]	0.10	7.08	4.3[g]	0.06
Jul-02	8.03[i]	0.06	59.54[h]	0.07	7.41	4.7[bcd]	0.07
Aug-02	6.72[j]	0.08	59.07[i]	0.09	8.79	4.4[efg]	0.07

Means with the same letter in a column are not significantly different (P=0.05)

Significant differences ($P<0.0001$) were observed for CP and DOM on different farms for the different months of the year (Table 5.2).

The mean BCS for cattle on the different farms for the period of the study (Table 5.1; Appendix R) ranged from the lowest of 3.7 (NAH-01) to highest of 5.0 (BAG-01). The overall differences among the farms were highly significant ($P<0.0001$). Mean BCS post parturition was about 4.9. Mean BCS by month (Table 5.2) were significantly different ($p < 0.05$) and indicated a bimodal distribution in BCS with peaks in July and January. When compared to the rainfall pattern for the same period, the peaks in BCS came after the rainfall peaks (April and October/November). Similarly peak in BCS showed approximately a 30-day lag after peak CP (Figure 5.1). Mean monthly BCS by farm are given in Appendix R.

Interactions between CP, DOM, BCS and farm vegetation characteristics

Vegetation characteristics on the different farms were identified and delineated into farm groups (Chapter III). CP, DOM and BCS showed significant differences ($P<0.0001$) among the different farm groups.

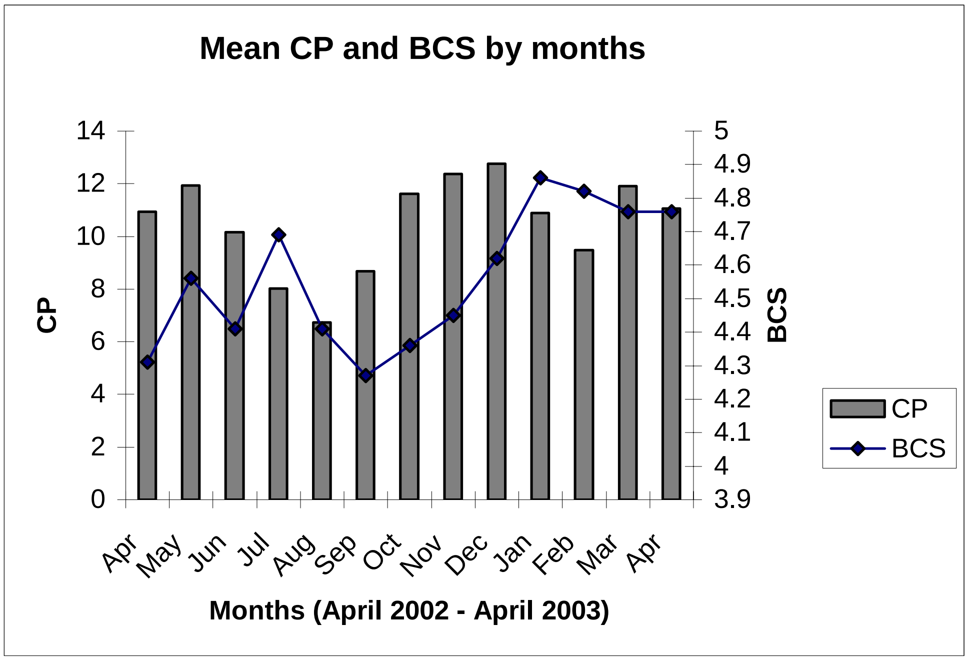

Figure 5.1. Mean diet CP & mean BCS by month on farms.

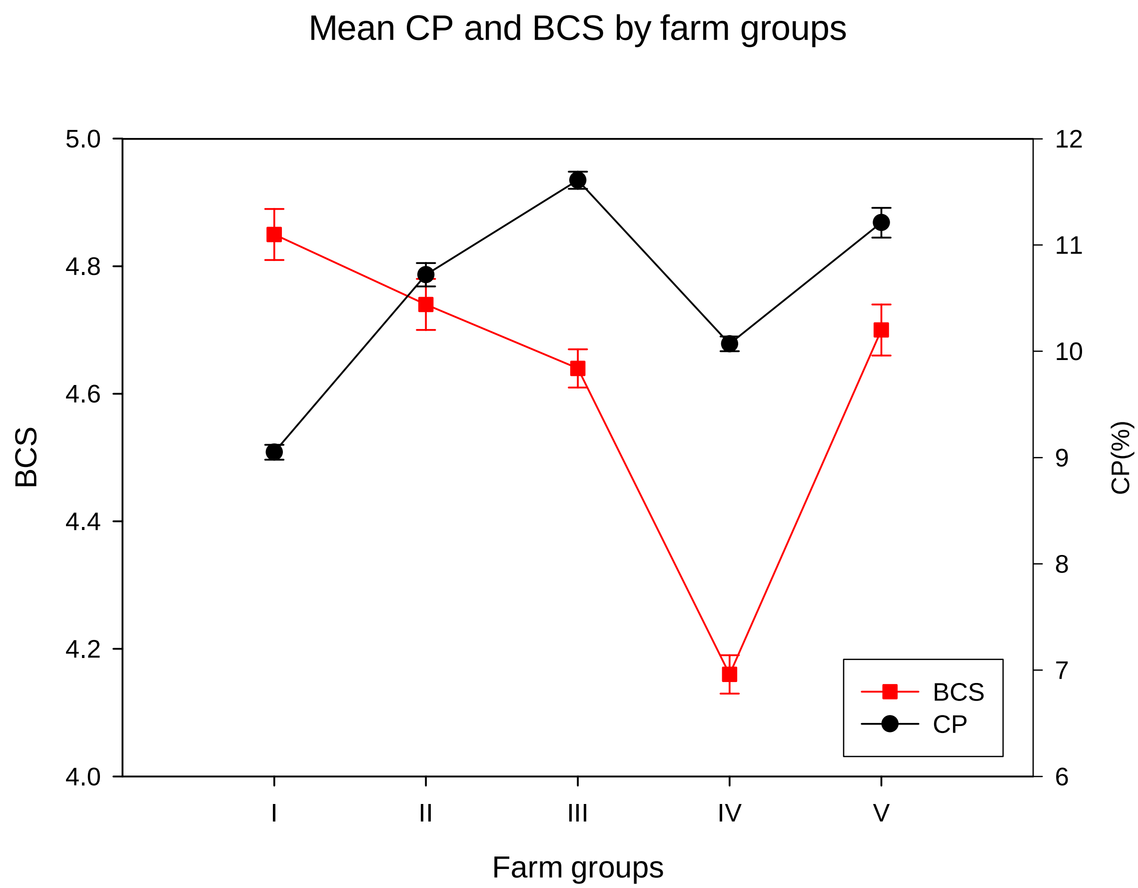

Figure 5.2. A comparison of cattle diet CP and BCS by farm groups.

Farm group characteristics:

I - Herbaceous species dominated farms ('improved' farms)
II - Herbaceous species dominated but with a moderate woody component
III - Woody species dominated farms with minimal or no *Cymbopogon*.
IV - *Cymbopogon* dominated farms with minimal or no woody species
V - High *Cymbopogon* and high woody components farms

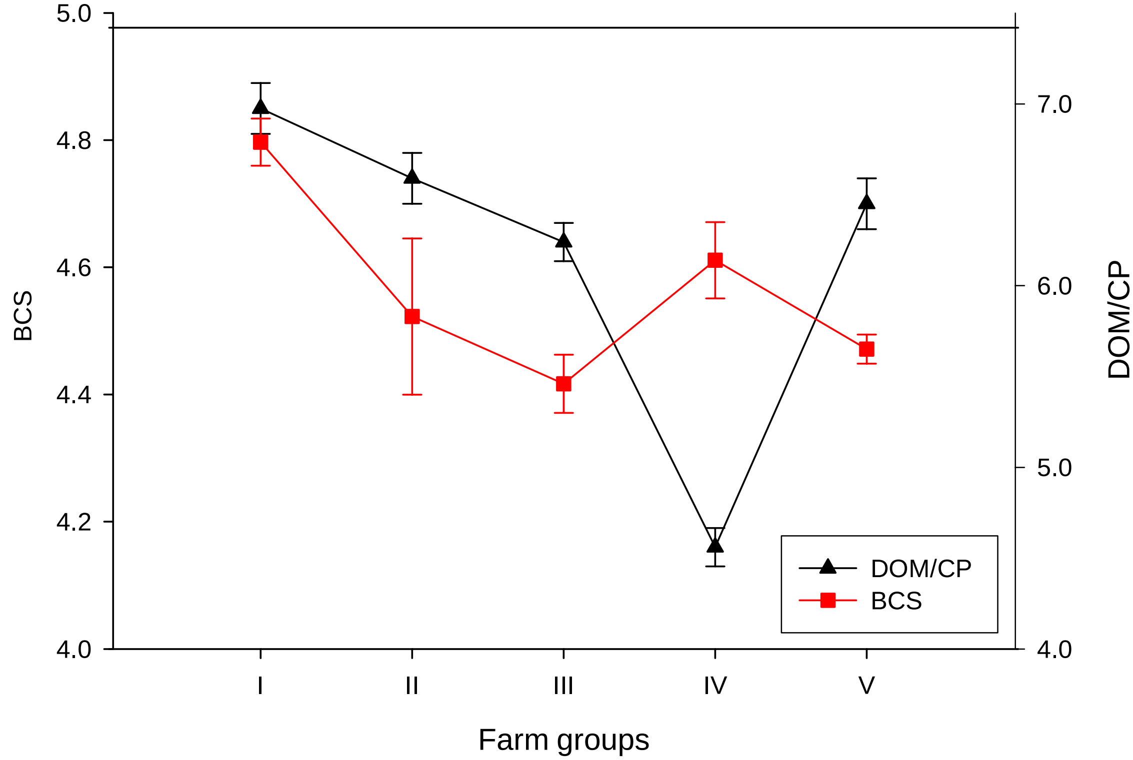

Figure 5.3. A comparison of cattle diet DOM/CP ratio and BCS by farm groups.

Farm group characteristics:

I - Herbaceous species dominated farms (‘improved’ farms)
II - Herbaceous species dominated but with a moderate woody component
III - Woody species dominated farms with minimal or no *Cymbopogon*.
IV - *Cymbopogon* dominated farms with minimal or no woody species
V - High *Cymbopogon* and high woody components farms

CP mean values were 11.61^{a}, 11.21^{ab}, 10.72^{b}, 10.06^{c} and 9.05^{d} for farm groups III (woody species dominated farms with minimal or no *Cymbopogon)*, V (high *Cymbopogon* and high woody components farms), II (herbaceous species dominated but with a moderate woody component), IV (*Cymbopogon* dominated farms with minimal or no woody species) and I (herbaceous species dominated farms -'improved' farms), respectively (groups means with same letters are not significantly different). DOM means values were 63.28^{a}, 63.26^{a}, 62.14^{b}, 61.56^{bc} and 61.28^{c} for farm groups III, V, II, IV and I, respectively (groups means with same letters are not significantly different). BCS means values were 4.85^{a}, 4.74^{ab}, 4.68^{b}, 4.66^{b} and 4.17^{c} for farm groups I, II, V, III and IV, respectively (groups means with same letters are not significantly different). "Improved" farms (group I), farms with no *C. afronardus* or woody species had the lowest CP values but maintained highest BCS (Figure 5.2) while farms heavily infested with *C. afronardus* with low or no woody species infestation (group IV) manifested by having the lowest cattle BCS despite the comparable diet CP with other farm types. Farms with a relatively high woody component (groups III & V) exhibited high CP values but with intermediate BCS (Figure 5.2). This could possibly indicate that there was some intake restriction on such farms.

Analysis of CP and DOM by farm type and months also indicated lower CP & DOM values for group I farms in most months while groups III & V maintained higher values (Figures 5.4 and 5.5, respectively). Differences in farm types were greatest during those months when diet quality was high but differences among farm types were low during the dry season months when diet quality differences were low. There was a high correlation (r = 0.71) between CP values and effective canopy cover of woody species. Similarly a high but negative correlation (-0.66) between DOM/CP ratio and effective canopy cover of woody species was observed. The correlation between BCS and woody species was low (r = 0.30), while both CP and BCS were negatively correlated with *C. afronardus* (Appendix S).

Evaluation of DOM/CP ratios showed that improved farms exhibited highest mean DOM/CP ratios (6.79) indicating high energy intake that was translated into high BCS (Figure 5.3). Groups II, III and V farms showed intermediate DOM/CP ratios with intermediate BCS. Group IV farms however had higher DOM/CP ratio but surprisingly had the lowest BCS. The relationship between farm type and BCS at peak calving period was not investigated which would have indicated which farm type would more likely produce more calves.

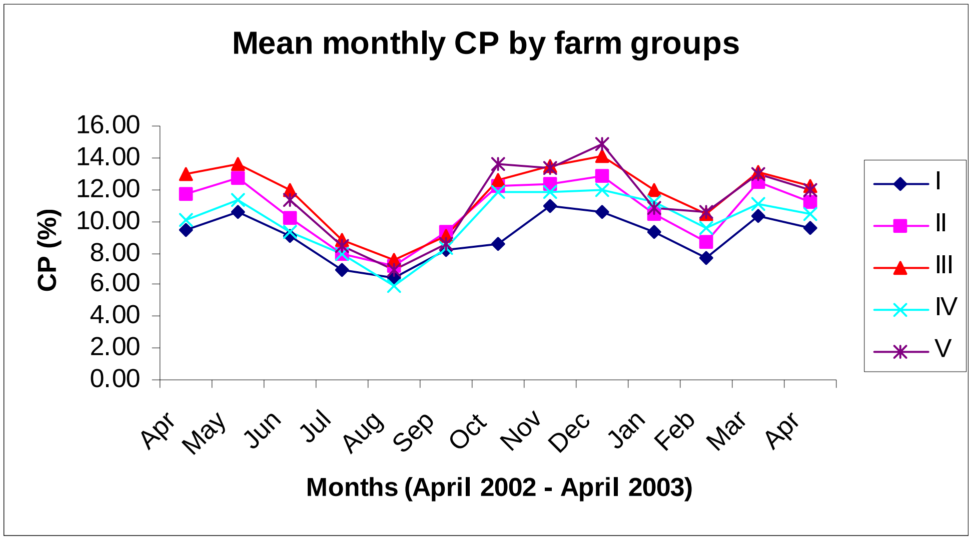

Figure 5.4. A comparison of mean monthly CP (%) trends for the different farm groups.

Farm group characteristics:

I - Herbaceous species dominated farms (‘improved’ farms)
II - Herbaceous species dominated but with a moderate woody component
III - Woody species dominated farms with minimal or no *Cymbopogon*.
IV - *Cymbopogon* dominated farms with minimal or no woody species
V - High *Cymbopogon* and high woody components farms

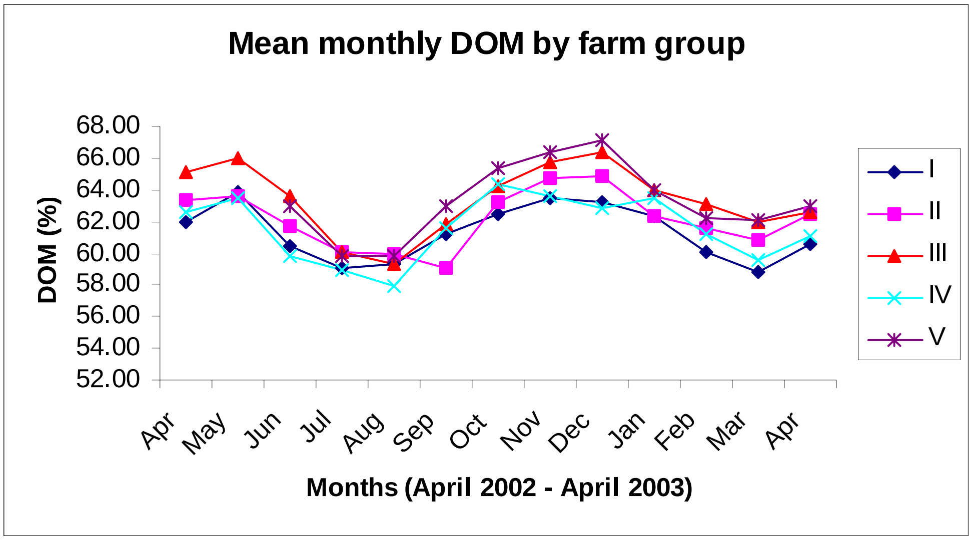

Figure 5.5. A comparison of mean monthly DOM (%) trends for the different farm groups.

Farm group characteristics:

I - Herbaceous species dominated farms ('improved' farms)
II - Herbaceous species dominated but with a moderate woody component
III - Woody species dominated farms with minimal or no *Cymbopogon*.
IV - *Cymbopogon* dominated farms with minimal or no woody species
V - High *Cymbopogon* and high woody components farms

Livestock productivity and nutritional status on farms

NUTBAL (nutritional balance analyzer) nutritional management support model was also used to predict livestock nutritional status and productivity on farms. NUTBAL predictions rest on the assumptions that estimates of the Ankole breed attributes are within acceptable levels. Therefore results are based on the following mean attributes for the Ankole breed as used in NUTBAL:

Peak milk day (45), peak milk yield (3 kg, personal), mature weight (317 kg, Ndumu (2000)), milk solids (8.3%, Ndumu (2000)), milk fat (5.45%, Ndumu (2000)), milk protein (3.4%, Ndumu (2000)), gestation period (283 days), age at puberty (365 days), age at maturity (60 months), hide factor (thin), maximum hair length over crest of 13th rib (2 cm), maximum intake (4.2 kg/d, Stuth, personal communication), lactation duration (212 days, Ndumu (2000)), frame score (-1.57, computed), maximum daily gain (2 kg/d), energy adjustment factor (-0.2, computed), intake adjustment (0.95, computed). The physiological status of the cattle as used in NUTBAL was that at the beginning of the study in April 2002, they were 45 days into lactation and the assumption is that they did not get pregnant during the 13 months of the study, as we did not have the mechanism to test for pregnancy.

Cattle weight changes

Cattle weight changes on different farms were predicted through NUTBAL from April 2002 to April 2003 based on observed body conditions and nutritional status from fecal CP and DOM. NUTBAL satisfactorily predicted cattle weight changes (R^2 = 0.53, SEP = 13.08) over the months as indicated in Figures 5.6 and 5.7. NUTBAL predicted lower weights than observed during the dry period (July to September) but predicted higher weights from October till the end of the study in April 2003. This implies that NUTBAL predicted cattle performance more precisely, beyond what the human eye could observe in the form of body condition scoring. The low accuracy with body condition scoring compared to NUTBAL predictions is due to the fact that the precision in BCS was to the accuracy of 0.5 BCS. It was not possible to determine BCS with accuracies of e.g. 0.1 – 0.4 or 0.6 – 0.9. The level of observation accuracy varied significantly among farms and seasons. Body condition scores were slightly more accurate in more stressed animals than those that had no apparent stress.

Cattle weights were lowest following the peak of the dry season in August and September in which cattle lost a mean of over 8% of their body weights following the May growth period. Cattle attained highest live weights in January, following the wet season that started in September. An increment of about 7% in body weight above the May wet season was observed. This is probably due to the better rains received during this season, coupled with an aspect of compensatory growth usually observed following a severe nutritional stress.

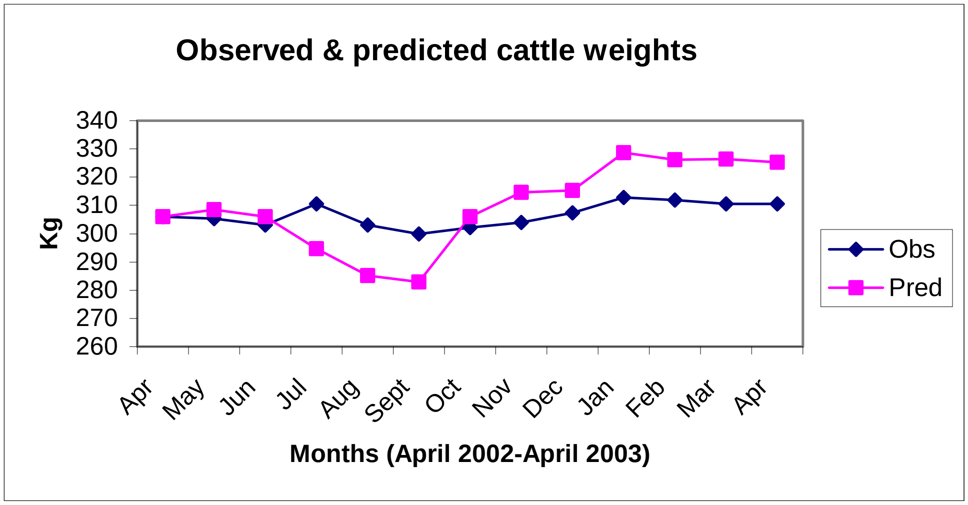

Figure 5.6. Observed and NUTBAL predicted cattle weights on farms (representing mean weights for all the farms for each month).

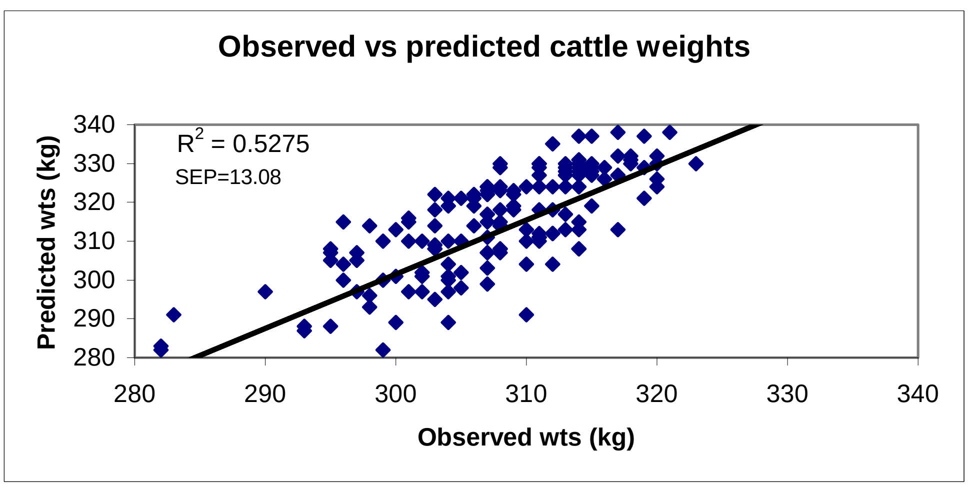

Figure 5.7. Regression analysis for observed vs. predicted cattle weights on farms by month (mean observed animal weight was 306 kg and mean predicted animal weight was 310 kg)

Both observed and predicted weight differences among the different farm types were significant (P<0.0001). The *Cymbopogon* dominated farms had significantly lower observed and predicted weights than the other farm types (Figure 5.8). The other four farm types were predicted to have no significant weight differences although "improved" farms had higher weights than the other farm types. Monthly farm type differences were not significant.

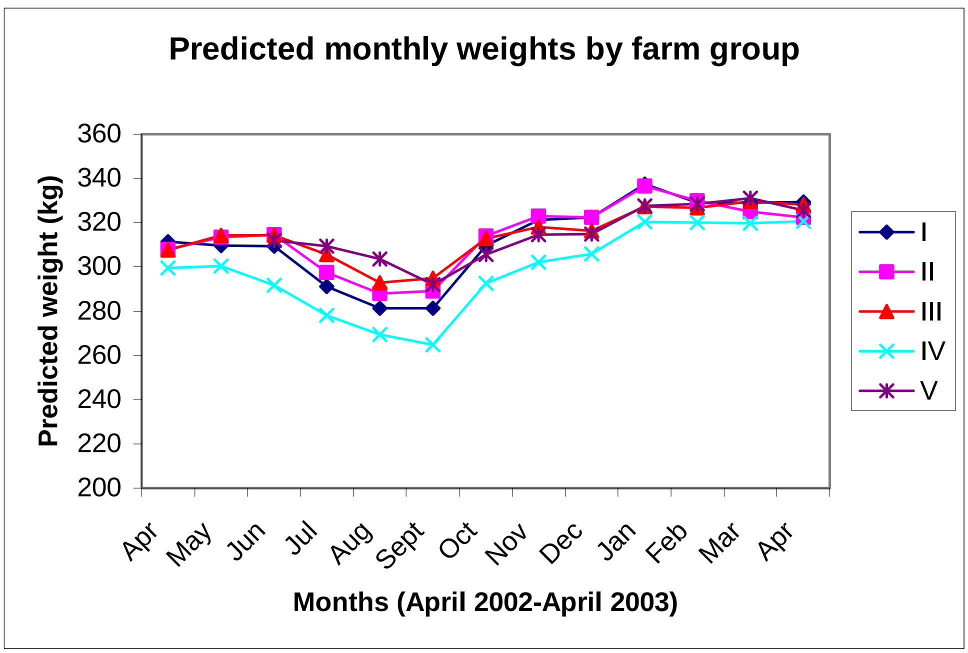

Figure 5.8. Predicted mean monthly cattle weights (kg) by farm group.

Farm characteristics:
I - Herbaceous species dominated farms ('improved' farms)
II - Herbaceous species dominated but with a moderate woody component
III - Woody species dominated farms with minimal or no *Cymbopogon*.
IV - *Cymbopogon* dominated farms with minimal or no woody species
V - High *Cymbopogon* and high woody components farms

Predicted daily weight gain / loss by cattle ranged from a mean of –0.94 kg/day in August to a mean of 0.54 kg/day in October and January (Figure 5.9). There were no significant differences in daily gains among the farms but significant differences (P<0.0001) in daily gain / loss was predicted for the different months of the study. Cattle lost weight during June, July, August and September. The mean predicted weight on farms during April 2002 was 306 kg while the mean predicted weight in April 2003 was 325 kg.

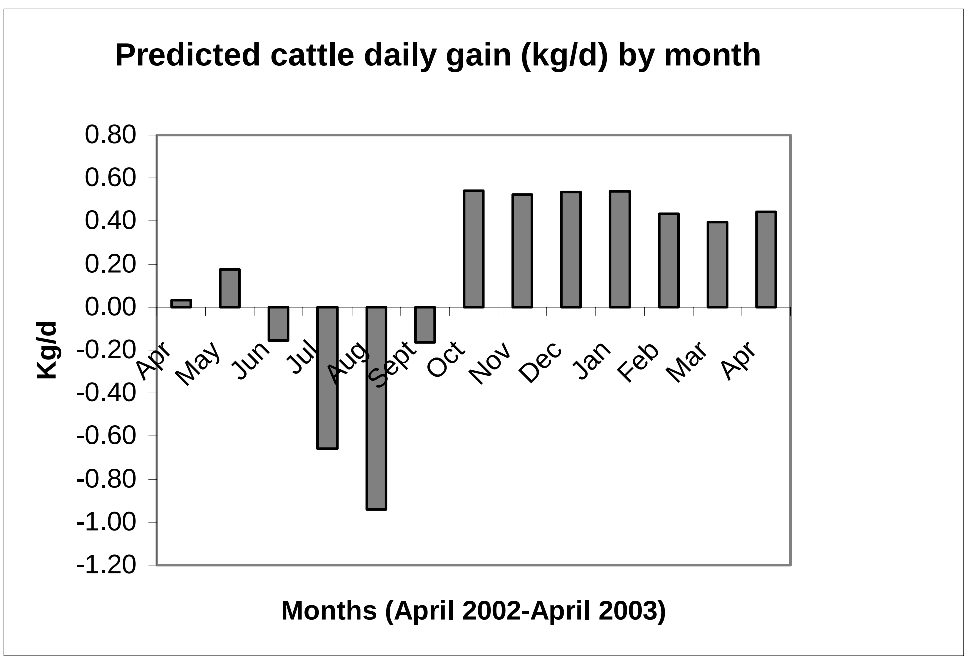

Figure 5.9. Predicted average cattle weight gain / loss (kg/day) by month.

Forage, protein and energy intake

Forage dry matter (DM) intake was estimated to be 7.07 kg/day (SE $\pm$ 0.102 kg/day), which was about 2.23 % of the body weight. DM intake was not significantly different on all the farms. DM intake was significantly lower during the dry months of July and August (6.74kgDM/day and 6.74kgDM/day, respectively) but higher in the wet season (7.40 and 7.37kgDM/day in May 2002 and January 2003, respectively).

Crude protein intake/day on farms ranged from 0.45kgDM/day (SE $\pm$ 0.044) to 0.89kg/day (SE $\pm$ 0.044) (Table 5.3). CP intakes were lowest in the dry months of July and August with intakes being 0.54 and 0.45kgDM/day, respectively but rose to the highest of 0.90kgDM/day in December (Table 5.3). Livestock nutritional requirement for CP was however predicted to be 0.55kgDM/day therefore indicating that the animals did not meet their CP nutritional requirements during some months. Cattle CP requirement by farm did not differ significantly but significant differences ($P<0.0001$) were observed for the different months. Similarly the CP balance for cattle on different farms did not differ significantly but seasonal / months differences were significant ($P<0.0001$). A negative CP balance was observed during July, August and September. Therefore during these months, livestock performance was limited by availability of CP in the diet. On *Cymbopogon* infested farms (NAH-01, RAN-04, RAN-13) and the improved farms (BAG-01, KAK-01, KAP-01), CP also limited performance during the month of April. Otherwise energy was the limiting factor to performance during the other months (Appendix T).

Table 5.3. Monthly cattle CP intake (kg/day), CP requirement (kg/day) and CP balance (kg/day) with SE ± 0.030, 0.0006 and 0.030 respectively.

Month	CP intake***	CP req ***	CP bal ***
Apr-02	0.784	0.717	0.067
May-02	0.881	0.709	0.172
Jun-02	0.713	0.695	0.019
Jul-02	0.542	0.682	-0.139
Aug-02	0.451	0.661	-0.210
Sep-02	0.618	0.650	-0.032
Oct-02	0.840	0.442	0.398
Nov-02	0.866	0.442	0.425
Dec-02	0.897	0.442	0.456
Jan-03	0.809	0.442	0.367
Feb-03	0.674	0.442	0.232
Mar-03	0.833	0.442	0.391
Apr-03	0.779	0.442	0.338

*** P<0.0001
CP intake = crude protein intake
CP req = crude protein requirements
CP bal = crude protein balance

Net energy for maintenance (NEm) requirement by cattle was not significantly different among the different farms but significant differences ($P<0.0001$) in NEm requirement were predicted for the different months of the study. NEm intake was significantly different ($P<0.0001$) for the different farms and months of the year. The mean NEm requirement was predicted to be 7.42 Mcal/day while the mean NEm intake was about 10.50 Mcal/day. The mean NEm intake ranged from 9.66 (SE $\pm$ 0.17) Mcal/day to 11.08 (SE $\pm$ 0.17) on farms. The mean NEm intake was lower in the drier months during July and August (9.38 and 9.19 Mcal/day respectively) (Table 5.4.). NEm requirement, NEm intake and NEm balance for different months of the study are presented in Table 5.4. NEm balance was significantly different for the different farms and months with a mean of 3.073 Mcal/day. No significant differences for NEm requirement, intake and balance were predicted among the different farm groups. Partitioning of energy into growth (NEg) was found to be significantly different ($P<0.0001$) among the farms and months, with a mean of 1.88 Mcal/day. Less energy was partitioned for growth during the dry months.

Table 5.4. Monthly cattle NEm intake, NEm requirement and NEm balance (Mcal/day) with SE ± 0.164, 0.014 and 0.162 respectively.

Month	NEm intake***	NEm req ***	NEm bal ***
Apr-02	10.908	8.980	1.928
May-02	11.500	9.809	1.691
Jun-02	10.252	9.512	0.741
Jul-02	9.385	9.276	0.109
Aug-02	9.194	8.891	0.303
Sep-02	10.385	8.674	1.711
Oct-02	11.184	6.059	5.125
Nov-02	10.981	6.056	4.924
Dec-02	11.101	6.050	5.052
Jan-03	11.206	6.065	5.141
Feb-03	10.385	6.078	4.307
Mar-03	9.956	6.068	3.888
Apr-03	10.355	6.086	4.269

*** $P<0.0001$
NEm intake = Net energy for maintenance intake.
NEm req = Net energy for maintenance requirement.
NEm bal = Net energy for maintenance balance.

Milk Production

There were no significant differences in simulated milk production on the different farms. Milk production progressively declined from about 3kg at 45 days to about 1.25 kg at 205 days of lactation (Figure 5.10). This was based on the assumption that peak milk yield for the Ankole breed was about 3 kg (personal observations) and that the lactation length was about 212 days (Ndumu, 2000).

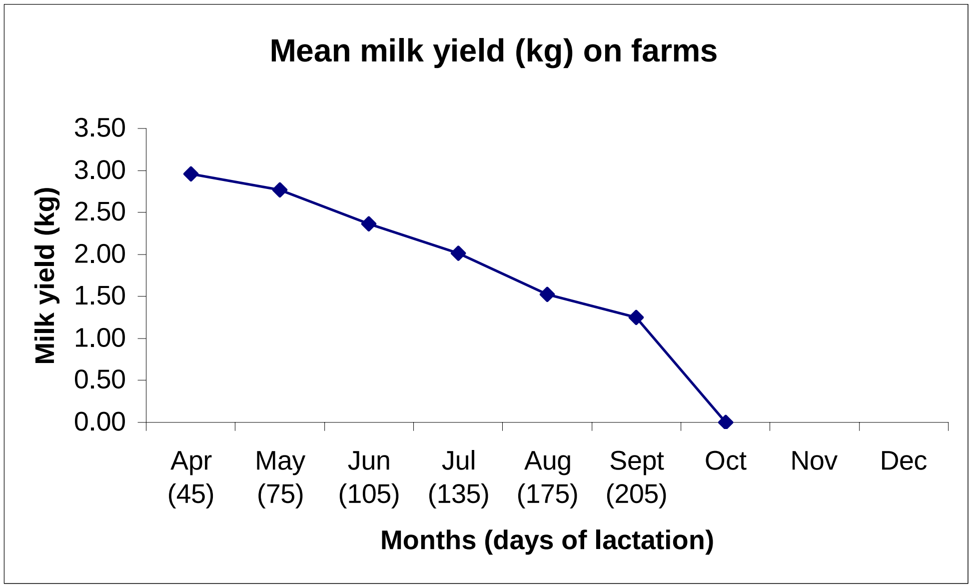

Figure 5.10. Milk production profile for cattle on farms

Fecal output

Fecal output from cattle was significantly different (P = 0.0045) for the different farms with a mean output of 2.45 kgDM/day. Improved farms registered highest fecal outputs per head (2.51 kgDM/day) while the *Cymbopogon* dominated farms produced the least amounts of feces at 2.38 kgDM/day/head of cattle. Fecal output during the different months was significantly different with highest output of 2.53 kgDM/day being in the drier months of July, August, September and March. The least output was during the wet months of November and December (2.26 and 2.29 kg/DM/day, respectively).

Discussion

Higher crude protein (CP) and digestible organic matter (DOM) values were observed during the wet period. Rains facilitate plant growth resulting in the growth of new shoots that are of high nutritive value. Differences in farm types were greatest during the wet season months when diet quality was high but differences among farm types were low during the dry season months when diet differences were low. This is due to the fact that the dry season results in general decline in forage quality across all farm types. Cattle body conditions were best on *Cymbopogon afronardus* and woody species free farms ("improved farms"= group I) but unexpectedly, diet CP and DOM were found to be the lowest on such improved farms. Thornton (1968) reported higher weight gains even in a drought year on *C. afronardus* free paddocks. The cause of low CP intake on improved farms is not very clear. Removal of the more competitive *C. afronardus* and woody species could result in increased production of other grasses of low nutritional value and depending on stocking rate, animals could easily consume more of the lower quality forages in addition to consuming more dead or mature standing forage. However, grazing animals are known to select for more nutritious forage. Increased presence of *Hyparrhenia spp* and *Loudentia kagerensis,* reported to be of low nutritional quality, on *Cymbopogon* free farms were noted. Dradu and Harrington (1972) suggest that differences in CP over different months were due to the mixing of young growing herbage with low quality mature herbage. McCollum (1993) indicates that short-term stocking rate increases on previously lightly or moderately stocked ranges may result in lower diet quality because animals are forced to consume more dead, standing forage. If a pasture has a history of heavy stocking, forage quality of grasses will generally be higher because plants will be consumed at more immature growth stages with less dead forage present (McCollum 1993). Therefore on *Cymbopogon* infested farms, animals continuously pick the young shoots because of limited good quality forages, which may result in selectivity induced intake restriction. The selectivity induced intake restriction might therefore be responsible for the observed lower body condition scores on *Cymbopogon* infested farms. Differences in forage quality can also be due to differences in range sites (Launchbaugh et al. 1990).

Cattle on farms with a high prevalence of woody species were observed to have higher diet CP and DOM but these were not translated into higher BCS. The higher CP and DOM could be the result of the high positive correlation between woody species and the more palatable high nutritious *Brachiaria spp*. The possibility of the cattle feeding on the woody species that are known to have higher CP cannot be ruled out but the author during the execution of this work did not observe cattle seriously consuming the woody species although only a few times cattle were seen biting off a few leaves of *Acacia hockii* trees. Kibet (1984) also reports of no browse consumption by cattle in a study conducted at Kiboko in Kenya. Mnene (1985) reported higher dietary CP in cattle in high bush paddocks than those in low bush paddocks, attributing it to availability of higher quality forages, particularly browse and green leaf fractions of the diet but then reported lower organic matter intake on high bush paddocks. Mnene (1985) also reported that browse replaced grasses in cases where grass composition declined in the cattle diets. Harrington and Pratchett (1973) report that herbs, browse and *C. afronardus* were highly unacceptable but that cattle demonstrated a requirement for some food of this category and for a few minutes after about 3 hours of grazing, they were eaten to exclusion of all else. Dradu and Harrington (1972) also report of seasonal differences in the levels of browsing by cattle. Lower CP values but high BCS observed on improved farms and high CP values and lower BCS on woody species infested farms is probably associated with the level of intake on both groups of farms. Improved farms produced relatively higher biomass (Chapter IV) of more acceptable forage resulting in higher intake. Woody species are usually negatively correlated with understorey biomass productivity that may be translated into reduced biomass intake by cattle, resulting in lower BCS. The high stocking rates observed on the farms coupled with a dense woody component would imply that cattle more often consumed young shoots that were high in crude protein. The high CP may therefore be associated with lower dry matter availability and reduced intake (Mnene 1985).

The robustness of the NIRS fecal profiling system for estimation of CP and DOM was demonstrated based on comparison of three separate studies in the area. CP values obtained in three separate studies including this one in the same environment during 1966/67 (Dradu et al. 1972), 1969/70 (Harrington and Pratchett 1974b) and 2002/03 (current study) are compared in Table 5.5. Cattle have been found to select more nutritious diet than cut samples of the forage in the field (Bredon et al. 1967). Therefore, Dradu et al. (1972) and Harrington and Pratchett 1974b used oesophageal fistulated steers in their studies to obtain the actual diets of the grazing steers before conducting proximate analysis on the samples while the current study used fecal samples scanned with NIRS. Considering the different conditions under which the different experiments were conducted, the results obtained are generally similar. The use of fecal samples that are then scanned through NIRS is the simplest method for determining dietary CP of grazing livestock with an extra advantage of eliminating any form of animal suffering.

Efforts to obtain literature on estimates of digestibility in this study area were not successful. However Marshall et al. (1969) carried out *in vitro* dry matter digestibility of individual grasses in Ankole and the Queen Elizabeth National Park based on the two - stage incubation / acid pepsin digestion method (Tilley and Terry 1963) and related the *in vitro* values to *in vivo* values through a regression equation. The results of the study are presented in Table 5.6 for comparison with NIRS based DOM estimates (Tables 5.1 and 5.2, Appendix Q). Considering the currently common forage species (dominated by *Brachiaria spp.*), animal selectivity and the methodological differences, the results can be regarded as being similar.

Table 5.5. A comparison of NIRS and Oesophageal fistula/Proximate analysis CP derived values in 3 separate studies in south-western Uganda rangelands

	CP (%)		
Month	2002/3*	1969/70**	1966/67***
January	10.89	10.2	6.98
February	9.47	9.1	7.91
March	11.91	9.3	10.15
April	10.99	10.9	11.51
May	11.93	11.0	16.59
June	10.16	8.0	11.42
July	8.03	6.7	7.25
August	6.73	7.0	5.53
September	8.68	6.2	11.93
October	11.63	11.5	11.06
November	12.38	10.9	9.49
December	12.75	11.9	-

* Current study
** Harrington and Pratchett (1974b).
*** Dradu and Harrington (1972)

Table 5.6. Mean in vitro and calculated in vivo dry matter digestibilities and crude protein values for ten random samples of the twenty-two most frequently occurring grasses

Grass	In vitro % digestibility	S.D	Estimated in vivo % digestibility	Mean % CP
Andropogon dummeri	42.7	4.9	54.0	5.22
Beckeropsis uniseta	44.9	6.0	55.9	5.78
Bothriochloa insculpta	49.2	7.2	59.7	5.36
Brachiaria brizantha	50.3	10.6	60.6	6.94
B. decumbens	53.9	6.4	63.7	7.80
B.sp. near *B. decumbens*	51.6	6.2	61.7	7.82
B. platynota	49.8	4.8	60.2	6.49
Chloris gayana	44.2	8.1	55.3	6.03
Cynodon dactylon	47.2	9.3	57.9	7.93
Digitaria scalarum	44.7	5.4	55.7	8.17
D. ternata	48.6	6.8	59.1	5.65
Eragrostis tenuifolia	49.2	10.4	59.0	7.14
Heteropogon contortus	40.8	4.7	52.3	5.54
Hyparrhenia dissolute	34.7	8.1	47.0	3.30
H. filipendula	40.3	8.3	51.9	3.99
Loudentia kagerensis	39.6	4.7	51.3	4.61
Panicum maximum	50.2	4.5	60.3	7.48
Setaria aequalis	59.3	13.9	68.5	11.03
S. sphacelata	44.4	4.9	55.5	6.20
Sporobolus festivus	39.6	9.2	51.3	6.35
S. pyramidalis	42.2	6.8	53.9	5.02
Themeda triandra	36.3	5.4	48.4	3.89

Adopted from Marshall et al. (1969)

CHAPTER VI

GENERAL CONCLUSION AND RECOMMENDATIONS

The most prevalent grass species based on basal cover were *Brachiaria spp*. (33.57%), *Sporobolus pyramidalis* (20.35%), *Hyparrhenia spp.* (12.29%), *Cymbopogon afronardus* (10.29%), *Loudentia kagerensis* (6.53%) and *Panicum maximum* (5.75%). Although in terms of basal cover *Cymbopogon afronardus* is only moderately prevalent, the species has a large canopy with therefore a much more extensive canopy cover. Basal cover for individual grass species on the study farms was significantly different. There was no significant difference in distribution of *Cymbopogon* on hilltops and slopes but was significantly lower in valleys (by about 69%). *Sporobolus pyramidalis* was the most undesirable species in the valleys accounting for 33% of all grasses in the valleys. *Acacia gerrardii* (34.37 %) and *Acacia hockii* (33.66 %) were the most prevalent tree species on the landscape with no ecosite differences observed in their distribution. There was a high correlation (r = 0.88) between *Cymbopogon afronardus* and woody species distribution. Similarly there was a high correlation (r = 0.82) between *Brachiaria spp*. cover and woody species cover but a very low correlation (r = 0.063) between *Cymbopogon* and *Brachiaria spp*. implying that the role of *Brachiaria spp.* would be lower when associated with *Cymbopogon* in the absence of woody species. *Brachiaria spp.,* especially *Brachiaria decumbens,* is believed to be nutritionally highly desirable. A 6.29%

herbaceous legume frequency on the landscape was disappointingly low considering the importance of leguminous forage in animal production. A change in species composition in the land use system was noted, with a major decline in *Themeda triandra*, formerly one of the dominant species of the area.

Based on multivariate analysis of basal and canopy cover of the various plant species encountered on the study farms, the farms could be broadly grouped into five categories / farm groups, identifiable by the dominant plant communities signified by the level of presence of *Cymbopogon afronardus* and woody species. The farm groups were:

I - Herbaceous species dominated farms (‘improved’ farms)

II - Herbaceous species dominated but with a moderate woody component

III - Woody species dominated farms with minimal or no *Cymbopogon*.

IV - *Cymbopogon* dominated farms with minimal or no woody species

V - High *Cymbopogon* and high woody components farms

PHYGROW model was reasonably able to predict forage productivity on farms (R^2 = 0.69 and SEP $\pm$ 352). There were no significant differences between forage dry matter values through clipping and PHYGROW predicted forage dry matter values. The differences between observed and PHYGROW predicted values could be attributed to the level of accuracy of input information in the model and the methodological accuracy during validation. *Cymbopogon afronardus* and woody species negatively impacted forage availability on farms and therefore stocking rates and carrying capacity of the farms. Based on long-term forage yield estimates, *Cymbopogon* infested farms had about 25% less forage while farms with *Cymbopogon* and woody species had 27% less forage available to livestock compared to the best group of farms, with associated carrying capacity estimates of 0.39 and 0.38 AU/ha, respectively. Improved farms and farms with a moderate woody component had higher carrying capacity estimates (0.49 and 0.52 AU/ha, respectively). A mean carrying capacity was computed at 0.44 AU/ha. Based on the 2002/3 forage yields, all the farms in the study were overstocked during that year, with the mean values indicating an average overstocking of 3.2 times the computed would be stocking rate. Computed stocking rates for *Cymbopogon* and *Cymbopogon* with woody species infested farms were about 0.31 and 0.33 AU/ha, respectively compared to the weed free farms of about 0.39 AU/ha. Therefore, the presence of noxious plant species result in reduced forage and ultimately affecting stocking rates.

NIRS predicted CP and DOM values for the different farms were comparable to results of other studies in the area. Body condition scores (BCS) of animals on improved farms were higher than those on *Cymbopogon* and woody species infested farms. Farms with a high woody component had higher BCS compared to those farms with only high *Cymbopogon*, probably due to the association of woody species with *Brachiaria species*, which are of high nutritional quality. High *Cymbopogon* farms despite their reasonably comparable diet quality to other farms had the lowest BCS probably due to selectivity induced intake restriction on such farms.

Cattle diets showed lowest crude protein values on improved farms (mean of 9.05%) (despite their better BCS) compared to the other farm types including those with high *Cymbopogon*. Farms with high woody species showed the highest diet CP values (mean of 11.61%). The reason for the high CP values is not clear but could again be attributed to high prevalence of *Brachiaria species* and probably also associated with some browsing on woody species, most of them known for high CP values although the author did not observe serious browsing. Improved farms produced higher forage biomass, therefore higher intake (but of lower nutritional quality) and hence better BCS. Improved farms showed lower diet CP values possibly due to the fact that elimination of *Cymbopogon* and woody species from these farms resulted in increased growth / production of other forage species that are of lower nutritional value. Such species include *Hyparrhenia spp*. and *Loudentia kagerensis* that are found to be greater on improved farms. Higher forage productivity on improved farms could also result in more dead/litter in the sward, which when ingested lowered diet quality.

Diet CP and DOM levels had a bi-modal distribution following the rainfall pattern with highest peaks in the months of April / May and November / December, and lowest in the August / September period, with CP mean low of 6.7% in August to a mean high of 12.8% in December. Diet DOM ranged from 59.09% in August to 64.68 in December. Differences in farm types were greatest during those months when diet quality was high but differences among farm types were low during the dry season months when diet quality differences were low. The dry season caused a general decline in forage quality across all farm types. Crude protein was the limiting nutrient to productivity during the June - August period indicating a possible window where protein supplementation could play a role in improving productivity. Otherwise energy was the common limiting nutrient in most of the other months of the year implying that energy supplementation would be useful during those months. *Cymbopogon* infested farms had the lowest animal weights at all times of the year. Predicted daily weight gain / loss by cattle on the farms ranged from a mean of –0.94 kg/day in August to a mean of 0.54 kg/day in October and January. The NUTBAL / NIRS fecal profiling system tracked changes in performance of animals based on visual BCS and offered insights into timing of effects that visual BCS did not. The study adequately demonstrated the negative impacts of *Cymbopogon afronardus* and woody species on livestock performance in the pastoral system of south-western Uganda. Reduced forage, lower carrying capacities, lower weight gains and animal weights and reduced fecal outputs were all predicted on the infested farms, justifying some of the management efforts being undertaken.

Recommendations

- Further research into economically and environmentally friendly control measures for both *Cymbopogon afronardus* and woody species. An integrated approach through the use of prescribed fire to control woody species and use of chemicals are some of the common alternatives.

- Sensitization about overstocking is necessary. No efforts in improvement in productivity will succeed with such high levels of overstocking. As the saying goes “Once you are overstocked, nothing works”.
- While many farmers are struggling to improve their farms by removing *Cymbopogon* and woody species, there is increased biomass but of lower quality as shown by this research. Research is needed on how to improve the quality of forage on improved farms. Supplementation for the dairy breeds usually kept on such improved farms is highly desirable for better production.
- NIRS, NUTBAL and PHYGROW models have proved to be useful tools that can give multiple results in a short time and therefore the need for their integration into our research and management systems in the country.
- Body condition scoring was found to be a useful tool even among farmers. Training institutions could probably give a little more emphasis to the tool.
- The increase in *Sporobolus spp*. was noted. The species can greatly lower livestock productivity if not checked. Further investigations and possible control measures are required.

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APPENDICES

Appendix A: Pearson Correlation Coefficients of prominent species on farms

	Plant species							
	BRA	CYMB	HYPA	SPOR	LKAG	PANI	ACAC	TWOD
BRA	-	0.0632	0.1803	0.0582	0.4348	0.2495	0.5031	0.8183
CYMB	0.0632	-	0.8301	0.0037	0.3336	0.2333	0.2673	0.8802
HYPA	0.1803	0.8301	-	0.8684	<.0001	0.0373	<.0001	<.0001
SPOR	0.0582	0.0037	0.8684	-	0.7065	0.4371	0.6302	0.9082
LKAG	0.4348	0.3336	<.0001	0.7065	-	0.1761	0.0027	0.0009
PANI	0.2495	0.2333	0.0373	0.4371	0.1761	-	0.3695	0.0802
ACAC	0.5031	0.2673	<.0001	0.6302	0.0027	0.3695	-	<.0001
TWOD	0.8183	0.8802	<.0001	0.9082	0.0009	0.0802	<.0001	
-								

BRA = *Brachiaria spp*. CYMB = *Cymbopogon afronardus* HYPA = *Hyparrhenia spp*.
SPOR = *Sporobolus pyramidalis* LKAG = *Loudentia kagerensis* PANI = *Panicum maximum*
ACAC = *Acacia spp.* TWOD= Total woody species

Appendix B: Farms and species cover matrix as used in ordination with PC-ord software.

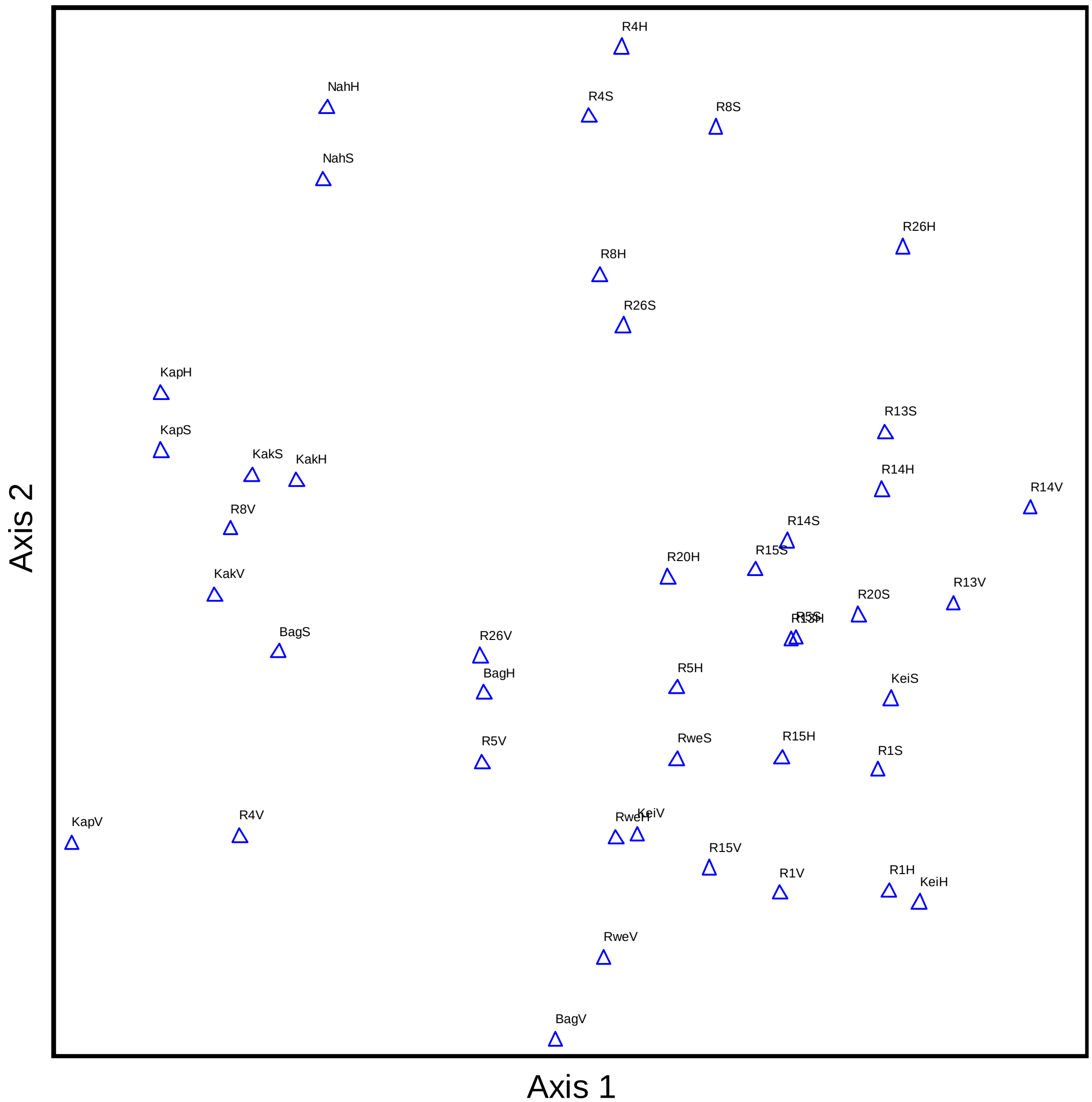
15 Farms
26 Species

	Q Ager	Q Ahoc	Q Asch	Q Asie	Q Bpla	Q Brac	Q Cedu	Q Cery	Q Cap	Q Chl	Q Cym	Q Cyn	Q Dcin	Q Dsca
BAG-01	5.93	0.00	0.07	0.00	0.00	12.80	0.00	0.00	0.00	1.60	0.13	0.87	0.00	0.53
KAK-01	0.00	0.00	1.40	0.67	0.20	18.33	0.00	0.00	0.00	0.40	0.07	2.20	0.00	0.00
KAP-01	0.00	0.00	0.33	0.00	0.13	13.13	0.00	0.00	0.27	0.13	0.07	1.40	0.00	0.00
KEI-01	5.53	5.93	0.00	0.00	0.20	8.80	0.60	1.20	0.00	0.20	0.07	0.47	1.60	1.13
NAH-01	0.00	0.25	0.00	0.00	0.00	4.25	0.00	0.00	0.00	0.00	9.92	0.50	0.00	0.00
RAN-01	8.67	3.20	0.00	0.80	0.47	14.07	0.20	0.47	0.80	0.27	0.07	0.60	0.00	0.07
RAN-04	0.00	2.53	0.73	0.00	0.00	7.87	0.00	0.00	0.00	0.13	14.27	0.60	0.00	0.13
RAN-05	0.73	4.67	1.20	0.07	0.00	13.27	0.00	0.00	0.47	0.20	2.73	3.80	0.00	6.27
RAN-08	0.13	4.40	0.13	0.07	0.07	14.07	0.00	0.67	0.00	0.93	9.60	0.87	0.00	0.13
RAN-13	3.07	2.80	0.00	0.20	0.00	11.68	0.47	0.73	0.13	0.00	5.20	0.20	0.00	0.67
RAN-14	8.00	8.20	0.20	0.00	0.00	16.40	0.67	1.27	0.47	0.00	7.67	0.20	0.00	0.67
RAN-15	5.80	1.60	0.40	0.53	0.00	19.27	0.07	0.13	0.73	0.00	0.00	1.80	0.20	0.07
RAN-20	0.00	4.30	0.00	0.40	0.00	16.50	0.00	0.50	0.00	0.20	1.80	1.20	2.20	0.00
RAN-26	0.60	7.47	0.00	0.40	0.13	9.33	0.00	0.40	0.00	0.00	10.00	1.27	0.00	0.67
RWE-01	6.40	0.73	0.07	0.00	0.00	15.87	0.00	0.33	1.20	1.00	0.13	0.67	0.47	0.20

Appendix B: Continued

	Q Eten	Q Fvir	Q Gmol	Q Hyp	Q Lkag	Q Oci	Q Pan	Q Rnat	Q Shom	Q Set	Q Spo	Q Them
BAG-01	0.00	0.00	0.00	7.60	4.93	0.00	2.60	0.00	0.00	1.47	14.07	0.07
KAK-01	0.00	0.00	0.00	11.40	9.07	0.00	0.07	0.00	0.00	0.47	7.13	0.00
KAP-01	0.00	0.00	0.00	14.07	8.13	0.00	0.40	0.00	0.07	5.73	5.67	0.20
KEI-01	0.73	0.20	0.40	0.93	1.47	0.07	1.53	1.67	0.33	1.47	10.60	0.00
NAH-01	0.40	0.00	0.00	13.92	0.00	0.00	1.50	0.00	0.00	0.00	0.34	0.00
RAN-01	0.53	0.07	1.53	0.73	0.07	0.47	6.93	0.67	1.20	0.00	8.87	0.00
RAN-04	0.00	0.00	0.00	5.27	2.80	0.07	0.13	0.13	0.27	2.73	8.07	0.07
RAN-05	0.00	0.00	1.47	2.60	0.40	0.40	7.00	0.47	0.33	0.33	17.80	1.80
RAN-08	0.27	0.00	0.00	10.33	0.93	0.00	0.07	0.00	0.00	0.00	4.20	0.07
RAN-13	0.13	0.53	1.40	0.13	0.60	0.07	3.47	1.67	0.67	0.00	3.80	0.00
RAN-14	0.00	0.33	0.60	0.33	1.67	0.07	0.87	1.20	0.40	0.00	2.80	0.00
RAN-15	0.00	0.13	0.53	0.27	0.13	0.27	0.13	0.00	1.00	0.00	4.27	0.00
RAN-20	0.00	0.00	0.00	1.30	0.10	0.40	3.00	0.20	0.00	0.00	5.00	0.00
RAN-26	0.53	0.60	0.13	3.00	3.73	0.07	1.87	0.60	0.60	0.47	8.00	0.00
RWE-01	0.00	0.00	0.87	2.27	2.67	0.27	4.07	0.07	0.33	0.53	15.53	0.00

Appendix C: DCA overlay of plant species structure on farms by ecosite ordination. The triangles represent hilltops (H), slopes (S) and valleys (V) of the 15 farms. Note farm names have been shortened to avoid crowding.



Appendix D: Pearson (r) and Kendall (tau) species correlations with ordination axes

Axis:	1			2			3		
	r	r-sq	tau	r	r-sq	tau	r	r-sq	tau
Ager	-.727	.528	-.671	.142	.020	.030	-.527	.277	-.310
Ahoc	-.425	.181	-.309	.619	.383	.483	.311	.097	.232
Asch	.220	.048	.217	-.535	.286	-.321	.216	.047	-.114
Asie	-.291	.085	-.237	-.071	.005	-.108	-.415	.172	-.216
Bpla	-.191	.037	-.036	-.141	.020	-.250	-.163	.027	-.131
Brac	-.419	.176	-.230	-.311	.097	-.172	-.683	.467	-.593
Cedu	-.519	.269	-.580	.526	.277	.328	-.125	.016	-.202
Cery	-.519	.269	-.453	.632	.399	.494	-.126	.016	-.062
Cap	-.536	.287	-.425	-.147	.022	-.090	-.382	.146	-.313
Chl	.033	.001	-.051	-.459	.211	-.501	-.190	.036	-.215
Cym	.472	.223	.315	.638	.407	.513	.577	.333	.591
Cyn	.009	.000	.174	-.619	.383	-.502	.259	.067	-.058
Dcin	-.332	.110	-.331	.111	.012	-.028	-.154	.024	-.221
Dsca	-.270	.073	-.362	-.249	.062	.221	.617	.381	.322
Eten	-.120	.014	-.166	.354	.126	.260	.212	.045	.237
Fvir	-.325	.105	-.411	.577	.333	.458	.119	.014	.012
Gmol	-.718	.515	-.575	.074	.006	.064	.082	.007	-.064
Hyp	.919	.844	.733	-.431	.186	-.314	.117	.014	.143
Lkag	.477	.228	.314	-.647	.419	-.238	-.131	.017	-.086
Oci	-.660	.435	-.503	-.055	.003	.032	-.085	.007	-.054
Pan	-.574	.330	-.337	-.153	.024	-.029	.258	.067	.087
Rnat	-.572	.327	-.507	.513	.264	.403	.147	.022	.197
Shom	-.666	.443	-.590	.313	.098	.224	-.244	.060	-.061
Set	.429	.184	.280	-.411	.169	-.345	.083	.007	.172
Spo	-.360	.129	-.162	-.584	.342	-.448	.266	.071	.048
Them	-.116	.014	.349	-.378	.143	-.271	.592	.350	.349

Appendix E: Soil parameters used in PHYGROW simulations for Kikaatsi sites

Farms represented KAP-01, KAK-01, NAH-01, RAN-04, RAN-08

1. Hilltop position		Soil layers			
Parameter	0	1	2	3	4
Soil type*	Evap	SCL	SCL	SC	Image
Soil depth (cm)	0.5	16.5	31	33	500
Rock factor (%)	0	0.01	0.01	0.1	0.1
Saturated hydraulic conductivity (cm/hr)	0.39	0.39	0.21	0.31	0.31
Moist bulk density (gm/cm^3)	1.43	1.43	1.37	1.33	1.33
Dry bulk density (gm/cm^3)	1.48	1.48	1.42	1.38	1.38
Volumetric water content (cm^3/cm^3)					
0 Bar	0.46	0.46	0.48	0.5	0.5
-1/3 Bar	0.24	0.24	0.28	0.31	0.31
-15 Bar	0.15	0.15	0.19	0.22	0.22
Surface water storage (cm)	6				
Surface slope (%)	5				
Max SCS condition curve	68				
Min SCS condition curve	49				
Bottom type	0				

2. Slope position		Soil layers			
Parameter	0	1	2	3	4
Soil type*	Evap	SC	SCL	SCL	Image
Soil depth (cm)	0.5	12.5	20	28	500
Rock factor (%)	0	0.05	0.5	0.5	0.5
Saturated hydraulic conductivity (cm/hr)	0.48	0.48	0.24	0.24	0.24
Moist bulk density (gm/cm^3)	1.45	1.45	1.38	1.38	1.38
Dry bulk density (gm/cm^3)	1.5	1.5	1.43	1.43	1.43
Volumetric water content (cm^3/cm^3)					
0 Bar	0.45	0.45	0.48	0.48	0.48
-1/3 Bar	0.23	0.23	0.27	0.27	0.27
-15 Bar	0.14	0.14	0.18	0.18	0.18
Surface water storage (cm)	6				
Surface slope (%)	5				
Max SCS condition curve	68				
Min SCS condition curve	49				
Bottom type	0				

* Evap (evaporative layer), SC (sandy clay), SCL (sandy clay loam), Image (image layer / sub soil).

Appendix E: Continued

Farms represented KAP-01, KAK-01, NAH-01, RAN-04, RAN-08

3. Valley position	Soil layers						
Parameter	0	1	2	3	4	5	6
Soil type*	Evap	SCL	SCL	SL	SC	SC	Image
Soil depth (cm)	0.5	18.5	20	18	20	23	500
Rock factor (%)	0	0	0	0	0.001	0.001	0.001
Saturated hydraulic conductivity (cm/hr)	0.39	0.39	0.39	0.77	0.12	0.12	0.12
Bulk density (gm/cm^3)	1.43	1.43	1.43	1.48	1.31	1.31	1.31
Dry bulk density (gm/cm^3)	1.48	1.48	1.48	1.53	1.36	1.36	1.36
Volumetric water content (cm^3/cm^3)							
0 Bar	0.46	0.46	0.46	0.44	0.51	0.51	0.51
-1/3 Bar	0.24	0.24	0.24	0.21	0.33	0.33	0.33
-15 Bar	0.15	0.15	0.15	0.13	0.24	0.24	0.24
Surface water storage (cm)	6						
Surface slope (%)	5						
Max SCS condition curve	68						
Min SCS condition curve	49						
Bottom type	0						

* Evap (evaporative layer), SC (sandy clay), SCL (sandy clay loam), SL (sandy loam), Image (image layer / sub soil).

Appendix F: Soil parameters for PHYGROW simulations for Kanyaryeru sites

Farms represented BAG-01, KEI-01, RAN-01, RAN-05, RWE-01

1. Hilltop position

Parameter	Soil layers 0	1	2	3	4	5	6	7
Soil name	Evap	SCL	SCL	SCL	SCL	SC	SC	Image
Soil depth (cm)	0.5	20.5	24	20	31	20	25	650
Rock factor (%)	0	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Saturated hydraulic conductivity (cm/hr)	0.52	0.52	0.34	0.19	0.19	0.2	0.2	0.2
Bulk density (gm/cm^3)	1.45	1.45	1.42	1.36	1.36	1.38	1.38	1.38
Dry bulk density (gm/cm^3)	1.5	1.5	1.47	1.41	1.41	1.43	1.43	1.43
Volumetric water content (cm^3/cm^3) 0 Bar	0.45	0.45	0.47	0.49	0.49	0.48	0.48	0.48
-1/3 Bar	0.23	0.23	0.24	0.29	0.29	0.27	0.27	0.27
-15 Bar	0.14	0.14	0.16	0.19	0.19	0.18	0.18	0.18
Surface water storage (cm)	4							
Surface slope (%)	5							
Max SCS condition curve	68							
Min SCS condition curve	49							
Bottom type	0							

2. Slope position

Parameter	Soil layers 0	1	2	3	4	5	6	7
Soil name	Evap	SCL	SC	SCL	SCL	SCL	SCL	Image
Soil depth (cm)	0.5	22.5	18	25	25	30	40	650
Rock factor (%)	0	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Saturated hydraulic conductivity (cm/hr)	0.51	0.51	0.64	0.4	0.4	0.4	0.28	0.28
Bulk density (gm/cm^3)	1.45	1.45	1.47	1.44	1.44	1.44	1.41	1.41
Dry bulk density (gm/cm^3)	1.5	1.5	1.52	1.49	1.49	1.49	1.46	1.46
Volumetric water content (cm^3/cm^3) 0 Bar	0.45	0.45	0.44	0.46	0.46	0.46	0.47	0.47
-1/3 Bar	0.23	0.23	0.21	0.23	0.23	0.23	0.25	0.25
-15 Bar	0.14	0.14	0.13	0.15	0.15	0.15	0.17	0.17
Surface water storage (cm)	4							
Surface slope (%)	5							
Max SCS condition curve	68							
Min SCS condition curve	49							
Bottom type	0							

* Evap (evaporative layer), SC (sandy clay), SCL (sandy clay loam), Image (image layer / sub soil).

Appendix F: Continued

Farms represented BAG-01, KEI-01, RAN-01, RAN-05, RWE-01

3. Valley position

Parameter	Soil layers 0	1	2	3	4	5
Soil name	Evap	SCL	SCL	C	C	Image
Soil depth (cm)	0.5	12.5	13	25	30	650
Rock factor (%)	0	0	0.01	0.01	0.01	0.01
Saturated hydraulic conductivity (cm/hr)	0.19	0.19	0.22	0.14	0.14	0.14
Bulk density (gm/cm^3)	1.38	1.38	1.36	1.28	1.28	1.28
Dry bulk density (gm/cm^3)	1.43	1.43	1.41	1.33	1.33	1.33
Volumetric water content (cm^3/cm^3)						
0 Bar	0.48	0.48	0.49	0.52	0.52	0.52
-1/3 Bar	0.27	0.27	0.28	0.37	0.37	0.37
-15 Bar	0.19	0.19	0.19	0.26	0.26	0.26
Surface water storage (cm)	4					
Surface slope (%)	5					
Max SCS condition curve	68					
Min SCS condition curve	49					
Bottom type	0					

* Evap (evaporative layer), SCL (sandy clay loam), C (clay), Image (image layer / sub soil).

Appendix G: Soil parameters used in PHYGROW simulations for Sanga sites

Farms represented RAN-13, RAN-14, RAN-15, RAN-20

1. Hilltop position

Parameter		Soil layers 0	1	2	3	4	5	6	7	8	9
Soil name		Evap	SC	SC	SC	SC	SC	SC	SC	SC	Image
Soil depth (cm)		0.5	12.5	21	30	30	25	25	25	11	650
Rock factor (%)		0	0	0	0	0	0	0.95	0.95	0.95	0.95
Saturated hydraulic conductivity (cm/hr)		0.84	0.84	0.16	0.16	0.16	0.16	0.16	0.16	0.18	0.18
Bulk density (gm/cm^3)		1.48	1.48	1.34	1.34	1.34	1.34	1.34	1.34	1.34	1.34
Dry bulk density (gm/cm^3)		1.53	1.53	1.39	1.39	1.39	1.39	1.39	1.39	1.39	1.39
Volumetric water content (cm^3/cm^3)	0 Bar	0.44	0.44	0.5	0.5	0.5	0.5	0.5	0.5	0.49	0.49
	-1/3 Bar	0.21	0.21	0.31	0.31	0.31	0.31	0.31	0.31	0.3	0.3
	-15 Bar	0.12	0.12	0.21	0.21	0.21	0.21	0.21	0.21	0.2	0.2
Surface water storage (cm)		4									
Surface slope (%)		5									
Max SCS condition curve		68									
Min SCS condition curve		49									
Bottom type		0									

2. Slope position

Parameter		Soil layers 0	1	2	3	4	5
Soil type		Evap	SCL	SCL	SC	SC	Image
Soil depth (cm)		0.5	21.5	32	20	26	650
Rock factor (%)		0	0	0	0.1	0.1	0.1
Saturated hydraulic conductivity (cm/hr)		0.41	0.41	0.27	0.12	0.12	0.12
Bulk density (gm/cm^3)		1.43	1.43	1.4	1.29	1.29	1.29
Dry bulk density (gm/cm^3)		1.48	1.48	1.45	1.34	1.34	1.34
Volumetric water content (cm^3/cm^3)	0 Bar	0.46	0.46	0.47	0.51	0.51	0.51
	-1/3 Bar	0.23	0.23	0.25	0.35	0.35	0.35
	-15 Bar	0.15	0.15	0.17	0.25	0.25	0.25
Surface water storage (cm)		4					
Surface slope (%)		5					
Max SCS condition curve		68					
Min SCS condition curve		49					
Bottom type		0					

* Evap (Evaporative layer), SC (Sandy clay), SCL (Sandy clay loam), Image (Image layer / sub soil).

Appendix G: Continued

Farms represented RAN-13, RAN-14, RAN-15, RAN-20

3. Valley position	Soil layers							
Parameter	0	1	2	3	4	5	6	7
Soil type	Evap	SCL	SCL	SCL	SC	SC	SC	Image
Soil depth (cm)	0.5	27.5	35	31	17	30	30	650
Rock factor (%)	0	0	0	0	0	0	0	0.001
Saturated hydraulic conductivity (cm/hr)	0.64	0.64	0.22	0.5	0.14	0.14	0.14	0.14
Bulk density (gm/cm^3)	1.45	1.45	1.36	1.44	1.33	1.33	1.33	1.33
Dry bulk density (gm/cm^3)	1.5	1.5	1.41	1.49	1.38	1.38	1.38	1.38
Volumetric water content (cm^3/cm^3) 0 Bar	0.45	0.45	0.49	0.46	0.5	0.5	0.5	0.5
-1/3 Bar	0.23	0.23	0.28	0.23	0.31	0.31	0.31	0.31
-15 Bar	0.13	0.13	0.18	0.14	0.22	0.22	0.22	0.22
Surface water storage (cm)	4							
Surface slope (%)	5							
Max SCS condition curve	68							
Min SCS condition curve	49							
Bottom type	0							

* Evap (Evaporative layer), SC (Sandy clay), SCL (Sandy clay loam), Image (Image layer / sub soil).

Appendix H: Soil parameters for PHYGROW simulations for RAN-26

Farm represented RAN-26

1. Hilltop position

Parameter	Soil layers 0	1	2	3	4	5	6
Soil type	Evap	SL	SCL	SCL	SCL	SCL	Image
Soil depth (cm)	0.5	18.5	17	20	20	24	650
Rock factor (%)	0	0	0.4	0.4	0.2	0.2	0.2
Saturated hydraulic conductivity (cm/hr)	1.1	1.1	0.36	0.36	0.25	0.25	0.25
Bulk density (gm/cm^3)	1.5	1.5	1.41	1.41	1.39	1.39	1.39
Dry bulk density (gm/cm^3)	1.55	1.55	1.46	1.46	1.44	1.44	1.44
Volumetric water content (cm^3/cm^3)							
0 Bar	0.43	0.43	0.47	0.47	0.48	0.48	0.48
-1/3 Bar	0.2	0.2	0.25	0.25	0.27	0.27	0.27
-15 Bar	0.12	0.12	0.16	0.16	0.17	0.17	0.17
Surface water storage (cm)	4						
Surface slope (%)	5						
Max SCS condition curve	68						
Min SCS condition curve	49						
Bottom type	0						

2. Slope position

Parameter	Soil layers 0	1	2	3	4	5	6
Soil type	Evap	SCL	SCL	SC	SC	SC	Image
Soil depth (cm)	0.5	22.5	32	20	24	22	650
Rock factor (%)	0	0	0	0	0	0.001	0.001
Saturated hydraulic conductivity (cm/hr)	0.42	0.42	0.26	0.15	0.15	0.16	0.16
Bulk density (gm/cm^3)	1.43	1.43	1.38	1.34	1.34	1.36	1.36
Dry bulk density (gm/cm^3)	1.48	1.48	1.43	1.39	1.39	1.41	1.41
Volumetric water content (cm^3/cm^3)							
0 Bar	0.46	0.46	0.48	0.49	0.49	0.49	0.49
-1/3 Bar	0.24	0.24	0.27	0.3	0.3	0.29	0.29
-15 Bar	0.15	0.15	0.17	0.21	0.21	0.2	0.2
Surface water storage (cm)	4						
Surface slope (%)	5						
Max SCS condition curve	68						
Min SCS condition curve	49						
Bottom type	0						

* Evap (Evaporative layer), SC (Sandy clay), SCL (Sandy clay loam), SL (Sandy loam), Image (Image layer / sub soil).

Appendix H: Continued

Farms represented RAN-26

3. Valley position	Soil layers				
Parameter	0	1	2	3	4
Soil type*	Evap	SCL	SCL	SCL	Image
Soil depth (cm)	0.5	21.5	23	36	650
Rock factor (%)	0	0	0	0.001	0.001
Saturated hydraulic conductivity (cm/hr)	0.66	0.66	0.58	0.2	0.2
Bulk density (gm/cm^3)	1.46	1.46	1.42	1.36	1.36
Dry bulk density (gm/cm^3)	1.51	1.51	1.47	1.41	1.41
Volumetric water content (cm^3/cm^3)					
0 Bar	0.45	0.45	0.46	0.49	0.49
-1/3 Bar	0.22	0.22	0.25	0.29	0.29
-15 Bar	0.13	0.13	0.14	0.19	0.19
Surface water storage (cm)	4				
Surface slope (%)	5				
Max SCS condition curve	68				
Min SCS condition curve	49				
Bottom type	0				

* Evap (Evaporative layer), SCL (Sandy clay loam), Image (Image layer /sub soil).

Appendix I: A sample of plant species and categories on farm RAN-14 (slope) used in PHYGROW

Species	RAN-14: Slope position
Grasses	Basal cover (%)
Andropogon schirensis	0.6
Brachiaria spp.	17.0
Cymbopogon afronardus	14.0
Loudentia kagerensis	2.4
Panicum maximum	1.0
Sporobolus pyramidalis	1.4
Forbs	Frequency (%)
Annual forbs	19.4
Commelina bengalensis	1.4
Kyllinga alba	6.4
Leguminous herbs	2.0
Woody / Tree	Effective canopy cover (%)
Acacia gerrardii	13.2
Acacia hockii	8.8

Appendix J: Plant species attributes used in PHYGROW

1. Leaf area index (LAI)
2. Dry matter to radiation ratio (gm dry matter/mega joule radiation)
3. Suppression temperature (^oC)
4. Base temperature (^oC)
5. Current years growth turnover (% current leaf/day)
6. Heat unit accumulation at seed (^oC)
7. Heat unit accumulation at death (^oC)
8. Rooting depth (cm)
9. Canopy height (cm)
10. Max above ground biomass (kg)
11. Current years growth /above ground biomass ratio
12. Wood area index (SAI)
13. Current years growth water storage capacity (gm water/gm dry matter)
14. Wood water store capacity (gm water/gm dry matter)
15. Fraction of water transferred from leaf to stem
16. Wood turnover (% current stem/day)
17. Cold unit accumulation to freeze leaf damage (^oC)
18. Current years growth green to dead rate
19. Current years growth green to dead rate during dormancy
20. Canopy base diameter (cm)
21. Canopy crown diameter (cm)
22. Height at canopy start (cm)
23. Height at beginning of canopy curvature (cm)
24. Max current years growth litter decomposition rate (% litter standing crop)
25. Max wood litter decomposition rate (% litter standing crop)
26. Current years growth litter water store capacity (gm water/gm dry matter)
27. Wood litter water store capacity (gm water/gm dry matter)
28. Contribution to range site hydrologic condition
29. Minimum required day length to grow (hours)
30. Optimum temperature (^oC)
31. Left side of temperature curve
32. Right side of temperature curve
33. Current year's growth maximum moisture
34. Live wood maximum moisture

Appendix K: Grazing decision rules used in PHYGROW

		Decision days						
Farm	SR	0	180	240	340	SR Incr	Min PDU	Max PDU
BAG-01	Min/Max	1.04	0.75	1.04	0.90	0	500	5000
KAK-01	Min/Max	0.70	0.63	0.70	0.76	0	500	5000
KAP-01	Min/Max	1.64	1.45	1.64	1.64	0	500	5000
KEI-01	Min/Max	1.67	1.45	1.64	1.52	0	500	5000
NAH-01	Min/Max	1.15	1.00	1.10	1.00	0	500	5000
RAN-01	Min/Max	0.67	0.62	0.67	0.62	0	500	5000
RAN-04	Min/Max	1.14	1.08	1.14	1.08	0	500	5000
RAN-05	Min/Max	1.63	1.56	1.63	1.56	0	500	5000
RAN-08	Min/Max	1.31	1.22	1.31	1.22	0	500	5000
RAN-13	Min/Max	2.08	1.93	2.08	1.93	0	500	5000
RAN-14	Min/Max	0.39	0.35	0.39	0.35	0	500	5000
RAN-15	Min/Max	0.39	0.38	0.39	0.38	0	500	5000
RAN-20	Min/Max	0.48	0.44	0.46	0.47	0	500	5000
RAN-26	Min/Max	1.69	1.63	1.69	1.66	0	500	5000
RWE-01	Min/Max	1.39	1.25	1.38	1.32	0	500	5000

SR = stocking rate, SR Incr = stocking rate increment, PDU = preferred, desirable, undesirable

Appendix L: Plant species grazing preferences by cattle

	Current year's growth					Wood growth				
Plant Species	FG	DG	DR	DD	LI	FG	DG	DR	DD	LI
Acacia gerrardii	E	E	E	N	E	N	N	N	N	N
Acacia hockii	U	U	E	E	E	N	N	N	N	N
Acacia sieberiana	E	E	E	E	E	N	N	N	N	N
Andropogon schirensis	D	U	U	U	E	N	N	N	N	N
Annual forbs	D	U	E	E	N	N	N	N	E	N
Brachiaria platynota	D	D	U	U	E	N	N	N	N	N
Brachiaria spp.	P	D	U	U	E	N	N	N	N	N
Capparis spp.	U	E	E	E	E	N	N	N	N	N
Carissa edulis	E	E	E	E	E	N	N	N	N	N
Chloris gayana	P	D	U	U	E	N	N	N	N	N
Commelina bengalensis	D	U	U	U	E	N	N	N	N	N
Cymbopogon afronardus	U	U	E	E	E	N	N	N	N	N
Cynodon dactylon	P	D	U	U	E	N	N	N	N	N
Dichrostachys cinerea	U	U	E	E	E	N	N	N	N	N
Digitaria scalarum	P	D	U	U	E	N	N	N	N	N
Eragrostis tenuifolia	D	D	U	U	E	N	N	N	N	N
Flueggea virosa	E	E	E	E	E	N	N	N	N	N
Grewia mollis	E	E	E	E	E	N	N	N	N	N
Hoslundia opposita	U	U	U	E	E	N	N	N	N	N
Hyparrhenia spp.	D	U	U	U	E	N	N	N	N	N
Hypoestes spp.	U	U	U	E	E	N	N	N	N	N
Indigofera spp.	D	D	U	U	E	N	N	N	N	N
Kyllinga spp.	D	U	U	U	E	N	N	N	N	N

Appendix L: Continued

Plant Species	Current year's growth					Wood growth				
	FG	DG	DR	DD	LI	FG	DG	DR	DD	LI
Lantana camara	E	E	E	E	E	N	N	N	N	N
Leguminous herbs	D	D	D	U	E	N	N	N	N	N
Loudentia kagerensis	D	U	U	U	E	N	N	N	N	N
Monechma subsessile	U	U	E	E	E	N	N	N	N	N
Neonotonia wightii	D	D	U	U	E	N	N	N	N	N
Ocimum spp.	U	E	E	E	E	N	N	N	N	N
Oxalis spp.	U	U	E	E	E	N	N	N	N	N
Panicum maximum	P	D	U	U	E	N	N	N	N	N
Rhus natalensis	U	E	E	E	E	N	N	N	N	N
Setaria homonyma	D	D	U	U	E	N	N	N	N	N
Setaria spp.	D	D	U	U	E	N	N	N	N	N
Solanum incanum	U	N	N	N	E	N	N	N	N	N
Sporobolus spp.	D	D	U	U	E	N	N	N	N	N
Themeda triandra	D	U	U	N	E	N	N	N	N	N
Triumfetta rhomboidea	U	U	U	U	E	N	N	N	N	N
Wyne cassia	P	D	D	U	E	N	N	N	N	N

Current year's growth / Wood growth: FG = fast growth, DG = declining growth, DR = dormancy, DD = dead, LI = litter

P = preferred, D = desirable, U = undesirable, E = emergency, N = non-consumed

Appendix M: Plant species grazing preferences by goats

	Current year's growth				Wood growth					
Plant Species	FG	DG	DR	DD	FG	DG	DR	DD	LI	LI
Acacia gerrardii	D	U	U	U	N	N	N	N	E	N
Acacia hockii	P	D	U	U	N	N	N	N	E	N
Acacia sieberiana	P	D	U	U	N	N	N	N	E	N
Andropogon schirensis	D	U	U	U	N	N	N	N	E	N
Annual forbs	D	D	U	U	N	N	N	N	E	N
Brachiaria platynota	D	U	U	U	N	N	N	N	E	N
Brachiaria spp.	D	D	U	U	N	N	N	N	E	N
Capparis spp.	P	D	U	U	N	N	N	N	E	N
Carissa edulis	D	D	U	U	N	N	N	N	E	N
Chloris gayana	D	U	U	U	N	N	N	N	E	N
Commelina bengalensis	D	U	U	U	N	N	N	N	E	N
Cymbopogon afronardus	U	E	E	E	N	N	N	N	E	N
Cynodon dactylon	D	U	U	U	N	N	N	N	E	N
Dichrostachys cinerea	P	D	U	U	N	N	N	N	E	N
Digitaria scalarum	D	D	U	U	N	N	N	N	E	N
Eragrostis tenuifolia	D	D	U	U	N	N	N	N	E	N
Flueggea virosa	U	E	E	E	N	N	N	N	E	N
Grewia mollis	D	D	U	U	N	N	N	N	E	N
Hoslundia opposita	U	U	E	E	N	N	N	N	E	N
Hyparrhenia spp.	U	U	U	U	N	N	N	N	E	N
Hypoestes spp.	U	U	U	U	N	N	N	N	E	N
Indigofera spp.	D	D	U	U	N	N	N	N	E	N
Kyllinga spp.	U	U	U	U	N	N	N	N	E	N

Appendix M: Continued

Plant Species	Current year's growth				Wood growth					
	FG	DG	DR	DD	FG	DG	DR	DD	LI	LI
Lantana camara	U	U	U	U	N	N	N	N	E	N
Leguminous herbs	P	D	D	U	N	N	N	N	E	N
Loudentia kagerensis	U	U	U	U	N	N	N	N	E	N
Monechma subsessile	U	U	E	E	N	N	N	N	E	N
Neonotonia wightii	D	D	U	U	N	N	N	N	E	N
Ocimum spp.	D	D	U	U	E	N	N	N	E	N
Oxalis spp.	D	D	U	U	E	N	N	N	E	N
Panicum maximum	D	D	U	U	N	N	N	N	E	N
Rhus natalensis	P	D	U	U	N	N	N	N	E	N
Setaria spp.	D	D	U	U	N	N	N	N	E	N
Solanum incanum	D	D	U	U	N	N	N	N	E	N
Sporobolus spp.	D	D	U	U	N	N	N	N	E	N
Themeda triandra	D	U	U	U	N	N	N	N	E	N
Triumfetta rhomboidea	U	U	U	E	N	N	N	N	E	N
Wyne cassia	P	D	D	U	N	N	N	N	E	N

Current year's growth / Wood growth: FG = fast growth, DG = declining growth, DR = dormancy, DD = dead, LI = litter

P = preferred, D = desirable, U = undesirable, E = emergency, N = non-consumed

Appendix N: Forage clipping dates on farms with observed and PHYGROW predicted DM yields.

Farm	Clipping Date	Obs wt (DM)	SE	Pred wt (DM)	*R^2
RAN-26	May, 19,2002	2781	284	2320	0.87
NAH-01	May, 29,2002	2244	204	2148	0.90
RAN-04	May, 29,2002	3646	452	3526	0.85
RAN-04	June, 26,2002	3135	276	3233	0.91
RAN-05	June, 26,2002	2758	227	3058	0.95
KEI-01	June, 27,2002	1253	155	1694	0.97
RWE-01	June, 27,2002	2481	240	2855	0.96
RAN-04	July, 19,2002	2687	452	2906	0.98
KEI-01	July, 20,2002	1151	115	1507	0.97
RAN-05	July, 20,2002	2162	227	2602	0.92
RWE-01	July, 20,2002	2081	173	2496	0.98
NAH-01	Aug, 21,2002	1771	174	1396	0.98
RAN-04	Aug, 22,2002	2502	364	2236	0.94
RAN-05	Aug, 23,2002	2218	201	1991	0.98
BAG-01	Aug, 25,2002	1669	152	2236	0.90
NAH-01	Dec, 16,2002	1749	235	1210	0.97
RAN-26	Dec, 15,2002	1290	83	1424	0.72
RAN-05	Dec, 12,2002	1657	157	1929	0.79
NAH-01	Jan, 23,2003	1647	220	1356	0.84
RAN-26	Jan, 23,2003	1527	151	1604	0.88
RAN-04	Jan, 23,2003	3209	562	2598	0.96
RAN-05	Jan, 23,2003	1880	185	2308	0.97
RAN-08	Jan, 23,2003	2680	382	2069	0.96
NAH-01	Feb, 18,2003	1288	168	1752	0.76
RAN-04	Feb, 18,2003	2766	299	2917	0.81
RAN-26	Feb, 20,2003	1951	165	1822	0.74
NAH-01	Mar, 26,2003	2072	275	1998	0.95
RAN-04	Mar, 26,2003	3323	416	2861	0.93
RAN-08	Mar, 26,2003	2954	294	2510	0.33
RAN-13	Mar, 27,2003	1930	290	1279	0.97
RAN-26	Mar, 27,2003	1853	259	1879	0.97

*(clipped & scored DM)

Appendix O: Forage DM (kg/ha) production on farms (ungrazed)

Farm	DM/kg/ha	SE
BAG-01	3995	320
KAK-01	4579	184
KAP-01	4284	296
KEI-01	3641	271
NAH-01	2861	276
RAN-01	4446	236
RAN-04	3418	345
RAN-05	4772	245
RAN-08	3846	331
RAN-13	3470	551
RAN-14	3913	465
RAN-15	4218	357
RAN-20	4371	107
RAN-26	3576	283
RWE-01	4247	131
Mean	3993	293

Appendix P: Monthly cattle diet CP (%) by farm

	Farms							
Month	BAG-01	KAK-01	KAP-01	KEI-01	NAH-01	RAN-01	RAN-04	RAN-05
Apr-02	9.90	9.27	9.10	11.24	8.82	12.35	9.55	11.99
May-02	11.26	10.41	10.14	11.87	9.86	14.04	10.94	13.60
Jun-02	8.78	10.90	7.39	12.80	8.53	11.33	9.19	11.42
Jul-02	7.92	7.05	5.79	8.36	8.05	8.63	6.75	8.14
Aug-02	8.28	5.35	5.56	6.40	5.24	8.50	6.51	6.31
Sep-02	8.23	7.74	8.65	9.46	7.87	8.92	8.79	10.97
Oct-02	9.59	8.01	8.05	11.04	10.18	12.54	10.84	14.02
Nov-02	8.84	11.68	12.51	12.32	9.47	13.32	10.96	13.12
Dec-02	10.30	11.40	9.95	12.29	10.93	12.83	11.04	13.92
Jan-03	8.45	10.63	8.83	10.51	10.53	11.48	12.56	11.81
Feb-03	7.62	8.23	7.24	8.88	9.44	10.93	8.94	9.83
Mar-03	11.18	9.84	10.08	11.55	10.08	13.53	9.50	13.14
Apr-03	10.44	9.61	8.76	10.90	10.74	12.05	8.54	12.07

Farm*Month are significantly different (P<0.0001)

Appendix P: continued

	Farms						
Month	RAN-08	RAN-13	RAN-14	RAN-15	RAN-20	RAN-26	RWE-01
Apr-02	11.46	-	-	15.28	-	10.68	11.53
May-02	12.88	-	-	14.88	-	11.50	11.74
Jun-02	10.58	-	11.30	11.87	-	8.87	9.07
Jul-02	8.77	8.49	8.27	10.01	8.46	8.01	7.82
Aug-02	7.12	6.95	6.96	8.12	7.06	4.66	7.94
Sep-02	8.28	8.52	8.63	8.81	9.30	8.27	7.79
Oct-02	11.96	11.77	15.37	12.07	14.50	14.17	10.38
Nov-02	12.99	13.26	13.38	14.84	13.39	14.17	11.50
Dec-02	12.47	13.86	15.89	14.84	16.41	13.27	11.89
Jan-03	11.11	11.48	10.18	13.36	12.60	10.83	9.00
Feb-03	10.16	9.54	11.61	11.77	10.21	9.97	7.63
Mar-03	13.05	13.25	12.77	14.15	13.12	11.50	11.88
Apr-03	12.49	12.22	11.69	14.03	11.90	10.01	10.26

Farm*Month are significantly different (P<0.0001)

Appendix Q: Monthly cattle diet DOM (%) by farm

	Farms							
Month	BAG-01	KAK-01	KAP-01	KEI-01	NAH-01	RAN-01	RAN-04	RAN-05
Apr-02	62.41	61.08	62.18	63.08	60.15	63.55	61.79	63.42
May-02	64.77	63.60	63.09	64.08	62.15	67.17	63.89	63.04
Jun-02	61.05	61.60	58.84	65.86	57.42	62.21	60.01	61.98
Jul-02	59.87	58.89	58.50	59.51	58.55	60.21	57.06	59.69
Aug-02	60.94	57.70	59.10	57.12	58.15	61.23	59.66	59.84
Sep-02	61.32	61.29	60.94	59.72	62.19	62.70	62.74	58.40
Oct-02	64.26	61.46	61.75	63.86	61.52	64.92	64.71	63.09
Nov-02	61.85	63.34	65.16	64.46	60.45	65.29	62.99	65.49
Dec-02	64.49	62.99	62.13	63.56	60.82	65.40	62.59	66.27
Jan-03	62.73	62.36	61.94	61.67	61.67	64.04	65.12	63.74
Feb-03	60.17	60.40	59.76	61.69	59.07	63.69	61.26	63.30
Mar-03	60.33	58.78	57.14	60.95	58.02	63.60	59.49	60.79
Apr-03	61.40	61.32	59.09	61.95	60.19	62.73	60.80	62.33

Farm*Month are significantly different ($P<0.0001$)

Appendix Q: continued

	Farms						
Month	RAN-08	RAN-13	RAN-14	RAN-15	RAN-20	RAN-26	RWE-01
Apr-02	62.72	-	-	68.57	-	67.72	63.37
May-02	64.12	-	-	66.76	-	63.52	64.02
Jun-02	61.25	-	62.93	62.72	-	60.71	61.52
Jul-02	60.09	59.85	59.86	61.48	59.29	59.77	60.51
Aug-02	58.07	59.47	60.19	59.78	59.01	55.89	60.14
Sep-02	62.28	62.33	63.54	61.91	62.75	59.02	59.79
Oct-02	64.95	63.88	66.83	62.77	65.48	66.16	63.36
Nov-02	64.97	65.58	67.23	67.05	66.03	66.16	63.85
Dec-02	63.71	66.60	67.52	66.87	69.81	64.10	63.38
Jan-03	62.95	63.96	64.10	65.61	64.74	64.04	60.96
Feb-03	61.71	60.17	64.27	63.73	63.05	62.50	59.94
Mar-03	60.98	61.94	62.28	63.83	59.57	59.64	60.95
Apr-03	62.21	62.39	63.60	64.36	61.23	61.25	62.55

Farm*Month are significantly different (P<0.0001)

Appendix R: Mean monthly cattle BCS by farm

	Farms							
Month	BAG-01	KAK-01	KAP-01	KEI-01	NAH-01	RAN-01	RAN-04	RAN-05
Apr-02	-	4.80	4.73	-	3.40	-	4.07	-
May-02	5.67	4.13	4.67	5.33	3.20	4.53	4.15	4.47
Jun-02	5.30	4.36	4.47	4.46	3.20	4.80	3.80	4.75
Jul-02	5.44	4.00	5.00	4.60	3.60	4.93	4.23	4.86
Aug-02	4.93	3.93	4.93	4.47	3.29	5.08	3.64	4.54
Oct-02	4.50	4.50	5.15	4.64	3.38	4.85	3.20	4.77
Nov-02	4.88	4.95	4.79	4.60	3.46	4.80	4.17	4.58
Dec-02	4.90	4.96	5.18	4.70	4.17	4.67	4.00	4.63
Jan-03	4.97	5.15	5.20	4.80	4.00	4.93	4.62	4.93
Feb-03	5.00	5.17	5.11	4.70	4.00	4.96	4.47	4.87
Mar-03	4.89	5.17	5.18	4.60	4.14	4.83	4.43	4.67
Apr-03	4.91	5.10	5.14	4.43	4.39	5.00	4.67	4.65

Farm*Month are significantly different (P<0.0001)

Appendix R: continued

			Farms				
Month	RAN-08	RAN-13	RAN-14	RAN-15	RAN-20	RAN-26	RWE-01
Apr-02	4.60	-	-	4.67	-	3.88	-
May-02	4.07	-	4.87	4.40	-	4.50	5.07
Jun-02	4.20	-	4.83	4.33	-	4.47	4.33
Jul-02	4.40	4.80	5.33	4.73	4.80	5.00	4.87
Aug-02	4.20	4.47	4.83	4.60	4.27	4.27	4.73
Oct-02	4.07	4.27	4.44	4.43	4.07	4.36	4.80
Nov-02	4.40	4.33	4.67	4.57	4.20	4.27	4.93
Dec-02	4.37	4.60	4.71	4.60	4.43	4.40	5.00
Jan-03	4.92	4.97	4.93	5.03	4.63	4.89	5.00
Feb-03	4.80	4.97	4.93	5.12	4.60	4.92	4.67
Mar-03	4.96	4.80	4.86	5.00	4.70	5.03	4.50
Apr-03	4.93	4.47	4.75	4.93	4.60	4.93	4.57

Farm*Month are significantly different (P<0.0001)

Appendix S: Pearson Correlation Coefficients for nutrition aspects and major vegetation types on farms

	BCS	CP	DOM	SR	BRAC	CYMB	WOODY	DOM/CP
BCS	1.000	0.199	-0.073	-0.043	0.467	-0.415	0.298	0.059
CP	0.199	1.000	0.650	-0.214	0.450	-0.129	0.715	-0.942
DOM	-0.073	0.650	1.000	-0.466	0.378	0.240	0.427	-0.738
SR	-0.043	-0.214	-0.466	1.000	-0.560	0.125	-0.154	0.232
BRAC	0.467	0.450	0.378	-0.560	1.000	-0.556	0.204	-0.359
CYMB	-0.415	-0.129	0.240	0.125	-0.556	1.000	-0.200	0.019
WOODY	0.298	0.715	0.427	-0.154	0.204	-0.200	1.000	-0.655
DOM/CP	0.059	-0.942	-0.738	0.232	-0.359	0.019	-0.655	1.000

Appendix T: Nutrient limiting factor (CP or E) by farm, farm group and month

Farm	Months (April 2002-April 2003)													Group
	A	M	J	J	A	S	O	N	D	J	F	M	A	
BAG-01	CP	E	CP	CP	CP	CP	E	E	E	E	CP	E	E	I
KAK-01	CP	E	E	CP	CP	CP	E	E	E	E	E	E	E	I
KAP-01	CP	E	CP	CP	CP	CP	E	E	E	E	CP	E	E	I
RAN-05	E	E	E	CP	CP	E	E	E	E	E	E	E	E	II
RWE-01	E	E	CP	CP	CP	CP	E	E	E	E	CP	E	E	II
KEI-01	E	E	E	CP	CP	CP	E	E	E	E	E	E	E	III
RAN-01	E	E	E	CP	CP	CP	E	E	E	E	E	E	E	III
RAN-15	E	E	E	E	CP	CP	E	E	E	E	E	E	E	III
RAN-20	-	-	-	CP	CP	CP	E	E	E	E	E	E	E	III
NAH-01	CP	CP	CP	CP	CP	CP	E	E	E	E	E	E	E	IV
RAN-04	CP	E	CP	CP	CP	CP	E	E	E	E	E	E	E	IV
RAN-08	E	E	E	CP	CP	CP	E	E	E	E	E	E	E	IV
RAN-26	CP	E	CP	CP	CP	CP	E	E	E	E	E	E	E	IV
RAN-13	-	-	-	CP	CP	CP	E	E	E	E	E	E	E	V
RAN-14	-	-	E	CP	CP	CP	E	E	E	E	E	E	E	V

CP = crude protein, E = energy

Farm group characteristics:

I - Herbaceous species dominated farms ('improved' farms)
II - Herbaceous species dominated but with a moderate woody component
III - Woody species dominated farms with minimal or no *Cymbopogon*.
IV - *Cymbopogon* dominated farms with minimal or no woody species
V - High *Cymbopogon* and high woody components farms

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