EFFECTS OF LARGE HERBIVORES ON SELECTED CHEMICAL PROPERTIES OF TWO SOIL TYPES IN LAIKIPIA, SAVANNA ECOSYSTEM, KENYA

BY

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A Thesis Submitted to the Department of LARMAT, Faculty of Agriculture, University of Nairobi, In Partial Fulfilment of the Requirements for Master of Science Degree in Range Management (Ecology Option)

(2007)

DECLARATION

This thesis is my original work and has not been presented for award of degree in any other university.

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This thesis has been submitted for examination with our approval as the University of Nairobi supervisors.

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DEDICATION

This work is dedicated to my dad and mum, Mr. and Mrs. Jackson Ngatia and my lovely brothers the Ngatia's (Waweru, Kariuki, Ngari and Mwangi) for living their lives for me, you are the reason I press on. To the late uncle Muriithi I know this would have made you proud, rest in peace.

ACKNOWLEDGEMENT

Am indebted to Smithsonian women's committee for awarding me the research grant to carryout my work at Mpala research centre for this I am forever grateful. Likewise, I am more than grateful to my advisors Dr. Jesse Theuri Njoka, Prof. C.K.K Gachene and Dr. Ben Turner. Their sustained guidance and positive criticism of various drafts tremendously improved this thesis. Dr. Ben Turner for facilitating part of my laboratory work and also providing very essential literature materials, many thanks. Prof. Truman Young deserves recognition in this thesis for allowing me to use his KLEE plots in Mpala research centre. Many thanks to the chairman LARMAT and all his academic staff for the direction they provided during the various departmental seminars. To the former chairman Range Management Department Prof. Dickson Nyariki I will forever be grateful for your great encouragement and support during my studies.

The administrators and staff at Mpala Research Centre- Nanyuki deserve recognition in this work, Dr.Nicholas Georgiadis the Centre Director, Kerry Outrum the administrator, Nasser Olwero the GIS specialist and Christopher Odhiambo the resident scientist. They made my stay reasonably relaxed at the centre, in addition to providing necessary academic and scientific materials, which I dearly needed for the success of this research work. In the field Francis Lomojo gave more than enough to help in this study. The long hours we spent together in the field collecting invaluable samples not only guaranteed success but also dependable data and consequently excellent results displayed in this study. For this I am grateful.

Am grateful to soil science laboratory Kabete campus laboratory staff, Martha, Ndambuki, and Mureithi for their great work in samples analysis. Appreciation to John Musembi for assistance in plant species identification. Many thanks to ICRAF soil laboratory staff, Mercy Nyambura, chacha and others for their selfless work in sample analysis. To Smithsonian Soil Laboratory staff many thanks. Statisticians also deserve recognition in this thesis, Mr. Obudho, Mrs. Kurji, Mr. Mong'are and Mr. Kamau your

3team work contributed a lot to this study, many thanks. To Kiros, Harrison, Waweru and Sam thanks for the many printouts you made for me.

I also thank my friends and relatives who stood by me before and after this study. Julie Mwaura, Samuel Ndirangu, Maggie Njoki. My close interaction with you contributed something to this study.

Above all, I acknowledge and thank the Almighty God for strength and grace throughout the period of research and write-up.

ABSTRACT

Livestock and wildlife co-exist throughout the semi-arid ecosystems of the world. There is increasing emphasis on management activities that are both sustainable and more compatible with native biodiversity conservation. Various factors determine the structure and function of savannahs. The study investigated and compared the grazing effects of large herbivores on selected chemical properties of two soils types in Laikipia savannah ecosystem of Kenya. The main objective was to contribute to the understanding of the impact of grazing by large herbivores on nutrient content in Laikipia savannah rangeland.

The study tested the following hypotheses:

1. Herbivores affect the cycling of nitrogen and phosphorus, accumulation of organic matter, C/N ratio and pH in both red sandy loams and black cotton soils.
2. Herbivores affect sequential phosphorus fractionation in both red sandy loams and black cotton soils

The experimental treatments included glades in the grazed area, bush land in the grazed area where the exclosures (which exclude all large herbivores) were used as the control for grazing. Glades are former cattle kraals which were abandoned for several decades of years. In each type of soil, the treatments were replicated three times. The soil sampling design involved 50x50 m^2 plots, diagonal line transects were run and sampling done every 16 m. The samples from each plot were mixed to make a composite sample.

With or without grazing herbivores, the black and red soils are different in terms of the concentration of N, P, C/N ratio and organic matter due to differences in inherent soil fertility. The results of effects of large herbivores on N,P,C/N ratio and organic matter therefore indicate that the two soil types were different, with black cotton soils having higher contents of N, C, organic matter and C/N ratio at $P<0.05$. The C and N correlation coefficient was very high ($r^2>0.9$) in all treatments, indicating a strong and positive relationship between the two variates. Total P was not significantly different between the two soils. The pH was slightly acidic to neutral in the bush land and neutral to slightly

alkaline in the glades. The grazing treatment in glade indicated a trend of increased N, C, C/N ratio and organic matter and decreased P, while the bush land grazing treatment appears to lead to a trend of lower N, C, C/N ratio, organic matter, and total P

Results of effects of large herbivores on sequential phosphorus fractionation also indicated differences between the two soils. Organic P was higher in the black cotton soils glades than in red sandy loams glades while inorganic P was higher in the red sandy loams glades and bush land than in the black cotton soils. The grazing treatment was not significantly different although it appears that the glade grazing treatment led to a trend of increased sequential P fractions, while bush grazing treatment led to a trend of decreased sequential P fractions.

In conclusion glades are enriched with nutrients in expense of bush. The black cotton soil has higher amounts of N, C, C/N ratio and organic matter compared to the red sandy loams but relatively lower amounts of P and P fractions. This suggests differences in nutrient limitation between the two types of soils. While grazing treatment have positive effects on glade soils and negative effects on bush land in relation to the studied nutrients elements.

The study recommends that the frequency of relocation and abandonment of the livestock boma should be reviewed in order to increase the size of the area with high quality forage and low predation risk. Herbivores play an important function in the savannah ecosystem by facilitating the accumulation of major nutrients. The apparent decrease of nutrients in grazed bush lands whether on black cottons soils or in red soils is possibly an indication that grazing treatment was too light or that more time was required to accumulate the nutrients in form of glades or herbivore bedding grounds. Hence it is important to support herbivore grazing and in particular the coexistence of wildlife and livestock in African savannah ecosystems.

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ACRONYMS AND ABBREVIATIONS

Bicarb inorg P	Bicarbonate inorganic P
Bicarb organic P	Bicarbonate organic P
C	Carbon
C/N ratio	Carbon Nitrogen ratio
FAO	Food and Agriculture Organization
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
IUBS	International Union of Biological Science
KLEE	Kenya Long-term Exclusion Exclosures
MRC	Mpala Research Centre
N	Nitrogen
NaOH inorg P	NaOH inorganic P
OM	Organic Matter
P_i	Phosphorus Inorganic
P_o	Phosphorus Organic
S.D	Standard Deviation
SEM	Standard Error of Mean
SOM	Soil organic matter
USDA	United States Department of Agriculture

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Rangelands comprise about 50% of the world land area (Friedel *et al.*, 2000), and include natural grasslands, scrublands, savannahs and desert (Kamau, 2004). Rangelands carry over 25% human population; support more than half of the total livestock population and a large number of various species of wildlife (Brown 1994). Rangelands consist primarily of native communities managed, typically for livestock production (Fuhlendors and Engle, 2001).

Because they embrace extensive native plant communities, rangelands serve as biodiversity repositories. The rangelands supply edible, palatable fodder of sufficiently high nutrients quality (Walker, 1993). The long term ability of a rangeland to sustain productivity under herbivory is of high priority in rangeland management (Milchunas and Lauenroth, 1992). Studies evaluating the role of nutrient limitation in semiarid ecosystems have focused primarily on ungrazed grassland under controlled conditions, while ecosystem-level studies evaluating linkages between soil nutrients, grass production, and grazers are relatively limited (McNaughton, 1988). Small-scale fertilization experiments have shown that soil nutrients limit plant productivity in many semiarid grasslands and savannahs, but linkages among nutrients, grasses, and grazers are rarely studied in an ecosystem context (Augustine *et al.*, 2003).

Factors that affect plant productivity include nutrient recycling, energy, and water availability. Inputs of nutrients into the system are constant and occur as organic or inorganic nutrients, while losses to the system occur through mineral nutrient leaching, and erosion. Plant nutrient uptake is proportional to plant biomass, and is a function of the soil mineral nutrient pool of nitrogen (Link, 2004).

A large number of studies have investigated the importance of various nutrient cycling pathways namely, litter fall, through fall and root turnover (Kenneth and John, 2004).

The role of herbivores in the cycling of nutrients in rangeland ecosystems remains poorly understood. Herbivores have a strong impact on plant productivity in grasslands (Bakker *et al.*, 2003). In many terrestrial systems plant growth is limited by nitrogen (N) and phosphorus (P). However most N in terrestrial systems is locked in the soil organic matter that has a slow turnover rate. Herbivores affect plant productivity by modifying rate of N cycling and therefore N availability for plants growth. The impact of herbivore in nutrient cycling may lead into two alternative outcomes: herbivore can enhance nutrients cycling or herbivores can decrease the rate of nutrient cycling (Bakker *et al.*, 2003). Phosphorus is poorly available because it is strongly absorbed to soil components such as clays and iron oxides, and typically represents the limiting nutrient on plant growth in tropical ecosystems on old soils dominated by iron and aluminium oxides (Bakker *et al.*, 2003).

Studies on grazing systems have found that herbivores, through their consumption and deposition of nutrients, alter the following primary components of nutrient cycling (Kenneth and John , 2004): Size of nutrient pools (biomass, litter, and soil); flux of nutrients within the ecosystem (litter fall, decomposition, mineralization, plant uptake); and flux of nutrients into and out of the ecosystem (volatization, denitrification, and leaching, spatial movement of nutrients due to herbivore emigration/immigration). In nutrient-poor rangelands, the redistribution of soil nutrients via herbivores is likely to have significant consequences, not only for the nutrient-enriched plant community that develops after the enrichment, but also for the surrounding landscape from which nutrients are withdrawn.

Rangeland may be viewed as a natural ecosystem in which nutrient levels in soil are in a steady state or dynamic equilibrium. This description means that the nutrient levels are in balance within the soil, vegetation, animals and climatic effects. Essential nutrients such as nitrogen (N), phosphorus (P), potassium (K) and sulphur (S) are thus in a steady state (McKenzie *et al.*, 2003).

Virtually all nitrogen in soil is stored in the soil organic matter. Nitrogen required for plant growth comes from the natural breakdown of soil organic matter. Soil organic matter is composed of a number of different fractions that have different rates of breakdown and decomposition (McKenzie *et al.* 2003). Additional N added to the soil comes from fixation by native legume species and atmospheric additions by lightning storms.

About half the P in surface soil on rangeland is contained in the organic matter, with the remaining P tied up in soil minerals. Much of the P for plant growth comes from the breakdown and decomposition of organic matter and a small amount from release by soil minerals (Mckenzie *et al.* 2003).

If other factors are not limiting plant production, such as water availability, temperature, and sunlight, plant abundance should decrease when nutrient cycling is slowed down and increase when nutrient cycling is speeded up. It has long been hypothesized that herbivory may affect the speed of nutrient cycling. Herbivores change nutrient cycling by deposition of excrement, by changing the quantity and quality (nutrient content and decomposition rate) of plant litter, and by sequestering nutrients in their bodies. However, because consumption reduces plant abundance, herbivory can increase plant abundance only if the enhancement of nutrient cycling exceeds the depressing effect of consumption (Belovsky and Slade, 2000). Mammals may either decelerate nutrient cycling and diminish plant abundance or accelerate cycling and increase plant abundance (Belovsky and Slade, 2000).

1.2. Problem statement and justification

Nitrogen (N) and phosphorus (P) are considered in this study because these elements are known to limit primary production in most terrestrial ecosystems (Daufresne and Loreaua, 2001; Gusewell, 2004). As a consequence of limiting primary productivity these elements also limit the secondary productivity thus affecting free ranging livestock and wildlife productivity.

The herbivory nutrient cycling perspective has been studied more thoroughly in aquatic systems than in terrestrial systems (Belovsky and Slade, 2000). All herbivores return N and P to the soil through faeces, urine, and dead bodies thus enhancing N and P cycling. Nutrient release from excrement and dead herbivores has been termed the fast cycle because this detritus rapidly decomposes and releases nutrients for plant uptake. Release of nutrients from plant litter has been termed the slow cycle, because this detritus slowly decomposes and releases nutrients for plant uptake. Herbivory affects the slow cycle by changing the quantity and quality of plant litter, as a result of selective feeding. Preferential feeding on plants that produce slower decomposing litter reduces their relative abundance, speeding up the slow cycle. (Belovsky and Slade, 2000)

Approximately 75 to 90 per cent of the nutrients consumed by grazing animals are cycled back to the soil in urine and feaces (Mckenzie *et al.* 2003) and only a small amount of consumed nutrient is removed from a field with the animal. Hence elimination of herbivore from the ecosystem would lead to loss of nutrients through leaching and slow decomposition process.

Although the effect of cattle on African rangelands has been a major focus of recent research (Augustine, 2003), few studies have considered the indirect effects herbivore may exert on rangelands through the redistribution of soil nutrients. In particular, soil N and P can both limit grass productivity in many semi-arid African rangelands ;(Augustine, 2003) and can influence local and regional distributions of ungulate herbivores. However, little is currently known regarding the process of nutrient inputs by the herbivores. This study aims at analysing the impact of large herbivore on selected soil properties of two contrasting soil types in Laikipia central ecosystem at the Mpala Research Centre.

1.3 Study objectives

The overall objective of this study is to contribute to the understanding of the impact of grazing by large herbivores in nutrient content in Laikipia rangelands.

The specific objectives therefore are:

1. To determine and compare the effects of large herbivores on nitrogen and phosphorus nutrients content, organic matter distribution, C/N ratio and soil pH on red sandy loams and black cotton soils.
2. To determine and compare the effects of large herbivores on sequential phosphorus fractionation between the red sandy loams and black cotton soils.

1.4 Hypothesis

1. Herbivores influence content of nitrogen and phosphorus, accumulation of organic matter, C/N ratio and pH in both red sandy loams and black cotton soils.
2. Herbivores have effect on sequential phosphorus fractionation in both red sandy loams and black cotton soils

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. Importance and limitation of soil nitrogen and phosphorus in the tropical rangelands

Nitrogen is part of all plant and animal proteins. Human survival depends on an abundant supply of nitrogen in nature. About 80 percent of the atmosphere is nitrogen gas (Holder *et al.*, 2005) but since most plants cannot use this form of nitrogen, supplemental nitrogen must be supplied to the soil. A crop well supplied with nitrogen can produce substantially higher yields on the same amount of water than one deficient in nitrogen (Holder *et al.*, 2005). Properly fertilized crops use both nitrogen and water more efficiently, thus improving environmental quality and profitability. Phosphorus, like nitrogen, is essential for plant growth. The immobilization, mineralization, and redistribution of P is best discussed with reference to P cycling in soils (Stewart, *et al.*, 1981). Naturally occurring phosphorus exists in a phosphate form either as soluble inorganic phosphate, soluble organic phosphate, particulate phosphate or mineral phosphate. The mineral forms of phosphorus (calcium, iron and aluminium phosphates) do not readily dissolve in water. The amount of these elements (calcium, iron and aluminium) present in reactive forms varies with different soils and soil conditions (Holder *et al.*, 2005). The immediate source of phosphorus for plants is that which is dissolved in the soil solution. Phosphate is absorbed from the soil solution and used by plants. A soil solution containing only a few parts per million of phosphate is usually considered adequate for plant growth. Phosphate used by plants is replaced in the soil solution by soil minerals, soil organic matter decomposition or applied fertilizers or animal waste. The amount of N in the soil available for uptake by plants is a balance between the incorporation of N in microbial bodies (immobilization) and the release of N from decomposition of soil organic matter (Schoenecker *et al.*, 2004).

One of the main soil limiting factors for plant growth is nutrient deficiency (Robert, 2001). The widespread occurrence of nitrogen limitation to net primary production in terrestrial and marine ecosystems is something of a puzzle. It would seem that nitrogen fixers should have a substantial competitive advantage wherever nitrogen is limiting, and that their activity in turn should reverse limitation. However, there is substantial evidence that nitrogen limits net primary production much of the time in most terrestrial biomes and many marine ecosystems (Vitousek and Howarth, 1991). There is particular interest in understanding the factors that regulate nitrogen (N) cycling and retention in grasslands, given that N is an important constraint on productivity and given concerns about N transfers to aquatic ecosystems and the atmosphere (Vitousek and Howarth, 1991).

Biogeochemical mechanisms that favour nitrogen limitation include: the substantial mobility of nitrogen across ecosystem boundaries, which favours nitrogen limitation in the "source" ecosystem especially where denitrification is important in sediments and soils; or in terrestrial ecosystems where fire is frequent and differences in the biochemistry of nitrogen as opposed to phosphorus (with detrital N mostly carbon-bonded and detrital P mostly ester-bonded), which favour the development of nitrogen limitation where decomposition is slow, and allow the development of a positive feedback from nitrogen limitation to producers, to reduced decomposition of their detritus, and on to reduced nitrogen availability (Vitousek and Howarth, 1991)

Available phosphorus remains more or less constant in both the grazed and ungrazed plots, with an indication of possible decline in enclosed plots. Rock weathering may be the only significant source of additional phosphorus for range soils (Kamau, 2004). This uniformly low content is attributed to the fact that this element is stored in unavailable forms to plants but which becomes available to plants at low pH (Juo, 1978). It also suffers from fixation by hydrous oxides and silicate minerals. This element is doubly critical, because of low total amounts and a very low availability. Low phosphorus availability to plants in savannah soils would usually be considered to be due to strong fixation of phosphorus to metal oxides.

Evaluating N and P cycling processes in a landscape context that encompasses a wide range of environmental conditions increases our mechanistic understanding of these processes and provides a stronger basis for management and assessment of savannah ecosystems. Cattle management via bomas exerts a greater effect on the distribution of P relative to N within the landscape (Augustine, 2003). Permanent N loss does occur via leaching, but the majority is probably volatilized and redistributed in rainfall. Nitrogen deposition in rainfall is more than sufficient to offset losses due to cattle grazing and deposition in bomas. In contrast, P deposited in bomas is more tightly retained, creating small P-enriched 'hotspots' while causing a permanent loss of the P from the surrounding bush land landscape (Augustine, 2003).

2.2 Importance of soil pH

Soil pH is a major factor in agricultural production and nutrient management. Soil pH or soil reaction is an indication of the acidity or alkalinity of soil and is measured in pH units (Bickelhaupt, 2005). Soil pH affects the availability of nutrients to plants and is a measure of the acidity or alkalinity expressed in a number from 1 to 14. The number 7 is considered a neutral sample (Farmnote, 2000). Samples with numbers below 7 are acidic while those above 7 are alkaline (Holder *et al.*, 2005)

The level of soil acidity in cropping systems has a fundamental effect on plant growth and nutrient availability. The higher the concentration of hydrogen ions in the soil, the lower the pH. Plant nutrient availability varies quite dramatically with soil pH.

The pH of soil or more precisely the pH of the soil solution is very important because soil solution carries in it nutrients such as Nitrogen (N), Potassium (K), and Phosphorus (P) that plants need in specific amounts to grow, thrive, and fight off diseases(Spector ,2001). If the pH of the soil solution is increased above 5.5, nitrogen (in the form of nitrate) is made available to plants. Phosphorus, on the other hand, is available to plants when soil pH is between 6.0 and 7.0 (Spector, 2001). If the soil solution is too acidic plants cannot utilize N, P, K and other nutrients they need. In acidic soils, plants are more likely to take up toxic metals and some plants eventually die of toxicity (poisoning).

2.3 Ecology of soil nutrient cycling by large herbivores

Grazing management is a challenge for resource managers because different grazing management concepts and theories exist (Schoenecker *et al.*, 2004). Recently, there has been a substantial debate about whether or not herbivory can increase net primary production, and if so under what ecological conditions or level of ecological organization where net primary production may increase (Biondini *et al.*, 1998). Several mechanisms have been proposed to explain how grazing can affect primary productivity, including juvenilisation, reallocation and hormone redistribution of the plant, direct effects of growth promoting substrates in ruminant saliva and nutrient recycling from dung and urine (McNaughton 1979).

Several mechanisms could account for a positive effect of herbivores on plant production (McNaughton 1979). One possible mechanism is the effect of herbivores on the cycle of a limiting nutrient. Some authors propose that herbivores increase nutrient turnover rates that is, they have an accelerating effect on nutrient cycling, and that this in turn results in an increased primary production (Ruess and McNaughton, 1987). Two different factors can generate such acceleration. First, following herbivory, plants regrow with a higher tissue nutrient concentration (de Mazancourt and Loreau, 2000), and the resulting litter is faster to decompose. Second, herbivores produce detritus that is more readily decomposed.

More recently, several hypotheses focused on the role of increased rate of nitrogen cycling in the promotion of primary productivity by grazing (Loreau 1995, Olofsson, *et al.*, 2001, de Mazancourt *et al.* 1998). Grazing optimization occurs when herbivory increases primary production at low grazing intensities. In the case of simple plant-herbivore interactions, such an effect can result from recycling of a limiting nutrient (de Mazancourt and Loreau, 2000). However, in more complex cases, herbivory can also lead to species replacement in plant communities, which in turn alters how primary production is affected by herbivory (de Mazancourt and Loreau, 2000). Soil factors, and particularly soil water and nutrient availability, have been central to recent discussions on land degradation and land use sustainability (Stocking, 1995). Properly managed grazing lands provide positive environmental benefits, including the provision of clean water supplies, the capacity to sequester atmospheric carbon (C), and the potential to maintain biodiversity (Krueger *et al.*, 2002).

Grazers have marked effects on decomposition and N cycling processes, generally resulting in increased net N mineralization (Verchot *et al.*, 2002). Removal of grazing in the Serengeti grasslands led to an increase in the N immobilized in litter and standing dead biomass, and a reduction in soil microbial turnover rates and net soil N mineralization (Biondini, *et al.*, 1998).

Grazing animals affect the movement and utilization of nutrients through the soils and plants systems, and thus on the fertility of pasture soils (Kauer, *et al.*, 2004). The effects of grazing on plants and soils include plant defoliation, nutrients removal and redistribution through excretion and mechanical impacts on soils and plants through trampling (Vallentine, 1990; Ampe *et al.*, 2002). As large herbivores tend to graze in preferential areas and in their habitats and often move to other localities for resting, the habitat often becomes partly nutrients poor and partly nutrients richer (Kauer, *et al.*, 2004). Stocks of organic matter and total soil N in the mineral soil overall decrease under grazed conditions (Kooijman and Smit, 2001). Increased nutrient cycling by grazing has been found in several ecosystems (Holland and Detling, 1990, Ruess and McNaughton, 1987, Frank and McNaughton, 1993, Olofsson, *et al.*, 2001). Herbivory favours more productive plant species, improve the litter quality, increase the soil temperature by removing the isolating moss-carpet and consequently increase the net mineralization rate and the productivity (Olofsson, *et al.*, 2001). The increase in primary productivity in the heavily grazed zone is associated with an increase in free ammonium, enhanced activity of decomposer microbes and nutrient cycling. This has been found previously both in the African savannah (Ruess and McNaughton, 1987). Some theories focus on increases in nutrient cycling as the mechanisms through which grazing increase primary productivity (Loreau, 1995, de Mazancourt *et al.* 1998). Urine and faeces create an organic nutrient pool where the nutrients are easily decomposable and are quickly recycled to inorganic form (Olofsson, *et al.*, 2001). Feaces and urine provide large amounts of soluble N that is readily available to plants, and ungulate excretions promote decomposition rates (Schoenecker *et al.*, 2004).

Urination and dung are important means of returning part of the nutrients to the soil; as they form local additions of fertilizer, which are unevenly spread through time and space (Peterson *et al.* 1956, Ampe *et al.*, 2002). Grazing can accelerate and alter the timing of nutrient transfers, and increase amounts of nutrients cycled from plant to soil (Klemmedson and Tiedemann, 1995). Nutrients consumed, digested, and deposited in feaces and urine return to the soil more rapidly than through senescence-decomposition pathways (Miller, 2000). Grazing can influence soil organic matter or carbon pools through its effect on plant productivity, erosion from runoff after soil compaction and/or by wind if percent cover of bare ground increases, and by altering decomposition rates through effects on soil moisture and temperature (Miller, 2000).

Grazing animal behaviour influences the distribution of nutrients to various landscape positions. Animals may graze in one area but move to another area to rest or to drink. Dung and urine may thus be more plentiful in the resting area and around a watering place than in the grazing area, a fact affecting the soil fertility of both areas, resulting in a net transfer of nutrients from the grazed area to the resting and watering areas (Krueger *et al.*, 2002).

Grazing promotes nutrient cycling through rapid breakdown of organic matter into smaller particles in the system, so organic matter is available more readily for soil micro organisms such as soil bacteria and fungi. Micro organisms use the organic matter as an energy source and can release nutrients back into the soil for plant uptake. Thus, grazing may increase the rate at which nutrients cycle through an ecosystem (Krueger *et al.*, 2002). It may be argued that if nutrients are not bound up in soil or plant matter, then they are more vulnerable to being lost from the ecosystem in runoff or erosion or through removal in animal products from the system.

Herbivores cycle nutrients from the forest/woodland canopy to the forest floor in faeces and urine, which can potentially increase the rate at which nutrients are mineralized and made available for plant uptake because these nutrients are generally more concentrated and labile than those contained in falling leaf litter (McNaughton 1976, Ruess and McNaughton 1984, Holland and Deitling 1990, Seagle *et al.* 1992, De Mazencourt *et al.* 1998, Pastor *et al.* 1993).

Nutrients such as nitrogen and phosphorus often limit primary or secondary production (McNaughton *et al.*, 1997). The experiments of Sam McNaughton showed that large free-ranging mammalian herbivores in Serengeti National Park, Tanzania, accelerate nutrient cycling in a way that enhances their own carrying capacity (McNaughton *et al.*, 1997).

By consuming plant material, herbivores influence decomposition and nutrient cycling in communities. Experimental studies have confirmed the role of vertebrate herbivores as mediators of decomposition processes in terrestrial systems. Both empirical and theoretical studies suggest that herbivory, by both vertebrates and invertebrates, can have significant effects on decomposition and nutrient availability in soils (Rinker and Lawman, 2001)

Traditionally in ecology, plant–herbivore interactions have been considered antagonistic, that is herbivores have a negative effect on plants. This assumption has been questioned for some years. Indeed, many authors have suggested that herbivory can have a positive effect on plants and their productivity (de Mazancourt, *et al.*, 1998). According to Loreau's model, grazing optimization occurs if herbivores sufficiently increase the ecosystem's nutrient turnover rate and if the total amount of nutrient in the ecosystem is sufficiently high (de Mazancourt, *et al.*,1998). Herbivores can have indirect effects on local nutrient availability if their direct effects on plants lead to changes in the amount or chemical composition of litter reaching the soil surface (McNeil and Cushman, 2005)

Plants absorb nutrient from a pool of inorganic nutrient which is assumed to constrain primary production. Plant nutrient can be recycled through two different pathways, termed the "plant pathway" and the"herbivorepathway" (de Mazancourt, *et al.*, 1998). The former represents the fate of nutrient that is not consumed by the herbivore; for example plant dead matter either supplies plant detritus or is exported out of the ecosystem. Plant detritus is mineralized, but a fraction leaves the ecosystem through leaching or other processes. Nutrient consumed by herbivores follows the herbivore pathway. Herbivores might immigrate (resulting in an input of herbivores into the system), leave the ecosystem, defecate in other places, or be removed from the system (resulting in an output of nutrient for the system). Herbivores produce detritus, which can be mineralized or leached from the system. Herbivore detritus may be decomposed partly by the same bacteria that act upon plant detritus. However, because the dynamics of mineralization and leaching for these two types of detritus are different, they are represented in the by separate pathways. Inputs of nutrient into the system are assumed to be constant. They occur as inorganic nutrient or as organic nutrient, such as plant detritus, herbivore detritus, or through immigration of herbivores.

Herbivores can directly influence ecosystem properties through their activities as soil disturbance agents and producers of metabolic wastes. Although less frequently considered, herbivores can also indirectly alter nutrient availability through their role as consumers of plant biomass (McNeil and Cushman, 2005). These indirect effects arise primarily from herbivore-mediated changes in the amount or chemical composition of plant litter reaching the soil surface.

Herbivore-mediated changes in litter quantity can occur via several pathways, each of which has implications for soil nutrient availability. First, herbivores may reduce the number and or size of individual plants and in turn reduce the amount of leaf litter that these hosts deposit underneath their canopies. Second, selective feeding by herbivores may alter the competitive dynamics between browsed and unbrowsed plant taxa and thereby lead to changes in community composition and or litter production Herbivores may also reduce the fecundity of individual plants and, if the system is seed-limited, cause decreases in host abundance and litter deposition throughout the landscape. Under all of these scenarios, changes in litter quantity will affect the influx of nitrogen into the soil and possibly the rates at which it cycles; such changes may be especially influential when they involve nitrogen-fixing plants that can deposit substantial amounts of nitrogen to the soil via their leaf litter (McNeil and Cushman, 2005). Thus, it follows that herbivores which induce chemical changes in the tissue of their food plants may indirectly affect local nutrient availability.

Native ungulates and grasslands that they graze share a long and intimate co-adaptation (McNaughton, 1991). Grazers remove about 40% of the net aboveground production; stimulate that production by about an equivalent amount, and double net N mineralization and the availability of N to plants (Hamilton and Frank, 2000). In addition the faeces and the urine may become mixed with the litter on the forest floor and increase the rate of litter decomposition by decreasing over all C: N and therefore increasing microbial activity (Kenneth and John, 2004). The increased availability of nutrients can increase the plant nutrient uptake and net primary productivity, such that plant in heavily grazed areas may have significantly faster growth rate than non grazed plants (Singer and Shoenecker, 2003)

Heavily grazed or browsed plants have also been found to decrease their allocation of the photosynthates to root biomass (Kenneth and John, 2004) possibly due to increased nutrient availability. Alternatively herbivory may decrease nutrient availability through several different mechanisms (Singer and Shoenecker, 2003) Nitrogen may be rapidly volatilized and lost from waste excretions (Kenneth and John, 2004). Management is important for ensuring that nutrient resources within the ecosystems are not depleted (Krueger *et al.*, 2002). The removal of grazers for example both domestic and wild ungulates will not improve range production and range condition in the long term (Oba, 1995).

Livestock grazing can be effective as a management tool while imposing limited damage to the ecosystem (Zaady *et al.*, 2001). Grazing has a greater influence on species composition, perhaps suggesting a better adaptation of vegetation of the study site to grazing as a result of the long association of the plants and livestock and to some extent small mammals like rabbits and dik dik (Kamau, 2004).

2.4. Effects of grazing on plant species composition

The hypothesis that grazing history was the main factor determining plant community composition in the rangelands was supported by the species richness, vegetation cover and high level of organic matter and moisture content because these factors are likely consequences of herbivory (Crawley, 1997). In addition to its effects on net primary production, grazing intensity can have a significant impact in two other areas of interest to range management: nutrients cycling and plant species composition (Biondini *et al.*, 1998). Grazing can alter the spatial heterogeneity of vegetation, influencing ecosystem processes and biodiversity (Adler, *et al.* 2001). Grazing also influences plant diversity in many ecosystems (Adler, *et al.* 2001).

Many of the world's grazing lands are managed today with an emphasis on changes in plant species composition (Schoenecker *et al.*, 2004). Plant community changes affect ecosystem processes, and ungulate herbivory thus has the potential to regulate ecosystem processes and alter plant communities (Schoenecker *et al.*, 2004).

Herbivores are thought to increase plant diversity by consumption of competitive dominant species and thereby allowing smaller and less competitive species to coexist and by creating disturbances in the soil and the vegetation (Belsky, 1992). Grazing effects on plant diversity are hypothesized to vary across environmental gradients of soil fertility and precipitation (Olff and Ritchie 1998). Grazing also decreases the amount of litter in grasslands and thereby increase seedling establishment, in particular small-seeded species are hampered by a relatively thick litter layer (Pihlgren, 2005)

Abandonment of grasslands leads to reduction in seedling recruitment due to increased thickness of the litter layer and may be a main mechanism causing the decrease in species diversity after ceased grazing (Pihlgren, 2005), also have the hypothesis that nutrient-poor ecosystems often exhibit decline in species richness under high grazing pressure due to resource limitation that prevents regrowth after grazing. In dry environments, with fertile soils (for example savannahs) plants are likely to tolerate grazing and have good regrowth opportunities (Olff and Ritchie 1998). The dietary choices of grazing animals play a major role in shaping the sward structure thus alter the competitive status between plant species by selective removal of plant biomass (Rook *et al.* 2004). In heterogeneous grasslands, cattle avoid areas with low forage quality and alternate among areas with high forage quality, leading to a mosaic of areas with low grazing pressure and areas with intense grazing (Pihlgren, 2005). At moderate grazing pressure animals are able to graze selectively, thus enhancing maximum biodiversity levels (Rook *et al.* 2004). At high grazing pressures, the possibility of selective grazing decreases compared to lower grazing pressures (Pihlgren, 2005). In a study of grazing intensities in semi-arid grasslands in China, the plant species diversity was highest at weak grazing pressure and lowest at intense grazing (Pihlgren, 2005).

Dung depositions cause uneven soil nutrient distributions and this result in heterogeneous plant growth due to the increased growth rate near dung and the fact that vegetation around excreta is usually not grazed (Shiyomi *et al.* 1998). The indirect effects that ungulates may have on ecosystem processes may exceed the direct effects of consuming plants. These indirect effects may include changes in N content and defense chemical concentrations in plants, changes in the quality and quantity of litter, altering soil microenvironments, and changes to decomposition and mineralization rates (Schoenecker *et al.*, 2004). To use grazing as a management tool, however, we must be able to predict when grazing pressure will increase rather than decrease spatial heterogeneity (Adler, *et al.* 2001).

2.5 Effects of grazing on soil phosphorus fractionation

In many tropical soils, shortage of phosphorus (P) is a major constraint to crop production (Buresh *et al.*, 1997). This deficiency is primarily a result of inherent low soil P, depletion of soil P through crop harvesting, sorption and precipitation involving Fe and Al oxides and hydroxides (Solomon and Lehmann, 2000). The inexpensive rock phosphate reserves remaining in the world could be depleted in as little as 60–80 years

(Runger-Metzger, 1995). Therefore, sustainable P management in both agriculture and natural environments requires additional information on the mechanisms in plants that enhance P acquisition in order to make plants more efficient at acquiring P. Phosphorus is essential for crop production. It stimulates early plant growth giving a good and vigorous start and, thereby, hastens maturity (Rehm and Schmitt, 1993).

The amount of P present in the soil solution and other readily available P is a small fraction of plant needs. It is thought that the remainder of the amount required by plants must be obtained from the solid phase by a combination of abiotic and biotic processes (Henríquez and Killorn, 2005) The sources that supply labile-P come mainly from the replenishment of both organic and inorganic P compounds or from other out of soil sources such as fertilizer application and organic residues (Henríquez and Killorn, 2005).

Phosphorus is readily adsorbed to sediment particles and forms insoluble precipitates with cations such as iron, aluminium and calcium (Sample *et al.*, 1980). Because of this phenomenon, called P retention, P is strongly associated with sediment particles in the soil. Consequently, the majority of P from diffuse sources is transported by surface runoff in particulate forms. The primary pathway of P loss from the majority of agricultural soils is through surface runoff, though loss from P can also occur through tile flow and interflow (Ge´rard-Marchant *et al.*, 2005)

The chemistry of phosphorus (P) in soils is complicated. Phosphorus exists in soils in both organic and inorganic forms. Organic phosphate is phosphate that is bound to plant or animal tissue. Organic forms are found in humus and other organic materials. The phosphorus in organic materials is released for plant growth by a process called mineralization which occurs as micro-organisms break down soil organic matter. The activity of the micro-organisms is highly influenced by soil temperature and soil moisture. The process is most rapid when soils are warm and well drained (Rehm and Schmitt, 1993).

In most natural ecosystems, geochemical processes determine the long-term distribution of P in the soil, whereas in the short term, biochemical processes influence the distribution since most of the P available to plants is derived from the soil organic matter (Solomon and Lehmann, 2000). Organic P is an important source of P in non-fertilized systems (Henríquez, and Killorn, 2005). Sharpley, (1985) found that most labile-P was maintained at a constant level possibly by mineralization and formation from moderately labile organic P.

Sequential fractionation analysis measures the amount of soil P in various fractions which are related to plant availability. These measurements provide information on the biological, geological, and chemical processes which have occurred in a soil and are useful for predicting the availability of P for plant uptake (Daroub *et al.* 2004). Phosphorus exists in different forms in soils with different availabilities for plant growth. Increased understanding is needed on the exchange among these P forms when manure and fertilizer are added (He *et al.*, 2004).

The supply of P to plants is controlled by complex biological and geochemical processes (Giardina, *et al.*, 2000). The Hedley P–fractionation method chemically separates soil P into plant-available and non-plant-available forms (Hedley, *et al.*, 1982) but the extent to which these fractions index P supply to perennial plants is not well understood (Giardina, *et al.*, 2000). The P removed by anion-exchange resin and $NaHCO_3$ (bicarbonate P) is viewed as being plant-available (Hedley, *et al.*, 1982). Portions of the P removed during the NaOH–extraction step are of organic matter and microbial origin (Hedley, *et al.*, 1982) and are likely to be plant-available over longer periods of time (Giardina, *et al.*, 2000). The P removed during the HCl, NaOH + sonication, and NaOH fusion–extraction steps are generally considered to be non-plant-available except over long time periods. Notably, some evidence indicates that plants can access most P fractions in soil (Giardina, *et al.*, 2000).

Accumulation of P can occur under heavy manure or fertilizer application. Hedley fractionation procedure, developed for natural, unfertilized, and uncultivated soils, recognizes plant-available forms (Resin P_i, Bicarbonate P_i, and Bicarbonate P_o) and refractory forms (NaOH P_i, NaOH P_o, Sonic P_o, HCl P_i, Residual P) of soil P (Hedley *et al.*, 1982). In this classification, plant-available or labile P includes the sum of Pi and Po from resin and bicarbonate extractions, while refractory or unavailable P includes all of the other fractions (Sperry, 2004).

In fractionation, inorganic and organic P in the soil solution is removed with a series of successively stronger reagents: resin, sodium bicarbonate (0.5 M $NaHCO_3$), sodium hydroxide (0.1 M NaOH), hydrochloric acid (1.0 M HCl) and an acid digestion (Hedley *et al.*, 1982). The labile P is available to microbial and vegetation communities in the short term because it quickly desorbs from the surface of soil particles. Non-labile P fractions are bound to soil particles and are not as readily available for plant uptake (Sperry, 2004). The underlying assumption in these approaches is that readily available soil P is removed first with mild extractants, while less available or plant-unavailable P can be extracted only with stronger acids and alkali. Several studies have related these different P fractions in tropical soils to plant growth (Crews, 1996;Friesen *et al.*, 1997)

Studies in New Zealand and Britain have shown that the return of dung and urine is necessary for the maintenance of soil fertility under grazed perennial pastures (Bromfield and Jones, 1970). It has been suggested that in the absence of grazing, a large proportion of the phosphorus in dry feed may resist leaching and decomposition and accumulate as organic phosphorus (Bromfield and Jones, 1970). Knowledge of phosphorus fractions in animals dung (dairy cattle, deer, sheep) in grazing pasture is important for soil fertility and in understanding the potential for P transport in runoff and subsequent surface water quality deterioration (McDowell and Stewart, 2004).

2.6 Importance of soil organic matter

Centuries before there was any science that acquainted people with the intricacies of plant nutrition, decaying organic matter, as in manure or other forms, was recognized as an effective agent in the nourishment of plants (Albrecht, 1938). Grasslands have high inherent soil organic matter (SOM) content that supplies plant nutrients, increases soil aggregation, limits soil erosion, and also increases cation exchange and water holding capacities (Conant *et al.*, 2001) . Thus, maintenance of SOM is a key factor in the sustainability of grassland ecosystems.

The high productivity of most virgin soils has always been associated with their high content of organic matter, and the decrease in the supply with cultivation has generally been paralleled by a corresponding decrease in productivity (Albrecht, 1938). The main stores of C on earth are the ocean, forests, grasslands and rangelands, with little difference between forests on the one hand and grasslands plus rangelands on the other (Goudriaan, 1990). In rangelands the total amount of C in above and below ground vegetation would be between 1600 and 8000 kg/ha. To this has to be added the accumulated organic matter below ground, which varies between soil and vegetation types, but a low estimate would be 50 tons/ha organic carbon (Jenkinson, 1988).

Soil organic matter is any material in the soil that was originally produced by living organisms (Robert, 2005). At any given time, it consists of a range of materials varying from the intact original tissues of plants (mainly) and animals to the substantially decomposed mixture of materials known as humus. The original tissues contain a wide range of organic compounds which typically decompose at different rates. It includes plant and animal remains in various stages of decomposition, cells and tissues of soil organisms, and substances from plant roots and soil microbes. Soil organic matter plays a key role in maintaining soil productivity and also in protection of environment (Körschens, 2002). Soil organic matter improves cation-exchange capacity and serves as a reservoir of nutrients for the growing crop (Gaskell *et al.*, 2000).

Most of the world's soils used for agriculture have been depleted of organic matter over the years under the conventional systems of ploughing or hoeing before every crop, compared with their state under natural vegetation (Robert, 2001). Soil organic matter represents a key indicator for soil quality, both for agricultural functions (that is production and economy) and for environmental functions (example C sequestration and air quality). Soil organic matter is the main determinant of biological activity. The amount, diversity and activity of soil fauna and micro organisms are directly related to the organic matter (Robert, 2001). Organic matter, and the biological activity that it generates, have a major influence on the physical and chemical properties of soils (Robert, 1996). Aggregation and stability of soil structure increase with organic matter content. These in turn increase infiltration rate and available water capacity of the soil, as well as resistance against erosion by water and wind. Soil organic matter also improves the dynamics and bioavailability of main plant nutrient elements. Organic matter may well be considered as fuel for bacterial fires in the soil, which operates as a factory producing plant nutrients (Albrecht, 1938).

The quantity and composition of soil organic matter vary significantly among major ecosystems. Soil in arid, semiarid, and hot, humid regions commonly has less organic matter than soil in other environments (USDA, 2001). The total content of organic matter ranges from less than 0.5 to more than 8 percent in the surface layer of rangeland soils (USDA, 2001). Soil organic matter includes three main components which includes the light fraction, physically protected and chemically stable. The light fraction is more biologically active than the other two and includes relatively fresh plant fragments. Physically protected organic matter is locked within aggregates of mineral particles, where it is protected from microbial decomposition. Chemically stable organic matter gives soil its dark colour and is generally the largest pool of organic matter in soil. Physically protected organic matter may also be chemically stable (USDA, 2001). Organic matter enhances soil fertility and plant productivity by improving the ability of the soil to store and supply nutrients, water, and air.

Nutrients in the natural ecosystems come from three sources which include: inputs from the atmosphere (both with precipitation and in dry form), weathering of the parent material underlying the soils and decomposition of dead organic matter (Muir, 2004). The amount of organic matter in the soil is a balance between additions of plant and animal materials and losses through decomposition and erosion (USDA, 2001).

Organic carbon content is a good predictor of labile organic and inorganic P, consistent with the large body of research indicating that mineralization of organic matter is important to plant nutrition in tropical ecosystems (Frizano *et al.*, 2003).

Grazing can change plant composition and distribution and increase or decrease the amount of organic matter in the soil. Grazing can increase the rate of root turnover, but overgrazing reduces the amount of plant energy available for the growth of new roots (USDA, 2001). Both temperature and moisture regime affects the equilibrium of organic matter contents of the soil. Increased temperature decrease organic matter content while increased moisture increases organic matter (Kamau, 2004).

There are strong relationships between C and N cycling and that these relationships may interact with grazing effects to affect N cycling and loss (Verchot *et al.*, 2002). It is probable that depletion of soil organic matter and nutrients is the most common cause of degradation (De Leeuw and Reid, 1995). The quality of organic matter in glades, as measured by C: OM ratios, is similar to old bomas but distinctly different from bush land soils (Augustine, 2003).This is clearly consistent with the hypothesis that organic matter in glade soils was originally derived from manure.

2.7 The soil C/N ratio

The estimated amount of carbon stored in world soils is about 1,100 to 1,600 petagrams (one petagram is one billion metric tons), more than twice the carbon in living vegetation (560 petagrams) or in the atmosphere (750 petagrams). Hence, even relatively small changes in soil carbon storage per unit area could have a significant impact on the global carbon balance (Rice, 2006). The soil is estimated to store twice as much carbon as the atmosphere, and three times that contained in the aboveground biomass (IPCC, 2001). Carbon is important because it is energy producing factor; nitrogen, because it builds tissue (Miller, 2000). When organic matter decays, the carbon is dissipated more rapidly than the nitrogen, thus bringing down the carbon-nitrogen ratio (Miller, 2000). The ratio of carbon to nitrogen is the carbon: nitrogen ratio or the C: N ratio. The C: N ratio of the organic material added to the soil influences the rate of decomposition of organic matter and these results in the release (mineralization) or immobilization of soil nitrogen (Knops and Tilman, 1998). The C: N ratio is an important factor affecting the rate of mineralization and release of available N from manures in which the majority of N is contained in organic forms (Qian and Schoenau, 2000). If the added organic material contains more nitrogen in proportion to the carbon, then nitrogen is released into the soil from the decomposing organic material (Knops, and Tilman, 1998). On the other hand, if the organic material has a less amount of nitrogen in relation to the carbon then the microorganisms will utilize the soil nitrogen for further decomposition and the soil nitrogen will be immobilized and will not be available.

There is a difference between the carbon- nitrogen ratio of raw organic matter and that of humus. The nitrogen in a leaf may be only 1 percent, but by the time it turns to humus, the percentage of nitrogen of that more or less refined substance would be about 5 percent. The average nitrogen content of practically all humus is about 5 percent, but in organic matter it fluctuates considerably with carbon however, a different condition exists. While decomposing organic matter turns to humus, the percentage of it to the total mass does not seem to increase or decrease considerably (Miller, 2000). Miller (2000) discovered that where the carbon nitrogen ratio of added organic matter tilled under was 33:1 or more, a withdrawal of nitrogen occurred. Between 17-33 to one nitrogen, nothing was added or withdrawn; in other words, nitrification ceased. But if the ratio was under 17 to one, the nitrogen store of the soil was increased (Miller, 2000). So in general, higher rainfall means a higher carbon-nitrogen ratio; higher temperature tends to lower the carbon-nitrogen ratios; and higher acidity raises the carbon-nitrogen ratio (Miller C., 2000). The carbon-nitrogen ratio of arid soils is always lower than those in regions of higher precipitation

2.8 Effects of fire on soil nutrients

Fire performs many beneficial ecosystem functions in dry forests and rangelands (Dellasala *et al.*, 2004). Slash-and-burn clearing of forest typically results in an increase in soil nutrient availability. Throughout the tropics, ash from consumed vegetation has been accepted as the primary nutrient source for this increase. In contrast, soil heating has been viewed as a secondarily important mechanism of nutrient release (Giardina *et al.*, 2000).

Regular fires are one of the characteristic features of tropical savannahs. While some are still caused by lightning (Frost and Robertson, 1987) the main source of ignition for the past tens of thousands of years has been man for hunting, preparing land for cultivation, improving the quality of grazing for livestock, and controlling the spread of woody plants (West, 1972). Fire is one of the few determinants which can be readily manipulated and, as such, is an important variable in any management programme. Fires reduce plant biomass and litter, thereby altering energy, nutrient and water fluxes between the soil, plants and atmosphere. These changes in turn may affect the long-term nutrient status and productivity of the system (Frost and Robertson, 1987). The direct effects of fire on the environment centre on the rise in soil and atmospheric temperatures during the fire, and on the reduction of organic matter and release of elements (Frost and Robertson, 1987). Fire has strong direct effects on understorey plant community structure by altering site conditions and microclimate (Laughlin *et al.* 2005).

Fire increases or decreases soil nutrient amounts, depending on the intensity and duration of the burn (Higgins *et al.* 1989). Two obvious direct effects are volatilization of certain elements and modification of soil particles due to heat. Volatilization sends carbon, hydrogen, and oxygen, (C, H, and 0) into the atmosphere, along with varying amounts of sulfur (S), and phosphorus (P) depending on the composition of the organic matter burned and the degree of combustion (Raison, 1979). Elements, mainly nitrogen, carbon and sulphur, but including to a lesser extent phosphorus and potassium, are volatilized and may be lost to the atmosphere (Frost and Robertson, 1987). One effect of fire on N is volatilization (DeBell and Ralston, 1970). Significant losses of nitrogen through volatilization during fires occur at temperatures above 400°C (Cass *et al.*, 1984). Most of the published estimates of nutrient loss through volatilization and up-draught during fires are probably not accurate (Raison, 1979). However, they serve as a guide. The reported losses due to volatilization in savannah fires vary between 4 and 33 kg N ha^{-1}. Regular losses of this magnitude might be expected to result eventually in lower levels of nitrogen in the soil (Frost and Robertson, 1987).

Phosphorus can be volatilized at temperatures above 500° C though this is only likely to be significant under complete combustion (Raison, 1979). The low solubility of P and its tendency to form complexes with Al and Fe in acid soils, or with Ca in alkaline soils makes it less vulnerable to leaching (Frost and Robertson, 1987). The input of base-rich ash after fire can cause a short term increase in soil pH. The extent of the increase depends on the amount and composition of the ash, and on the buffering capacity of the soil (Cass *et al.*, 1984).

Fire intensity, amount of green material, and fuel moisture has been reported to influence the amount of N lost through volatilization (Dunn and DeBano 1977). Although there is ample evidence that N in organic matter is volatilized, some authors report an increase in total soil N (which would include organic N, nitrate, and ammonia) after a fire (Vlamis, *et al.* 1955; White and Gartner 1975). Phosphorus as phosphate is another nutrient released by burning. Higgins *et al.* (1989) found the availability of P to vary by site. Others have found availability to increase (White and Gartner, 1975; Raison, 1979).

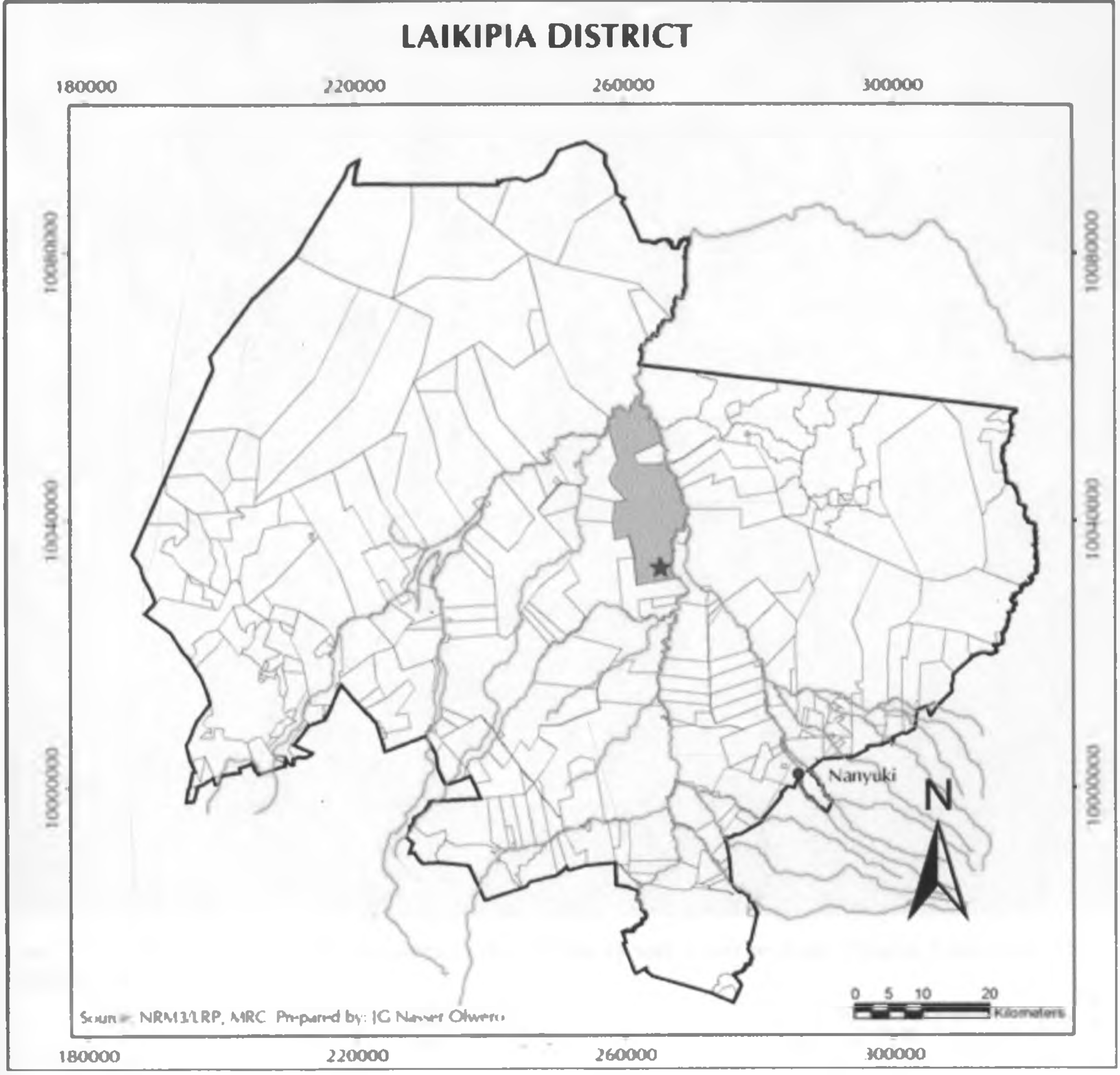
CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

The research was conducted at the Mpala Research Centre (MRC) and associated Mpala Ranch which encompasses 190 km^2 of semi arid savannah within the Laikipia District of Rift Valley Province (37^0 53'E, 0^0 17'N) (See fig. 3.1). The Centre is a collaborative trust dedicated to conservation of the Laikipia eco-system and the welfare of its inhabitants. It is administered by a consortium consisting of the National Museums of Kenya, the Smithsonian Institution, Kenya Wildlife Service, and Princeton University. Laikipia District is a semi arid *Acacia* savannah that boasts the largest population of wildlife in Kenya's non protected areas and is home to the endangered Grevy zebra (*Equus grevyi*) and the African wild dog (*Lycaon pictus*). A large mammal fauna remains intact and includes, among others, elephants (*Loxodonta Africana*) (plate 3.1), giraffe (*Giraffa camelopardalis)* (plate 3.2), buffalo (*Syncerus caffer*), eland (*Taurotragus oryx*), zebra (*Equus burchelli* and *E. grevyi*) and Grant gazelle (*Gazella granti*). The native biodiversity on Mpala/Segera consists of an estimated 70 mammal species, including 28 species of large herbivorous mammals (20 ungulates) and 19 species of large carnivorous (Young *et al*., 1998). The Mpala Ranch stocking rates are moderate (one livestock unit per 5-8 ha), and below levels that are detrimental to the range (Young *et al*., 1998).



Source: NRM3/LRP, MRC Prepared by: JG Nasser Olwero

Figure 3.1 Geographical Location of Mpala Research Centre in Laikipia District (Source: NRM3/LRP, MRC Prepared by: JG Nasser Olwero)

Plate 3.1 Herbivores in a watering place in the red sandy soil. (Source: Lucy Ngatia, University of Nairobi, 2005)

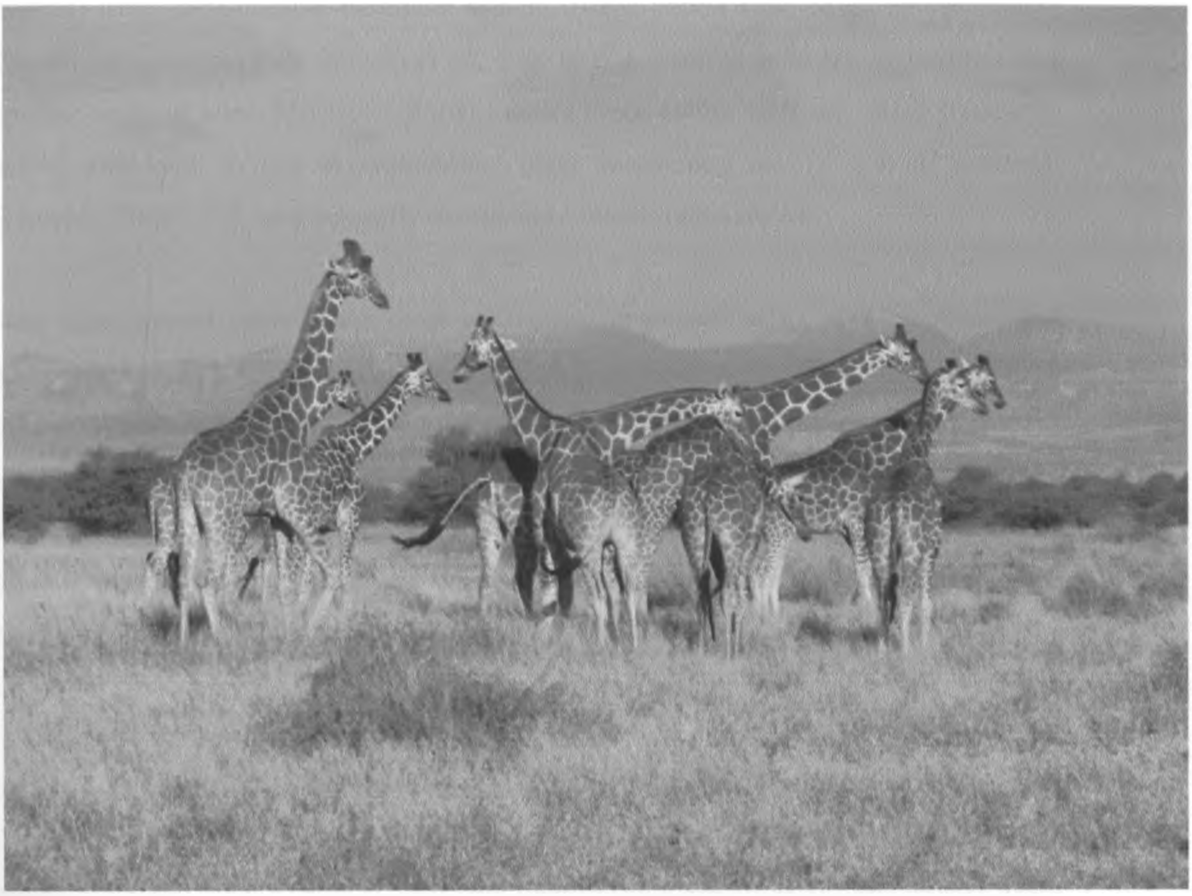


Plate 3.2 Giraffes, browsers in Mpala Research Centre. (Source: Lucy Ngatia, University of Nairobi, 2005)

3.1.2 Climate

The mean annual rainfall is 500 mm (coefficient of variation =0.35), with wet seasons typical during April-May, August and October, and a consistent dry season during January –March (Augustine, 2003). The rainfall is usually low in December, through February. High temperatures range from 25 to 30°C and low from 12 to 17°C. July and August are often the coldest and most windy months (Young *et al.* 1998).

3.1.3 Soils and topography

One of the surveyed landscape is underlain by soils which are well drained, moderate to very deep, friable sandy soils developed from metamorphic basement rocks (Augustine, 2003). Two major soil types are found in Laikipia ecosystem on the high central plain:

black cotton soils (vertisols) derived from basaltic lava flow and red sandy loams (luvisols) from metamorphic basement system. Black cotton soils cover approximately 43% of Laikipia ecosystem (Young *et al.*, 1998). Black cotton soils are characteristic of impeded drainage sites. Most of the areas under black cotton soils are characterised by wooded grassland. *Acacia drepanolobium* plant community covers 28% of Laikipia, ecosystem (Taiti 1992) and is locally restricted to black cotton soils.

These soils support some of the most productive rangelands in East Africa. Other soil types present include red friable soils on more sloping topographies (Young, *et al.*, 1998). Both soil types are characterized by a landscape mosaic with numerous isolated 'glades'. These features are treeless, have high levels of mineral nutrients, and are preferentially used by wild and domestic herbivores (Young *et al.*, 1998). These glades are usually less than one hectare in area, but there are also some extensive areas ('plains') of glade vegetation, most notably in Segera (Young *et al.*, 1998).

3.2 Vegetation

The native biodiversity in Mpala/Segera consists of an estimated 600-800 plant species (Young *et al.*, 1998). The vegetation on black cotton soils in Laikipia is grassland or bushed grassland where *Acacia drepanolobium* comprises 97% of the woody layer (Young and Okello, 1998) and the grass layer is dominated by five major species of C4 grasses (Young *et al.*, 1998). The dominant grasses are *Lintonia nutans stapf.*, *Bracharia brizantha* (Hocchst.*) Stapf.*, *Themeda triandra* (Forsk.) *Pennisetum mezianum* (Leeke) and *P. stramineum (*Peter). The dominant herbs are *Aerva lanata* (L.) Juss., *Rhinacathus ndorensis* (Schweinf.), *Dischoriste radicans* (Nees) and *Commelina sp.* Other woody species include *Cadaba farinosa* (Forssk.), *Balanites aegyptica* (L) (Del.), *Rhus natalensis* (Krauss) and *Acacia mellifera* (Vahl) Benth (Young *et al.*, 1998).

In the red sandy loams, abandoned bomas and long-term glades are distributed within a background of *Acacia* –dominated bush land community. Glades and older bomas are dominated by a short-statured sward of *Cynodon plectostachyus* and characteristically lack shrubs. In younger bomas, the annual forb *Gynandropsis gynandra* is abundant during certain rain cycles. In older bomas and glades, the annual forb *Tribulus terrestris*, the sedges, *Cyperus blysmoides* and *Cyperus cristatus* and the grass *Sporobolus pellucidus*, often occur within the *Cynodon* –dominated lawn (Augustine, 2003). The surrounding bush land contains a heterogeneous mosaic of bare soil and perennial grass dominated by *Digitaria milanjiana, Cynodon dactylon, Pennisetum mezianum* and *Pennisetum stramineum.* Woody vegetation is dominated by *Acacia brevispica, Acacia mellifera* and *Acacia etbaica* (Young, *et al.*, 1995).

In this study glades were defined as sites appearing as open grassland patches in the 1961 aerial photographs with no visible fence lines. Sites with visible fence lines were designated as bomas (Augustine, 2003).

3.3 Sampling design

The study site was divided into two distinct sites. These included the black cotton soils derived from basaltic lava flow and red sandy loams derived from metamorphic basement system. The two distinct sites were further subdivided into areas that have glades (former cattle bomas) where grazing is currently going on; and areas that have no glades and grazing is currently taking place. The exclosures in the areas that had bomas and areas that had no bomas were used as the control. The exclosures used excluded all large herbivores. The size of the exclosures used in both the red sandy loams and black cotton soils were 50x50 m^2. The 50x50m^2 plots inside the exclosure were obtained from the larger plots of 70x70 exclosures in red sandy loam soils(Augustine's exclosure) and 200x200m^2 exclosures in the black cotton soils (KLEE exclosures).Sampling process involved avoidance of termite moulds. Each exclosure was divided into four equal portions. Within each portion two diagonal line transects were set up and two samples were collected along each transect. The sixteen samples of soil from the four quarters were mixed to make one composite sample. This was repeated outside and 50 m away from the exclosures. The soil was sampled from 0-10 cm depth where soil properties are likely to be influenced by the large herbivores. The experimental design was complete randomized block. The species compositions of the key plant species of each site were recorded. Treatment of soil after sampling involved air-drying. The soil samples were then sieved using a 2mm sieve to remove stones and other litter materials before being finely ground for chemical analysis.

Plate 3.3 Scientists at Mpala Research Centre taking soil samples in the black cotton soils' bush. (Source: Lucy Ngatia, University of Nairobi, 2005).

Plate 3.4 Bush exclosure in the red sandy loams at Mpala Research Centre. (Source: Lucy Ngatia, University of Nairobi, 2005).

3.4 Chemical analysis

Total N and organic carbon was analyzed using automated analyzer while P was analyzed using Mehlich method (Mehlich, 1984). pH was determined using Schofield and Taylor (1955) method. The organic matter was obtained by conversion of total carbon to organic matter using the factor 1.724 (Nelson and Sommers 1996).

Sequential phosphorus fractionation was done using the method as outlined by Hedley *et al.* (1982). In fractionation, inorganic and organic P in the soil solution was removed with a series of successively stronger reagents: resin, sodium bicarbonate (0.5 M $NaHCO_3$), sodium hydroxide (0.1 M NaOH), hydrochloric acid (1.0 M HCl) and an acid digestion (Hedley *et al.*, 1982). The underlying assumption in these approaches is that readily available soil P is removed first with mild extractants, while less available or plant-unavailable P can be extracted only with stronger acids and alkali.

The P removed by anion-exchange resin and $NaHCO_3$ (bicarbonate P) is viewed as being plant-available (Hedley *et al.*, 1982). Portions of the P removed during the NaOH–extraction step are of organic matter and microbial origin (Hedley, *et al.*, 1982) and are likely to be plant-available over longer periods of time (Giardina *et al.*, 2000). The P removed during the HCl, NaOH + sonication, and NaOH fusion–extraction steps are generally considered to be non-plant-available except over long time periods. Some evidence however indicates that plants can access most P fractions in soil (Giardina *et al.*, 2000) . This study defines the anion resin and $NaHCO_3$-extractable P fractions as plant-available and all other P fractions as non-plant-available.

In this study it was not possible to include the residual P (organic and inorganic) and sonication NaOH P (organic and inorganic). Hence the total P by sequential phosphorus in this study includes resin P, bicarbonate organic P, and bicarbonate inorganic P, NaOH organic P, NaOH inorganic P and HCl P. The bicarbonate organic P and NaOH organic P form the total organic P in this study while resin P, bicarbonate inorganic P, NaOH inorganic P and HCl P form the inorganic P. While the addition of the six organic and inorganic P fractions constitute the total P in this study.

3.5 Statistical analysis

Data on total N, total C, C/N ratio, organic matter, total P, pH and sequential phosphorus fractionation was subjected to ANOVA and Student Unpaired T-test. All the analysis was done using Genstat (GenStat, 2005) and MS-Excel software. The results were considered significantly different at $p<0.05$ level.

CHAPTER 4

4.0. RESULTS AND DISCUSSIONS

4.1 Effects of herbivores on N, C, C/N ratio, pH, P and Organic matter

4.1.1. Characteristics and differences in experimental treatments

Table 4.1.1 shows that the two soil types were significantly different in terms of the selected soil chemical properties except for P and pH. From the results it is evident that black cotton soil had more N and organic matter content compared to the red sandy loams. Nitrogen and organic matter in the black cotton soil were more than 2 times higher than in the red sandy loams. Significant difference between the two soil types could be due to different inherent soil fertility of the two soil types where red sandy loams are developed from metamorphic basement rocks (Augustine, 2003) and black cotton soils derived from basaltic lava flow. Another possibility could be due to high soil cover in black cotton soils which could have a direct effect on the amount of nitrogen and organic carbon; which is likely to slow down the volatilization of nitrogen and organic carbon. Black cotton soils are characteristic of impeded drainage sites (Young *et al.*, 1998) which is likely to affect the rate of litter decomposition and mineralization. This in turn is likely to result in less leaching of nitrogen compared to red sandy loams. In contrast, the C/N ratio was lower in the red sandy loams which indicate high availability of N in the red sandy loams compared to the black cotton soils as this is clearly illustrated in (Fig. 4.1.1a). The higher C/N ratio in the black cotton soils could be due to low decomposition rate of litter material, low soil surface temperature and high soil moisture content especially during the wet season. Higher rainfall means a higher carbon-nitrogen ratio, while higher temperature tends to lower the carbon-nitrogen ratios; and higher acidity raises the carbon-nitrogen ratio (Miller, 2000).

Table 4.1.1 The difference between the two soil types in relation to the selected chemical properties.

Soil type	N (%)	OM (%)	C/N ratio	P (ppm)	pH
Black cotton soils	0.279^{d*}	5.64^{d}	11.77^{d}	161^{a}	6.90^{a}
Red soils	0.128^{a}	2.17^{a}	9.95^{a}	$190.^{a}$	6.77^{a}
LSD (5/%)	0.0517	0.855	0.731	33.2	0.486

*The different superscripts on the table of means along column indicate significant differences and have the following significance level a=No significant difference b=<0.05, c=<0.01, d=<0.001.

As indicated in Fig. 4.1.1 both N and C were strongly and positively correlated this indicated strong microbial activity.

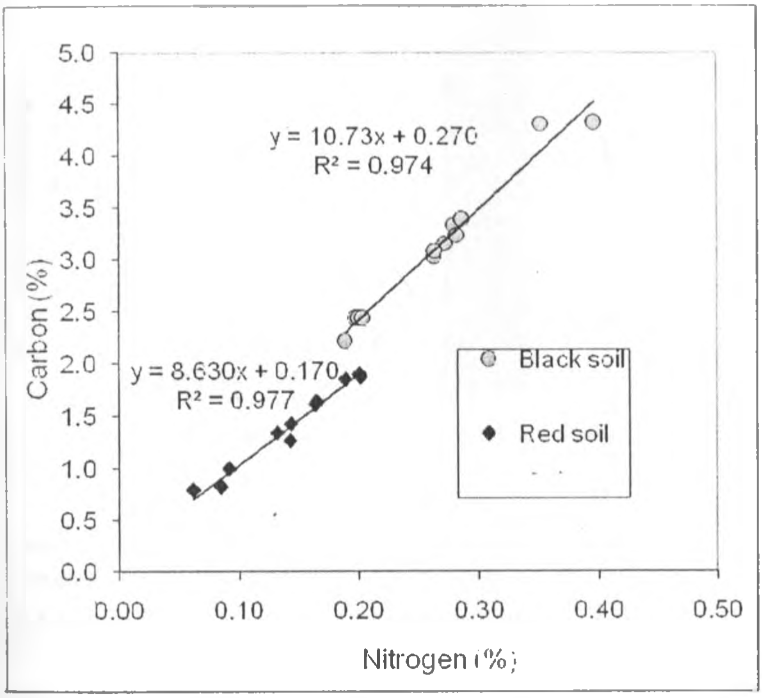
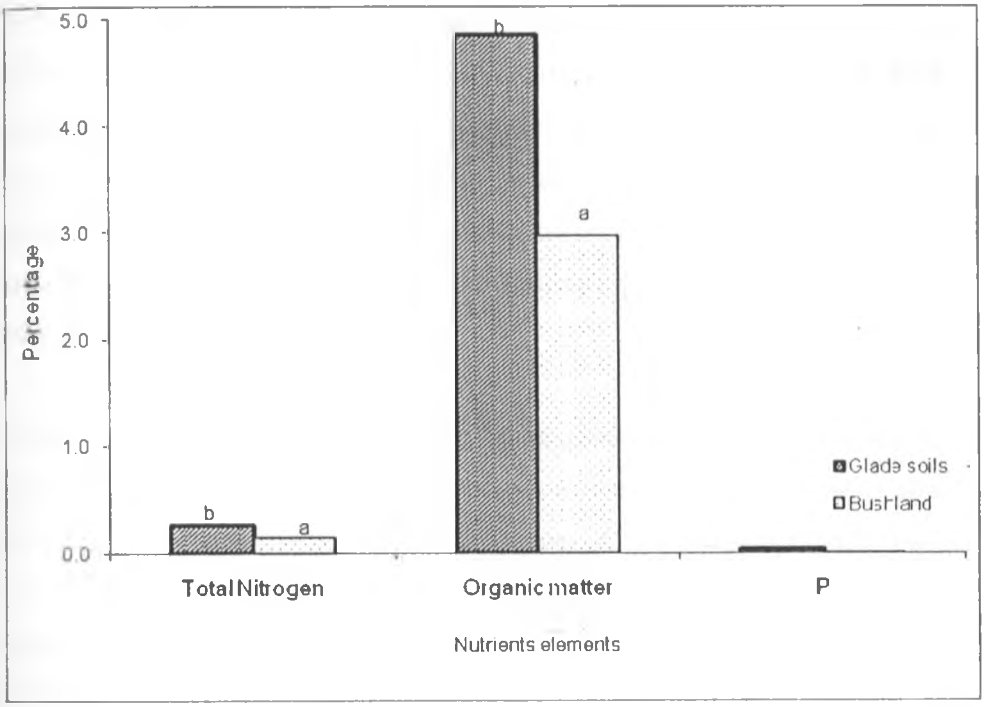


Fig. 4.1.1a Relationship of C and N in black cotton soils and red sandy loams

There was no significant difference in P between the two soils but P was relatively higher in the red sandy loams than in the black cotton soils possibly due to inherent soil fertility. Soil pH was slightly acidic in the two soils.

The glade and bush land were significantly different (P<0.05) in terms of nitrogen and organic matter. The C/N ratio was relatively lower in the glade than in the bush. This low C/N ratio in the glade than in the bush land indicates higher availability of N in the glade than in the bush. Knops and Tilman, (1998) indicated that if the added organic material contains more nitrogen in proportion to the carbon, then nitrogen is released into the soil from the decomposing organic material.

In both glade and bush land and irrespective of the soil type the C/N ratio was less than 12. Miller, (2000) indicated that if the C/N ratio was below 17 to one, the nitrogen store of the soil was increased.



*In the graph aa=no significance difference ab=significant different. The standard deviations of the above graph are in appendix 10.

Fig.4.1.1b. Nutrients elements in the glade and bush

The higher total nitrogen and organic matter in glade confirmed Young's observation (Young *et al.*, 1998) that as in the red sandy loams, glades on black cotton soils had high nutrients content than the surrounding black cotton soils under bush land. These glades were 'hotspots' of herbivore activity (Young *et al.*, 1998). Results on nitrogen, organic matter and phosphorus for nutrient-rich glade soils and nutrient-poor bush land sites indicated that large herbivores themselves cause a net N input to the glade soils and a net N loss from the bush land.

Hence, large herbivores respond to heterogeneity in soil nutrients across the landscape, and also play a role in maintaining the N-enriched status of highly productive and intensively grazed sites. In southern Turkana, Kenya, cattle are managed using a traditional pastoral practice which requires security whereby they are contained overnight in brush-ringed corrals or "bomas," where significant quantities of dung and urine accumulate (Reid and Ellis, 1995). Bomas are subsequently abandoned and colonized by a unique plant community as the manure layer becomes mixed with mineral soil. Though N is lost through volatilization, studies on feedlot manure decomposition Eghball *et al.*, (1997) showed that 92% of N was lost via NH_3 volatilization while only 0·5% was lost as ammonia and nitrate in leachate. However NH_3 volatilization from bomas may not represent a permanent ecosystem loss because this N is returned to the landscape in rainfall (Augustine, 2003). Most precipitation occurs as local convective storms that are unlikely to transport volatilized N long distances. Thus, a redistribution rather than permanent loss of N seems likely.

Phosphorus was also relatively higher in the glade compared to the bush. This is due to long term containment of cattle in the bomas which create a hotspot after abandonment of the bomas. These hotspots have a high content of P which is not easily lost because P is not volatilized or leached. Ge´rard-Marchant, *et al.*, (2005) observed that the primary pathway of P loss of the majority of agricultural soils was through surface runoff, although loss from P can also occur through tile flow and interflow. Hence cattle management by use of bomas exerts a greater effect on the distribution of P relative to N within the landscape. Phosphorus is highly conserved in bomas because losses via leaching and gaseous forms are minimal or non-existent. Schlesinger (1997) indicated that inorganic P often immediately complexes with soil minerals.

This heterogeneity in P distribution is also reflected in the primary productivity and possibly secondary productivity, Augustine, (2003) observed that P in boma and glade grass was above recommended levels for growing and lactating livestock, while P content of bush land grass was lower than recommended levels. Concentrations of P in *Cynodon* species growing on bush land soils were lower than the recommended levels of 4000–

6000 mg kg^{-1} for lactating and pregnant cattle. McDowell (1985) stated that spatial heterogeneity created by bomas improved herbivore carrying capacity by providing patches of P-sufficient forage.

Fig. 4.1.1c shows the relationship between C and N for both glade soils and bush land. Both glade soils and bush land had a very high correlation coefficient of C and N as indicated in the respective figures. The correlation coefficient was r^2=0.9705 and r^2=0.9729 for glade and bush land, respectively. This indicates a strong positive relationship between the two where an increase of N indicates an increase of C. This indicates that using the regression equation indicated in the Figs. (Fig. 4.1.1a and Fig.4.1.1c) it is possible to determine the content of C or N using these equations. The high correlation coefficient indicates strong microbial activity.

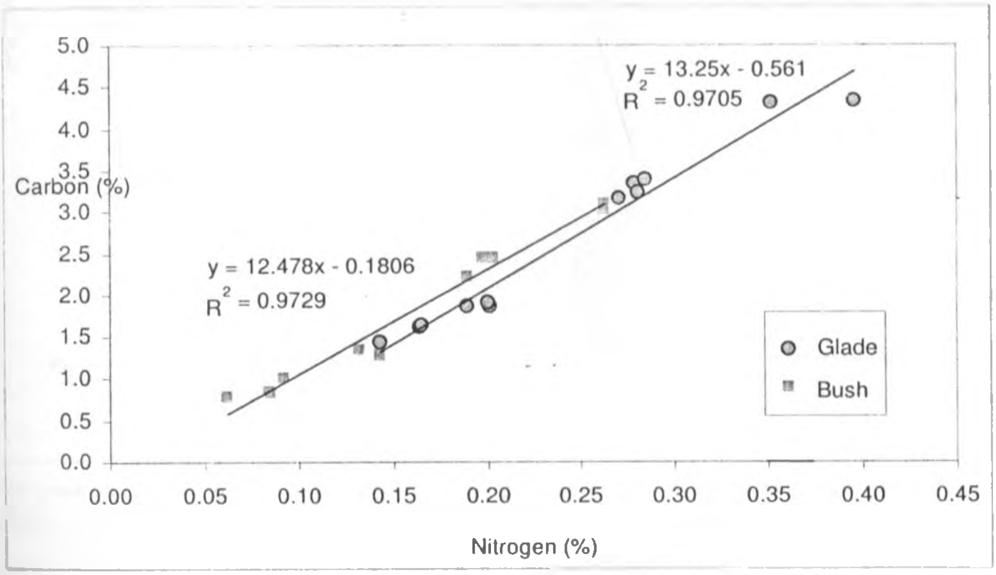
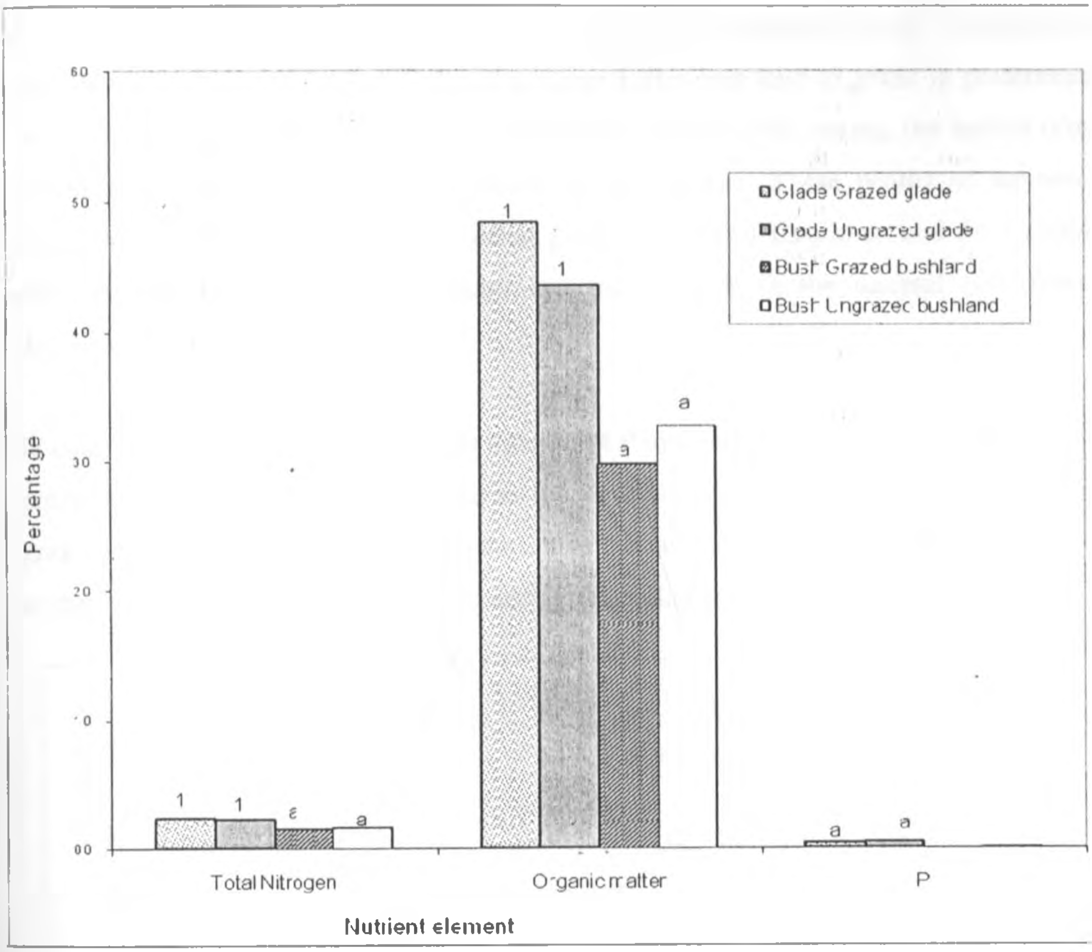


Fig.4.1.1c Relationship between C and N in the glade and bush

4.1. 2 Effects of herbivores on soil properties

4.1.2.1 Overall effects of herbivory on grazing lands

The long term effect of herbivory is represented by the nutrient concentrations of glades in both black and red soils. The grazed glades were not significantly different from ungrazed glades in terms of N, P, C/N ratio, pH and organic matter but N, C/N ratio and organic matter tended to increase in the grazed glades as indicated in Fig 4.1.2a. The lack of significant difference could be due to the short period of time (approximately ten years) that the exclosures have been set up.



In the graph aa or 11=no significance difference ab or 12=significant different, 11, 12 and aa, ab in the graph indicate different comparisons The standard deviation of above graph are in Appendix 11

Fig.4.1.2a Nutrients elements in the grazed and ungrazed glades and bush land

Though the results were not significantly different, this trend concurs with the observation that increased nutrient content by grazing has been known to occur in several ecosystems (Holland and Detling, 1990; Ruess and McNaughton, 1987; Frank and McNaughton, 1993; Olofsson, *et al.*, 2001). This is consistent with Schoenecker *et al.*, (2004) observation that feaces and urine provide large amounts of soluble N that is readily available to plants, and ungulate excretions promote decomposition rates. Peterson *et al.* (1956) and Ampe *et al.*, (2002) also indicated that urination and dung are important means of returning part of the nutrients to the soil; forming local additions of fertilizer, which are unevenly spread through time and space. Klemmedson and Tiedemann, (1995) also supported the observation that grazing can accelerate and alter the timing of nutrient transfers, and increase amounts of nutrients cycled from plant to soil. Kauer *et al.*, (2004) observed that as large herbivores tend to graze in preferential areas and in their habitats and often move to other localities for resting, the habitat often becomes partly nutrients poor and partly nutrients richer. These results of increased nitrogen and organic matter in the grazed glades contrasted Kooijman and Smit (2001) findings that stocks of organic matter and total soil N in the mineral soil overall decreased under grazed conditions.

In contrast there was a trend of higher amount of P in the ungrazed glade compared to the grazed glade. This possibly was due to the herbivores effects of translocating P after grazing to different sites, for cattle to the active bomas and for wild animals to other areas as they graze. Hence grazing might be acting as a redistribution agent of P.

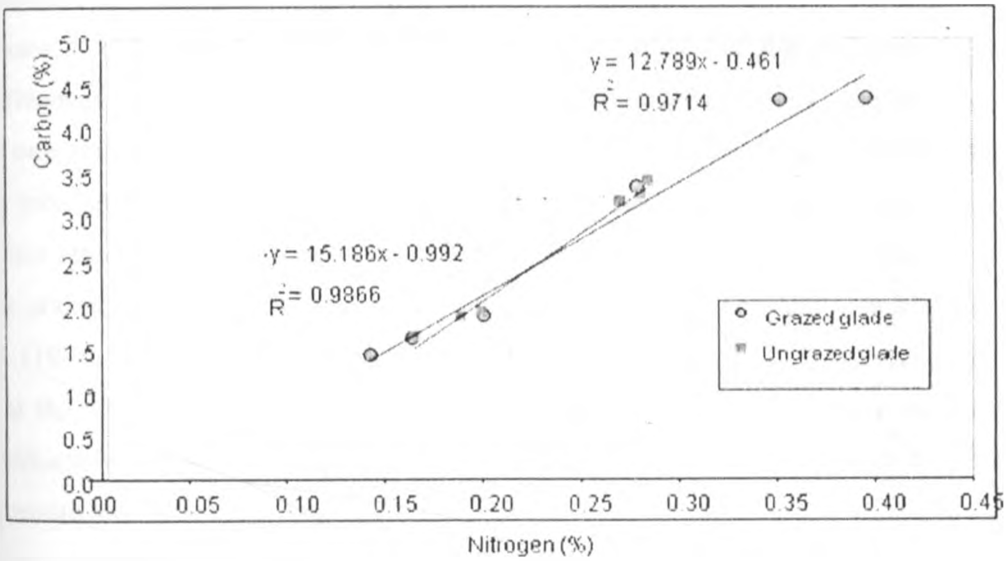


Fig.4.1.2b Relationship between C and N in grazed and ungrazed glades

The relationship between C and N in the grazed and ungrazed glades is shown in Fig. 4.1.2b. The correlation coefficient is slightly higher in the ungrazed glade (r^2=0.9866) than in the grazed glade (r^2=0.9714). This possibly signifies the influence of grazing which leads to unproportional increase of both C and N in the grazed glades.

4.1.2.2 Impact of grazing on soil properties in the bush land conditions

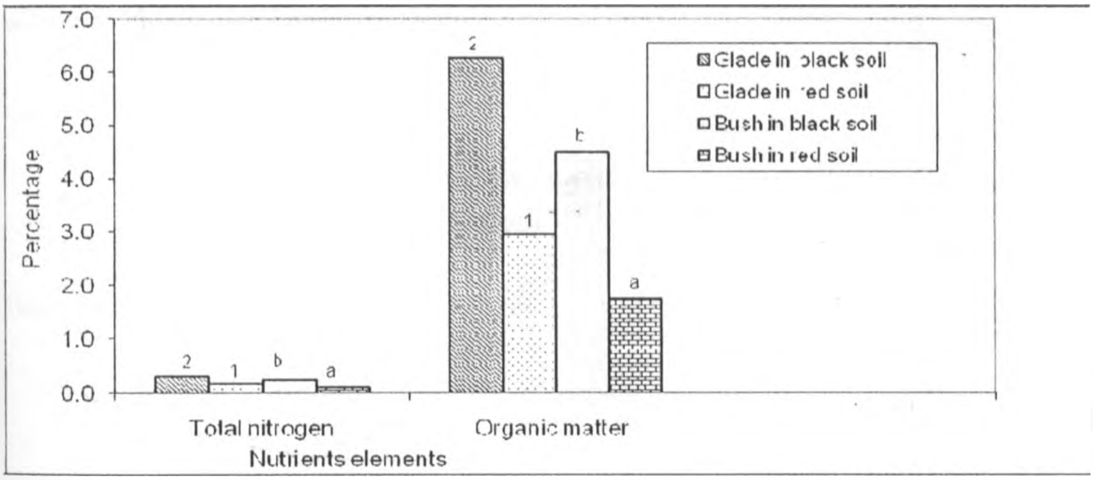
In contrast to glade grazing, Fig. 4.1.2a illustrates the negative effect of grazing in the bush land where nutrient are lost compared to ungrazed bush. There was no significant difference between grazed and ungrazed bush but N, P, C/N ratio and organic matter were relatively higher in the ungrazed bush compared to grazed bush. This is possibly due to harvesting of these nutrients by the large herbivores from grazed bush land and deposition of the same in the glades where they spend most of the time. This is consistent with Augustine *et al.*, (2003) observation and the explanation is that that cattle in this ecosystem graze for only 12 hours per day and excrete nutrients for 24 hours per day, their net effect on grazed swards is to remove N and redistribute it to active bomas. The results indicate that although cattle management through overnight corrals (bomas) enhances the availability of nutrient-rich forage across the landscape through glade creation, this nitrogen is withdrawn from the bush land landscape, creating localized losses. Krueger *et al.*, (2002) reported similar observation that grazing animal behaviour influences the distribution of nutrients to various landscape positions. Animals may graze in one area but move to another area to rest or to drink water. Dung and urine may thus be more plentiful in the resting area and around a watering place than in the grazing area, a fact affecting the soil fertility of both areas, resulting in a net transfer of nutrients from the grazed area to the resting and watering areas (Krueger *et al.*, 2002). de Mazancourt *et al.* (1998) reported that the theoretical analyses of soil–grass–grazer interactions predict that the net N loss at bush land sites will be associated with a negative grazer effect on productivity, whereas the net positive effect of herbivores on glade N balance will promote productivity.

Though grazed glades and grazed bushes were not significantly different from ungrazed glades and ungrazed bushes, respectively, it is apparent that P was higher in the ungrazed glades and bushes than the grazed glades and bushes. This could be due to harvesting of the P by the grazing herbivore and deposition taking place in a different area, whereas in the case of cattle, it is deposited in the active bomas. This is supported by Augustine *et al.*, (2003) findings that nutrients flowing from soils to grasses to grazers within several square meters in a single year may not be cycled back to the same plot. In the ungrazed glades and bushes there is no extraction of P by the large herbivores, but P is maintained with possibly minimal loss through runoff because of the high herbaceous layer in the exclosures that minimise the effects of run off.

4.1.3. Comparison of soil properties in the glades and bush land

4.1.3.1 Effect of the glade on soils properties in the two soil types

The glades in two soil type's glades were significantly different (P<0.05) with glades in black cotton soils having higher N, C/N ratio and organic matter content than glades in the red sandy loams as shown in Fig. 4.1.3a. The glade soil seems to have the same trend with the bush land as far as the differences between the two soils are concerned but with glades having higher amounts of the nutrients compared to the bush land.



In the graph aa or 11=no significance difference ab or 12=significant different, 11, 12 and aa, ab in the graph indicate different comparisons The standard deviation of the above table are in Appendix 12.

Fig.4.1.3a Comparison of nutrients elements in glades and bush land between black cotton soils and red sandy loams

This indicates that though the same factors likely to cause the differences in the bushes of the two soils might also apply in the glades of the two soils, namely different inherent soil fertility, different moisture and temperature regimes and different percentage of ground cover. The glade seem to be getting extra nutrients from elsewhere, most likely from the excretes accumulated by cattle when glades were active bomas and also from the accumulation of nutrients that has taken place as grazing hotspots for domestic animals due to high quality pastures availability. Wild herbivores also contribute due to low predation risk and high quality pastures availability. Young *et al.*, (1998) indicated that glades have high levels of mineral nutrients and are preferentially used by wild and domestic herbivores. There was no significant difference between glade in red sandy loams and black cotton soils in terms of P although there was an apparent trend of P being higher in the red sandy loams probably due to differences in inherent soil fertility in the two soil types. The pH was neutral in the glades in each of the two soils.

Fig. 4.1.3a indicates that the glades in the two types of soils are very different in terms of the amount of C and organic matter. The red sandy loams had a lower C/N ratio compared to black cotton soils possibly due to higher availability of N in glades located in red sandy loams' glade compared to black cotton soils glades. Both C and N in both soils were highly correlated.

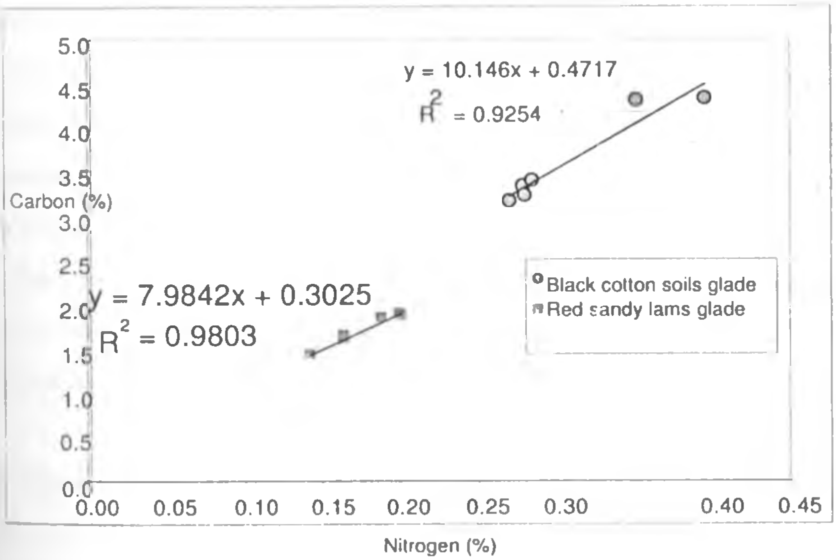


Fig.4.1.3b Relationship between C and N between black cotton soils glade and red sandy loams glade

4.1.3.2 Comparison of the bush land treatment in the two soil types

Fig. 4.1.3a indicate that though bush land in black cotton soils and red sandy loams had lower N, and organic matter content but higher C/N ratio compared to the glades in the two types of soils (Fig. 4.1.3a). The bush land soil parameters in the black cotton soil were significantly different ($P<0.05$) from bush land in the red sandy loams, with N, C/N ratio and organic matter content being higher in the black cotton bush land soils than red sandy loams bush land soils. This could be due to differences in inherent soil fertility of the two soils. These differences could also be due to low temperature in the black cotton bush soil due to high ground cover which lowers the volatilization rate of nitrogen. The poor drainage also minimizes losses of N through leaching and low rate of decomposition, because black cotton soils are characterized by impeded drainage.

For red sandy loam soil the temperature might be higher on the ground compared to black cotton soils. This may be due to relatively less ground cover, which might increase the rate of N volatilization due to higher temperature. Kamau, (2004) indicated that both temperature and moisture regime affects the equilibrium of organic matter contents of the soil. Increased temperature decreases organic matter content while increased moisture increases organic matter (Kamau, 2004). Drainage in red sandy loam soil is relatively better compared to black cotton soil; hence a lot of N could possibly be lost through leaching. The low moisture in the red sandy loam soil due to less cover and good drainage lead to high rate of decomposition. This factor could also be the reason that organic matter and carbon content are lower compared to black cotton soils. In contrast the C/N ratio was, in all cases, higher in the black cotton soils compared to red sandy loams in both bush land and glades soils.

While P was not significantly different between the two bush land soils, it was higher in the red sandy loams than in the black cotton soils. This supports the argument that the differences are most likely due to the different inherent soil fertility of the two soil types. The pH was neutral in the black cotton soils but slightly acidic in the red sandy loams.

(Fig. 4.1.3c) indicate the difference between the two soil types bush land, with black cotton soils (r^2= 0.9799) having higher correlation coefficient than red sandy loams (r^2=0.9039)

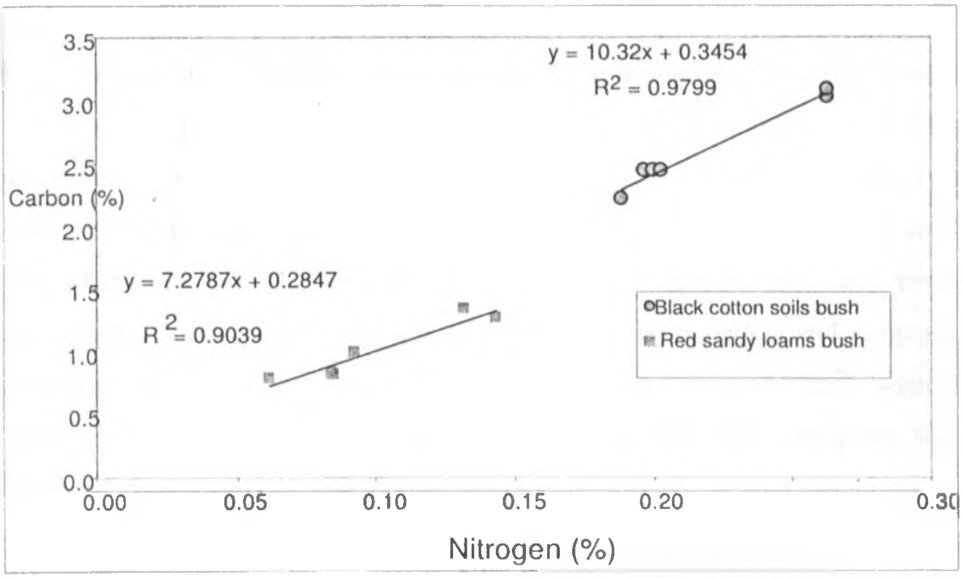


Fig.4. 1.3c Relationship between C and N under bush in the red and black cotton soils.

It is evident that the glades and the bushes of the two soil types are significantly different in terms of N, C/N ratio and organic matter. The correlation coefficients of C and N were very high in both bush land and glade soils which indicate a positive and strong relationship between the two elements.

The partitioning of the difference between the two soil types that is caused by different factors such as the presence of the glades, different inherent soil fertility, different moisture and temperature regimes and different percentage of ground cover should be investigated further.

4.2 Effect of herbivores on sequential phosphorus fractionation

Sequential phosphorus fractionation was done using the method as outlined by Hedley *et al.* (1982). The total P by sequential phosphorus in this study includes resin P, bicarbonate organic P, and bicarbonate inorganic P, NaOH organic P, NaOH inorganic P and HCl P. The bicarbonate organic P and NaOH organic P form the total organic P in this study while resin P, bicarbonate inorganic P, NaOH inorganic P and HCl P form the inorganic P. While the summation of the six organic and inorganic P fractions constitute the total P in this study.

4.2.1. Comparisons in black cotton soils, red sandy loams, glade soils and bush land

The two soil types were not significantly different as far as sequential P fractions were concerned. But black cotton soils had relatively higher organic P compared to red sandy loams, while red sandy loams had higher amount of inorganic P compared to black cotton soils (Table 4.2.1a). The organic carbon: organic P ratio in red sandy loams was 184 while that in black cotton soils was 374. The study by Solomon and Lehmann (2000) in semi arid Tanzania indicated that organic P mineralization could occur when the ratio of organic carbon to organic phosphorus was below 200. This compares well with the threshold given by Dalal, (1977).

All fractions of sequential P were significantly different in the glade compared to bush land irrespective of the soil type as indicated in Table 4.2.1b. This is due to accumulation of manure in the glades. Resin P in the glade soil was 31.7 times higher than in the bush land while bicarbonate organic P in the glade soil was 6.6 times higher compared with the bush land. Bicarbonate inorganic P in the glade soil was 5.2 times higher than in the bush land. The P fractions within the glade were generally in the following order: HCl P> Resin P> NaOH organic P> NaOH inorganic P> Bicarbonate organic P >Bicarbonate inorganic P. While in the bush land the P fractions were generally in the following order: NaOH organic P> NaOH inorganic P> Bicarbonate inorganic P> HCl P> Resin P> Bicarbonate organic P.

Table 4.2.1 a Phosphorus fractions in the red and black cotton soils

Soil type	Bicarb organic P	NaOH organic P	Total organic p	NaOH inorg P	Resin P	Bicarb inorg P	HCl	Total inorganic P	Total P
Black cotton soils	15.9^{a*}	86.3^{a}	102.2^{a}	39.7^{a}	96^{a}	29.8^{a}	145^{a}	$310.^{a}$	$412.^{a}$
Red sandy loams	9.9^{a}	59.9^{a}	69.8^{a}	62.4^{a}	$134.^{a}$	28.4^{a}	$157.^{a}$	$382.^{a}$	$452.^{a}$
L.S.D5 %	14.06	28.03	40.77	28.06	131.8	28.15	236.9	366.3	360.8

*The different superscripts on the table of means along column indicate significant differences and have the following significance level a=No significant difference b=<0.05, c=<0.01, d=<0.001.

It is evident from the results that the fractions of the sequential P were higher in the glades compared to the bush (Fig.4.1.2b). This could be due to the past and current manure accumulation in the glades. Resin P, bicarbonate inorganic P and bicarbonate organic P in glades were very high compared to the surrounding bush land which ensures higher availability of P in the glade compared to the surrounding bush. HCl P, NaOH inorganic and organic P were also higher in the glades compared to the bush land indicating availability of P over a longer period of time. It is worth noting that organic P is proportionally more important in the bush land than the glades as it is at least half the total P in the bush land soils, but only 20% or less in the glades. The animals are enriching the glades with inorganic P, but organic P is probably very important source for plant nutrition in the bush.

Table 4.2.1b Phosphorus fractions in the glade soils and bush land

Land type	Bicarb organic P	NaOH organic P	Total organic p	NaOH inorg P	Resin P	Bicarb inorg P	HCl	Total inorganic P	Total P
Glade	22.4^{b*}	95.0^{c}	117.4^{c}	83.9^{d}	222^{c}	48.8^{b}	293^{b}	649^{c}	766^{c}
Bush	3.4^{a}	51.2^{a}	54.6^{a}	18.1^{a}	7^{a}	9.4^{a}	9^{a}	43^{a}	98^{a}
L.S.D	14.06	28.03	40.77	28.06	131.8	28.15	236.9	366.3	360.8

*The different superscripts on the table of means along column indicate significant differences and have the following significance level a=No significant difference b=<0.05, c=<0.01, d=<0.001.

These results confirm the observation made by Augustine *et al.* (2003) that grasses of nutrient-rich sites (glades) contained sufficient P concentrations to meet requirements for pregnant and lactating ungulates, whereas grasses in nutrient-poor swards (surrounding bush) were P- deficient.

Augustine *et al.*, (2003) further indicated that low absolute P concentrations in bush land grasses (<0.30%) is likely to also indicated that P may affect secondary productivity this concentration of forage P is less than animal requirement concentrations of 0.40–0.60% that is recommended for pregnant and lactating ruminants. The P-rich soil in glades is likely to play an important role in meeting native ungulate nutritional requirements during pregnancy and lactation by supporting forage of high nutrition quality, a finding already reputed by McNaughton, (1988) and indicated that ungulate selection of productive patches within the landscape could be related to both energetic and nutrient-related aspects of forage quality. The heterogeneity in the spatial distribution of P can benefit native and domestic ungulate herbivores by providing unique habitats where requirements for mineral nutrients can be met during the growing season.

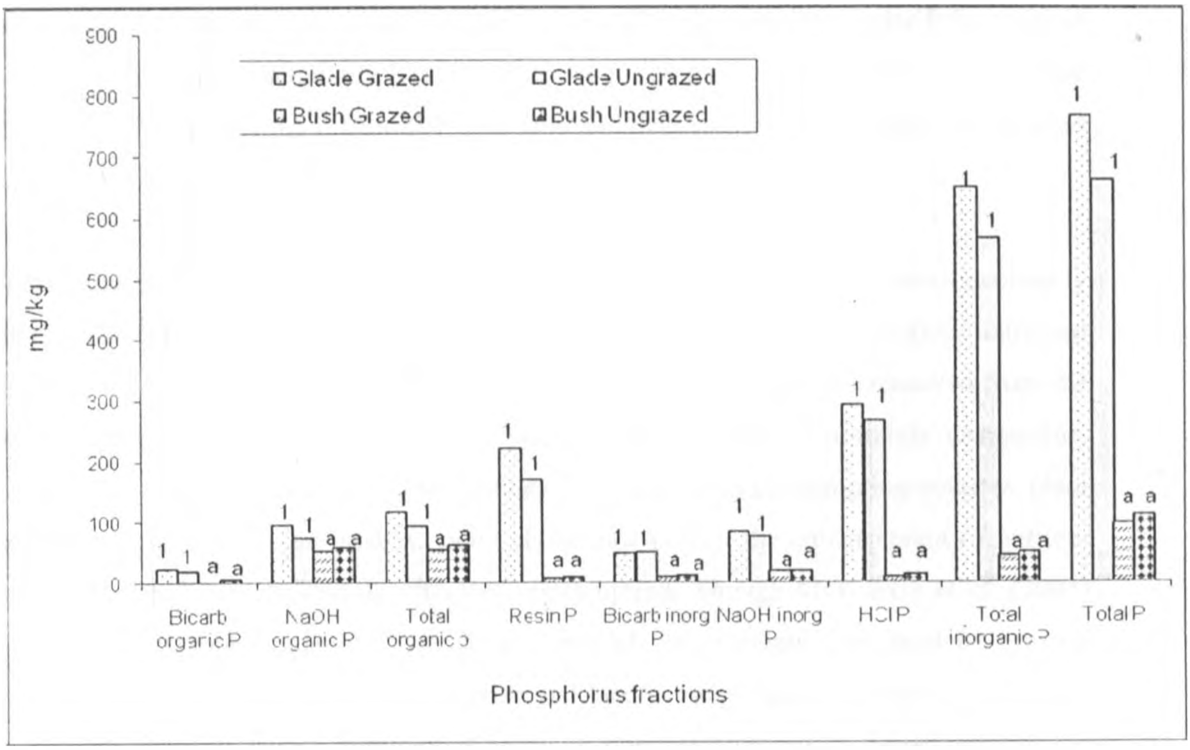
4.2.2. Effects of herbivory on grazing lands in relation to phosphorus fractionation

4.2.2.1 Effects of grazing in the black cotton and red soils glades

Though there was no significant difference between grazed and ungrazed glades, there was relatively higher content of P available fractions, namely resin P and bicarbonate organic P in grazed glade soils, compared to ungrazed glades (Fig 4.2.2). Kamau (2004) concurs with this observation that available P remains more or less constant in both the grazed and ungrazed plots, with an indication of possible decline in enclosed plots.

In the grazed glade soils, the plant unavailable P, namely NaOH organic P, NaOH inorganic P and HCl P was more than 1.6 times higher than the plant available P namely bicarbonate organic and inorganic P and resin P. In the ungrazed glade soils, plant unavailable P was 1.7 times higher than available P.

The low content of plant available P (resin P, bicarbonate organic P and bicarbonate inorganic P) is attributed to the fact that this element is stored in unavailable forms for plant assimilations (H_2PO4) as indicated by the values of NaOH organic and inorganic P, HCl P which are higher than the values of available P fractions, which becomes available to plants at low pH (Juo, 1978). This form is also fixed by hydrous oxides and silicate minerals. Sample *et al.*, (1980) observed that P is readily adsorbed by sediment particles and forms insoluble precipitates with cations such as iron, aluminium and calcium.



In the graph aa or 11=no significance difference ab or 12=significant different. 11, 12 and aa, ab in the graph indicate different comparisons. The standard deviation of the above graph are in appendix 13.

Fig.4. 2.2 Phosphorus fractions in the grazed and ungrazed glades and bush land

Inorganic NaOH P precipitate with iron and aluminium and HCl P precipitate with calcium (Daroub *et al.* 2004). Due to the P retention phenomenon, P is strongly associated with sediment particles in the soil. Consequently, the majority of P from diffuse sources is transported by surface runoff in particulate forms. This element is doubly critical, because of low total amounts and a very low availability. Urine and faeces create an organic nutrient pool where the nutrients are easily decomposable and are quickly recycled to inorganic form (Olfsson, *et al.*, 2001) hence loss of this critical element through run off is avoided.

4.2.2.2 Effects of grazing on bush land

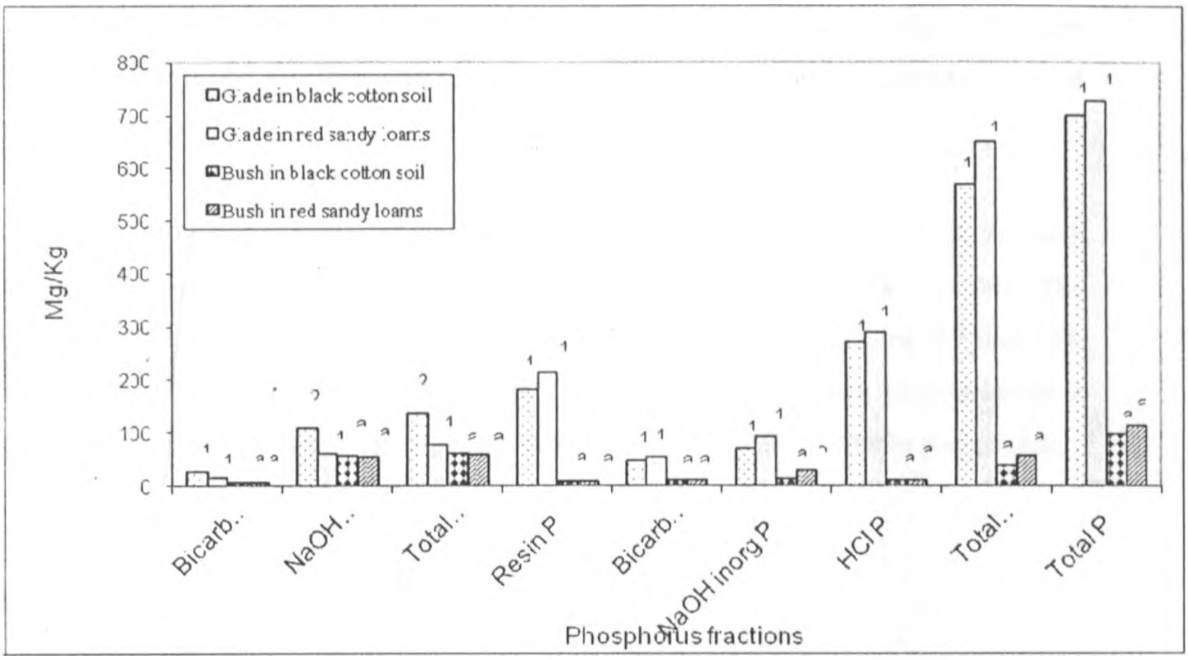
Though there was no significant difference between grazed and ungrazed bush land the ungrazed bush land had higher amount of P fractions than the grazed bush land (Fig 4.2.2). This is consistent with observation made by Augustine (2003) that at bush land sites, large herbivores represented permanent loss of P. The trend of higher P fractions in the grazed glade and relatively lower P fractions in the grazed bush land is possibly due to animals harvesting the P from the bush land and depositing it in the glades where they spend a lot of time because glades provide low predation risk.

This finding indicates that grazing pressure in the landscape is heterogeneously distributed and is supported by Augustine's observation that although nutrient-enriched glades can clearly benefit large herbivores, the nutrients in bomas are removed from the surrounding landscape with a potential cost to the bush land community (Augustine, 2003). Belovsky and Slade, (2000) indicated that because consumption reduces plant abundance, herbivory can increase plant abundance only if the enhancement of nutrient cycling exceeds the depressing effect of consumption. Though McKenzie *et al.* (2003) indicated that approximately 75 to 90 per cent of the nutrients consumed by grazing animals are cycled back to the soil in urine and faeces; only a small amount of consumed nutrient is removed from a field with the animal. The results of this study indicate that the location of consumption and deposition of nutrients through faeces and urine matters. This probably explains why the ungrazed bush land has higher amount of P than the grazed bush. The P produced in the slow cycle of organic matter decomposition is retained in the ungrazed bush land while in the grazed bush land the nutrients are harvested by herbivores and possibly deposited, in form of urine and feaces in the glades (dormant bomas), where wild herbivores spend a lot of time, in form of urine and feaces while domestic animals deposit these nutrients in the active bomas. Analyses of impala habitat selection with automated camera monitors showed that during dry seasons, large impala herds bedded and defecated nightly in glades, most likely due to low predation risk in these shrub-free habitats, but fed daily in the surrounding bush land where green leaves, primarily of shrubs, were still available Augustine (2002). During wet seasons, impala occupied the glades and shifted to both bedding and foraging in throughout the season. It was noted that during the wet season, there was, significant additional grass consumption in glades by cattle. The seasonal pattern of glade selection by impala suggests that intensive use of glades is driven primarily by low predation risk in dry seasons and a combination of forage quality and low predation risk in wet seasons (Augustine 2002).

4.2.3 Comparison of the phosphorus fractionations in the glades and bush land

4.2.3.1 Phosphorus fractions in the red sandy loams glade and black cotton soils glade

Glades in red sandy loams and glades in black cotton soils were significantly different in terms of P fractions (Fig 4.2.3). NaOH inorganic P in the red sandy loams glade was 1.4 times higher than glade in black cotton soils. NaOH organic P in black cotton glade soil was 1.8 times higher than glade in red sandy loam soils. Total organic P in black cotton glade soils was 1.8 times higher than glade in red sandy loams. But the total plant available P (bicarbonate organic P, bicarbonate inorganic P and resin P) was more than 1.1 times higher in the red sandy loams compared to the black cotton soils while the plant unavailable P was almost the same in the glades of the two soils. The significantly higher fractions of P in the black cotton glades, namely NaOH and total organic are of organic origin which indicate that possibly the mineralization rate could be higher in the red sandy loams compared to black cotton soils due to relatively higher temperatures and lower moisture regimes.



In the graph aa or 11=no significance difference ab or 12=significant different, 11, 12 and aa, ab in the graph indicate different comparisons. The standard deviations of the above graph are in appendix 14.

Fig.4.2.3 Phosphorus fractions in the black cotton soils and red sandy loams' glade soil's and bush land.

4.2.3.2 Phosphorus fractions in the red sandy loams and black cotton soils bush land

Only NaOH inorganic P was significantly different between the two soil types, whereby it was 2.5 times higher in the red sandy loams bush land than in the black cotton soils bush.

In both bush land and glades, black cotton soils had relatively higher total organic P probably due to organic matter content while red sandy loams had relatively higher total inorganic P this would be probably due to difference in parent material. This argument is supported by Rehm and Schmitt (1993), that the phosphorus in organic materials is released for plant growth through mineralization which occurs as micro organisms break down soil organic matter. The activity of the micro organisms is highly influenced by soil temperature and soil moisture. The process is most rapid when soils are warm and well drained (Rehm and Schmitt, 1993). In red sandy loams bush land, plant available P was relatively higher than in the black cotton soils bush land as indicated in Fig. 4.2.3 above and plant unavailable P was also more than 1.1 times higher in the red sandy loams in comparison to bush land in black cotton soil. This is possibly attributed to the differences inherent soil fertility, moisture and temperature regimes, and drainage characteristics of the two soil types.

The results of organic carbon: organic P ratio indicate that red sandy loams in the bush land had a ratio of 178 while in black cotton soils bush land had a ratio of 446. The glades in black cotton soils and red sandy loams glade soils had a ratio of 283 and 232, respectively. The ratio of less than 200 in the red sandy loams bush land indicates a greater contribution of organic phosphorus mineralization to plant available phosphorus.

CHAPTER 5

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

5.1.1. Effect of herbivores on soil properties in red sandy loams and black cotton soils.

Although the current grazing treatments do not produce significant differences in soil properties , the long term impacts of grazing that is responsible for the formation of glades from abandoned bomas has profound impact on secondary productivity of rangelands as a result, of critical role in the nutrition of herbivores. Results indicate that there is heterogeneous distribution of N, P, C, and organic matter in the study area with the bias towards of having higher N, P, C, and organic matter in the glades than in the bush land. This suggests that the high content of N, P and organic carbon in the glade is harvested from the bush and deposited in the glade. Rangeland managers need to recognize the importance of the placement and relocation rate of current bomas in the influence of the long-term distribution and availability of nutritionally important forage for livestock and wildlife. This spatial heterogeneity created by frequent relocation of bomas provides patches of N and P-sufficient forage.

The black cotton soils had higher content of N, organic matter and C/N ratio than the red sandy loams, while P was generally higher in the red sandy loams. The differences between the two soil types are mainly due to the different inherent soil fertility where red sandy loams are developed from metamorphic basement rocks and black cotton soils derived from basaltic lava flow.

Results indicate that grazed glades had higher N, C, organic matter and C/N ratio compared to ungrazed glades while ungrazed bush land had higher N, C, organic matter and C/N ratio compared to grazed bush land. This may indicate that the nutrients are relocated from the bush to the active bomas by the cattle and to the glades by the wild herbivores. The wild herbivore preference of spending a lot of time in the glades is because of the higher forage quality and low predation risk.

In the grazed glade and bush land soils there was a trend of P being lower relative to the ungrazed glade and bush land. This is because nutrients flowing from soils to grasses to grazers within several square meters may not be cycled back to the same plot. In this case the P is harvested from the grazed area and transported to the active bomas by the cattle and spread in different areas by the wild herbivores while P in the ungrazed areas (exclosures) is retained with minimum loss.

Black cotton soils glades versus red sandy loams glades, and black cotton soils bush land versus red sandy loams bush land were totally different. With black cotton soils having higher content of N, C, organic matter and C/N ratio and red sandy loams having higher amount of P fractions. This is because of the different inherent soil fertility of the two soils. The other possible cause of the difference with possibly minor effects is the different temperature and moisture regimes since it affects soil organic matter.

5.1.2 Effect of herbivores on sequential phosphorus fractionation in red sandy loams and black cotton soils

The fractions of the sequential P were higher in the glades compared to the bush land. This was because of manure accumulation in the glade soils. Resin P, bicarbonate inorganic P and organic P were very high in the glades compared to the surrounding bush land. HCl P, NaOH inorganic and organic P were also higher in the glades compared to the bush land indicating availability of P over a longer period of time. The results indicate that the glades have higher P fractions content at the expense of the bush land, because the high P fractions in the glades are harvested from the surrounding bushes. These glades are likely to play an important role in meeting native ungulate nutritional requirements during pregnancy and lactation. Factors such as increased sedentarization of pastoralists, the use of permanent bomas that more effectively deter predators, and the use of relatively permanent bomas around water sources and cattle dips will create a nutrient drain on the ecosystem by concentrating manure into a smaller area of the landscape and reducing opportunities for long-term glade development.

Grazing had a positive trend in the grazed glade soils compared to ungrazed glade soils, while it had a negative effect on the grazed bushes as far as sequential P fractions are concerned. This is due to harvesting of P from the bushes and depositing it in the active bomas by cattle and in glades by wild herbivores.

The relative uniformity in the two soil types glades compared to bushes in relation to sequential P fractions could be because of the accumulation of manure for a long period of time in the glade while bushes loose a lot of P through animal harvesting and deposition in the active bomas by livestock and in the glades by the wild herbivores. The bush land of the two soils is very different in relation to sequential P fractions with red sandy loams having higher content of P fractions which indicates that the differences in inherent soil fertility of the two soils play a big part in determining P content in the bush land.

Organic P is proportionally more important in the bush land than in the glades. It is at least half the total P in the bush land soils, but only 20% or less in the glades. So the animals are enriching the glades in inorganic P, but organic P is probably very important for plant nutrition in the bush.

5.2 Recommendations

1. Since glades contain high quality forage in both P and N that meet the requirements of both pregnant and lactating herbivores and also provide low predation risk for the wild herbivores, managers could increase the availability of nutrient-enriched patches on the landscape by increasing boma relocation and abandonment rates.

2. On many managed rangelands, the maintenance of native wildlife populations for eco- tourism or hunting is an important consideration. Current boma locations could therefore be managed with an aim of creating wildlife hotspots in desired locations for future glade development after boma abandonment.

3. Unlike N which can be added to the soils through natural breakdown of soil organic matter, fixation by native legume species and atmospheric additions by lightning storms, much of the P for plant growth comes from the breakdown and decomposition of organic matter and a small amount from release by soil minerals. Hence in the natural environments where there are no addition of P through artificial fertilizer application care should be taken to avoid depletion of P (through run off) which is a critical element in plant and animal production, yet limiting in most of the tropical areas. Therefore, sustainable P management in natural environments is critical and should be key issue in grazing management that need to be addressed in order to ensure sustainability in plant and animal production.

4. Herbivore management is important for ensuring that nutrient resources within the ecosystems are not depleted. The removal of grazers for example both domestic and wild ungulates will neither improve range production nor range condition in the long term but will lead to loss of nutrients through leaching, volatilization and runoff; hence livestock and wildlife grazing is effective as a management tool in sustainable ecosystem management.

5. In the Laikipia central savannah red sandy loams bush lands have higher P content compared to black cotton soils bush land, proving an ideal area for grazing both pregnant and lactating domestic animals because they need higher P content.

6. Further research needs to be carried out on residual P (organic and inorganic) and sonication NaOH P (organic and inorganic) fractions in the sequential P fractionation in order to know how the two different sources of P might be contributing to P availability which is a limiting nutrient of production in the tropical region.

7. The partitioning of the difference between the two soil types caused by different factors, that is; the presence of the glades, different geologic origin, different moisture and temperature regimes and different percentage of ground cover should be further investigated for management purposes. This will enable the ranch manager to reap maximum benefits in soil nutrients utilization by adjusting the grazing schedule depending on nutrients availability.

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APPENDICES

APPENDIX 1. ANALYSIS OF VARIANCE ON NITROGEN IN GLADE vs. BUSH SOILS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Soil type	1	0.068554	0.068554	45.53	<.001
Glade	1	0.032552	0.032552	21.62	0.002
Soiltype.glade	1	0.001430	0.001430	0.95	0.358
Residual	8	0.012046	0.001506		
Total	11	0.114582			

APPENDIX 2. ANALYSIS OF VARIANCE ON CARBON IN GLADE vs. BUSH SOILS

Source of variation	d.f.	s.s.	m.s.	V.r.	F pr.
Soil type	1	12.1364	12.1364	87.42	<.001
Glade	1	3.5491	3.5491	25.56	<.001
Soiltype.glade	1	0.3434	0.3434	2.47	0.154
Residual	8	1.1106	0.1388		
Total	11	17.1395			

APPENDIX 3. ANALYSIS OF VARIANCE ON C/N RATIO IN GLADE vs. BUSH SOILS

Source of variation	d.f.	s.s.	m.s.	V.r.	F pr.
Soil type	1	9.9008	9.9008	32.82	<.001
Glade	1	0.3675	0.3675	1.22	0.302
Soiltype.glade	1	0.0675	0.0675	0.22	0.649
Residual	8	2.4133	0.3017		
Total	11	12.7492			

APPENDIX 4. T-TEST ON NITROGEN IN THE GLADES OF THE TWO SOILS

Sample	Size	Mean	Variance	S.D	SEM
Nitrogen_glade_in_black	6	0.3107	0.002621	0.05120	0.02090
Nitrogen_glade_in_red	6	0.1770	0.000544	0.02332	0.00952

Test of null hypothesis that mean of NITROGEN_GLADE_IN_BLACK is equal to mean of NITROGEN_GLADE_IN_RED
Probability<0.001

APPENDIX 5. T-TEST ON CARBON IN THE GLADES OF THE TWO SOILS

Sample	Size	Mean	Variance	S.D	S.E.M
CARBON_GLADE_IN_BLACK	6	3.624	0.2916	0.5400	0.2205
CARBON_GLADE_IN_RED	6	1.716	0.0353	0.1880	0.0768

Test of null hypothesis that mean of CARBON_GLADE_IN_BLACK is equal to mean of CARBON_GLADE_IN_RED
Probability < 0.001

APPENDIX 6. ANALYSIS OF VARIANCE ON NaOH INORGANIC P IN GLADE VS.BUSH SOILS

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
SOIL_TYPE	1	1550.6	1550.6	3.49	0.099
GLADE	1	13005.4	13005.4	29.27	<.001
SOIL_TYPE.GLADE	1	162.0	162.0	0.36	0.563
Residual	8	3554.0	444.3		
Total	11	18272.0			

APPENDIX 7. ANALYSIS OF VARIANCE ON RESIN P IN GLADE VS.BUSH SOILS

Source of variation	d.f.	s.s.	m.s.	V.r.	F pr.
SOIL_TYPE	1	4365.	4365.	0.45	0.523
GLADE	1	139752	139752.	14.25	0.005
SOIL_TYPE.GLADE	1	4637.	4637.	0.47	0.511
Residual	8	78460.	9807		
Total	11	227214			

APPENDIX 8. T-TEST ON NaOH INORGNIC P IN THE GLADES OF THE TWO SOILS

Sample	Size	Mean	Variance	S.D	S.E.M
BLACK NaOH inorg P	6	68.18	373.2	19.32	7.887
RED NaOH inorg P	6	92.93	356.2	18.87	7.705

Test of null hypothesis that mean of BLACKNaOH_inorg_P_mg_kg_soil is equal to mean of RED_NaOH_inorg_P_mg_kg_soil

Probability = 0.049

APPENDIX 9. T-TEST ON NaOH ORGANIC P IN THE GLADES OF THE TWO SOILS

Sample	Size	Mean	Variance	S.D.	S.E.M
Black NaOH organic P	6	108.04	743.9	27.27	11.134
Red NaOH organic P	6	61.22	140.8	11.87	4.845

Test of null hypothesis that mean of BLACK_NaOH_organic_P_mg_kg_soil is equal to mean of RED_NaOH_organic_P_mg_kg_soil

Probability = 0.007

APPENDIX 10: STANDARD DEVIATION OF NUTRIENTS ELEMENTS IN THE GLADE AND BUSH

N	OM	P
0.10	2.32	0.03
0.08	1.65	0.00

APPENDIX 11: STANDARD DEVIATION OF NUTRIENTS ELEMENTS IN THE GRAZED AND UNGRAZED GLADES AND BUSH LAND

Column1	N	OM	P
Grazed glade	0.051196	2.315817	0.031669
Ungrazed glade	0.023315	1.39901	0.022591
Grazed bush	0.075402	1.647217	0.000602
Ungrazed bush	0.069895	1.52702	0.008325

APPENDIX 12: STANDARD DEVIATION OF COMPARISON OF NUTRIENTS ELEMENTS IN GLADES AND BUSH LAND BETWEEN BLACK COTTON SOILS AND RED SANDY LOAMS

	N	OM
Black glade	0.05	0.93
Red glade	0.02	0.32
Black bush	0.03	0.62
Red bush	0.03	0.41

APPENDIX 13: PHOSPHORUS FRACTIONS IN THE GRAZED AND UNGRAZED GLADES AND BUSH LAND

	Resin	bicarb inorga	NaoH inorg	HCl	total inorg	bicar org	NaOH org	Total org	Total P
Glade grazing	132.25	26.60	29.43	225.46	354.90	14.39	37.24	33.46	344.02
Glade ungrazed	52.38	18.90	14.26	82.02	129.45	10.92	23.57	33.16	134.61
Bush grazing	1.78.	3.34	13.69	4.45	14.37	3.62	10.40	11.28	23.06
Bush ungrazed	2.77	3.37	12.47	2.10	16.12	3.80	7.15	6.73	18.36

APPENDIX 14: STANDARD DEVIATION OF P FRACTIONS IN THE BLACK COTTON SOILS AND RED SANDY LOAMS' GLADE SOIL'S AND BUSH LAND

	Bicarb organic P	NaOH organic P	Total organic p	Resin P	Bicarb inorg P	NaOH inorg P	HCl P	Total inorganic P	Total P
Black glade	18.29	27.27	42.15	86.04	26.00	19.32	198.61	299.49	300.05
Red glade	5.54	11.87	14.61	116.94	18.93	18.87	135.38	229.61	229.36
Black bush	3.69	8.59	9.05	1.27	3.32	2.80	1.33	6.93	14.38
Red bush	3.91	10.23	11.15	3.35	3.32	13.60	5.05	16.36	25.03