INFLUENCE OF GRAZING MANAGEMENT PRACTICES AND TOPOGRAPHIC POSITIONS ON VEGETATION ATTRIBUTES, SOIL ORGANIC CARBON AND GREENHOUSE GAS EMISSIONS IN SEMI-ARID RANGELANDS OF LAIKIPIA COUNTY, KENYA

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DECLARATION

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

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DEDICATION

I dedicate this thesis to Mbarĩ ya Gitau and the Kirakou’s family

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
ASALs	Arid and semi-arid lands
C	Carbon
CH_4	Methane
CO_2	Carbon dioxide
GHG	Greenhouse Gas
IPPC	Intergovernmental Panel on Climate Change
MAOC	Mineral-associated organic carbon
MRV	measuring, reporting and verifying
N	Nitrogen
N_2O	Nitrous Oxide
NRT	Northern Rangelands Trust
POC	Particulate Organic Carbon
SOC	Soil organic carbon
SOM	Soil organic matter
TOC	Total Organic Carbon
TON	Total Organic Nitrogen
UNFCCC	United Nations Framework Convention on Climate Chang
WFPS	Water filled pore space

ABSTRACT

Semi-arid rangelands of Kenya have been managed through grazing for many years. This has influenced the landscape in terms of vegetation attributes such as species diversity, richness, composition, and abundance. Furthermore, a few studies have been done on how different land cover types under different grazing management practices as well as topographical positions influence soil organic carbon fraction content in the soil. Also, the aspect of greenhouse gas emissions under different land cover types and grazing management influence is poorly understood for semi-arid rangelands. The effect of grazing management practices on vegetation attributes, soil organic carbon fractions, and greenhouse gases was assessed for semi-arid rangelands of Laikipia County, Kenya. An experiment with a complete randomized design was set up to determine; (1) the effect of grazing practices and topographic positions on vegetation attributes, (2) effect of grazing practices, topographic positions, and land cover on soil mineral-associated carbon (MAOC) and particulate organic carbon (POC) and (3) effect of grazing management practices and land cover types on CO_2, CH_4 and N_2O emissions. The treatments were grazing management practices, continuous grazing and controlled grazing; and the topographic positions; mid-slope, foot slope, and bottomland. The land cover types, bare ground, patches of grasses, and mosaics of trees, were selected randomly and replicated three times. Both grazing practices and topographical positions had a significant ($p<0.05$) effect on the relative abundance of trees as well as grasses while it was highly significant ($p<0.001$) on herbs and forbs. Effect of grazing practices and topographical positions on species diversity was significant ($p<0.01$) on herbs cover. Tree density responded to grazing practices significantly ($p<0.05$). Under controlled grazed zones, bottomland recorded high species composition. Grazing practices had a significant effect ($p<0.001$) on POC. Controlled grazing (POC= 0.887%, CC SD=0.49) zones was significantly different compared to zones under continuous grazing (POC = 0.718% CC SD=0.3). Mosaic of trees (POC =1.15% CC, SD =

0.22) recorded the highest concentration of carbon followed by patches of grass (POC = 0.87% CC, SD= 0.37) whereas bare ground (POC = 0.38% CC SD = 0.12) had the least. Topographical position had an increasing trend of carbon concentration down the gradient that is mid-slope (POC = 0.59% CC, SD =0.4)< foot slope (POC = 0.84% CC, SD =0.34) < bottomland (POC = 0.98% CC, SD = 0.41). Grazing practices significantly ($p<0.001$) influenced CO_2 and N_2O fluxes though it was insignificant ($p>0.05$) on CH4 flux. Controlled grazing produced 74.16% CO_2-C and 82.47% N_2O-N fluxes compared to continuous grazing which was observed to be 21.5 mg.m-$^{2\cdot}$h-^{1} CO_2- C and 3.4µg.m^{2}h^{1} N_2O- N flux. Under different land covers, there was a significant ($p<0.05$) effect on CO_2 and N_2O but insignificant in CH_4. Bare ground had 27.86mg.m-$^{2\cdot}$h-^{1} CO_2- C flux, 0.007 mg.m-$^{2\cdot}$h-^{1} CH_4-C flux and 3.71µg.m^{2}h^{1} N_2O- N fluxes.Tree had 66.57 mg.m-$^{2\cdot}$h-^{1} CO_2- C emission -0.005 mg.m-$^{2\cdot}$h-^{1} CH_4-C fluxes and 11.43 µg.m^{2}h^{1} N_2O- N fluxes. Grass exhibited 61.88 mg.m-$^{2\cdot}$h-^{1} CO_2- C fluxes, -0.034 mg.m-$^{2\cdot}$h-^{1} CH_4-C fluxes and 18.81 µg.m^{2}h^{1} N_2O- N fluxes. Continuous grazing accelerated species richness of unpalatable species and increased bare ground, unlike controlled grazed zones. Controlled grazing management enhanced species relative abundance and led to less loss of POC but emitted more N_2O-N and CO_2-C fluxes, unlike continuous grazing. Controlled grazing should be used to increase species relative abundance and composition and reduce further loss of POC fraction. Destocking should be carried out under continuous grazing management to curb further loss of vegetation cover and enable vegetation to recover from intensive grazing. Grazing activity should be only in the bottomlands to avoid the further decrease of POC in mid-slope and foot slope which recorded less POC content.

Keywords: grazing management, land cover types, greenhouse gas emissions, topographical positions, particulate organic carbon,

CHAPTER ONE

INTRODUCTION

1.1 Background information

Wildlife and livestock tend to co-exist in these semi-arid rangelands (Smithers 1983; Homewood 2008; Craigie *et al.,* 2010). The semi-arid rangelands have been utilized to sustain livestock production through various grazing management approaches (Crawford *et al.*, 2018). These grazing management practices have created a link to the formation of mosaics of bushlands, densely wooded grasslands, thickets, and scrubs (Chidumayo et al., 2010; Ndegwa *et al.*, 2016). The most common grazing practices in semi-arid rangelands are controlled grazing and continuous grazing (Odadi *et al.*, 2017; Crawford *et al.*, 2018). Controlled grazing management practice has been characterized to have a fixed stocking rate of livestock. The mechanism used is based on the time-control of rotational grazing and is a technique used to promote sustainable semi-arid rangelands (Odadi *et al.,* 2017). Continuous grazing management practice is practiced by sedentarized pastoral groups and is an enterprise for livestock production. Moreover, it's been attributed to jointly own freehold title to land (Western *et al.*, 2009).

Continuous grazing has been characterized to have heavy grazing densities of livestock. This has been documented to have a negative environmental influence and has contributed to rangeland degradation, depletion of forage quality and quantity as well as accelerating desertification (Alkemade et al., 2013; Crawford *et al.,* 2018). On the contrary, it has been documented to reduce GHG fluxes but this comes at the expense of community function and loss of soil nutrients. High grazing management has led to dysfunctioning of semi-arid rangelands thus leading to the formation of patches and inter-patches of trees, grasses, and bare ground cover. Controlled grazing has been introduced in semi-arid rangelands to cub further loss of land cover and soil nutrients, though its influence on GHG is unknown. Moreover, it is essential to retain land cover which has been associated with biodiversity conservation and land productivity (Freudenberger *et al.*, 1997; Eldridge *et al.,* 2016).

Unfortunately, smallholder livestock farmers are significantly vulnerable to climate change and global warming due to poor grazing practices which aggravate the quality of forage and different stocking breeds in Kenya (Graham *et al.,* 2013; Osumba et. al., 2014 Kumar *et al.,* 2015). Furthermore, enteric emissions and animal droppings within the livestock production under the agricultural sector are the main sources of GHG in Kenya (WRI 2014; FAO 2015). Kenya for a long time has been relying on tier 1 method of estimating GHG emissions thus may lead to overestimating or underestimating (Pelster *et. al.,* 2016). On the other hand, other than grazing, the contribution of natural vegetation to soil emissions is poorly understood and there is insufficient information despite being the source of carbon and nitrogen in the soil through litter quality and quantity as well as root exudation (Carmichael *et al.,* 2014).

With livestock production being a major source of GHG emissions in Kenya, previous studies have shown controlling stocking density enhances land cover and soil C and N (McDonald *et al.,* 2018). Besides, patches of land cover acting as reservoirs of SOC there is insufficient information on the influence of POC, MAOC, and oxidation of C and N fluxes. Against this background, a study was carried out to evaluate continuous and controlled grazing management practices and their influence on landscape functioning of semi-arid rangelands of Kenya by measuring some vegetation attributes, soil organic carbon fractions, and GHG emissions.

1.2 Statement of the problem

Grazing management practices such as high stocking densities of livestock has been documented to have a setback on forage quantity and quality as well as desertification and degradation of rangelands (Savory, 1983; Fleischner, 1994; Steinfeld *et al*., 2006; Alkemade *et al*., 2013; Crawford *et al*., 2018). Most studies in semi-arid rangelands look at species diversity in terms of Herbaceous cover and woody cover (Mureithi *et al.,* 2014, Ombega *et al.,* 2017) However, there is insufficient knowledge on the contribution of grazing practices and topographical positions on herbs cover in particular. Moreover, species diversity and richness alone fail the attempt to explain the effect of grazing management practices. This creates a gap for understanding the relationship between patches and inter-patches of species which species composition attempts to explain. Most studies in Kenya have looked at grass and forbs composition but have left out the contribution of herbs, trees, and shrubs composition in semi-arid rangelands (Mureithi *et al.,* 2010; Ombega *et al.*, 2017; Jawuoro *et al.,* 2017). Also, the contribution of relative abundance of various species to species diversity and composition in semi-arid rangelands is poorly understood. Besides, there is insufficient information on how continuous and controlled grazing and topographical positions influence the distribution of species abundance as well as the species composition of herbs, trees, and shrubs.

The influence of different land cover types on soil carbon fractions and emissions is poorly understood. The active soil layer (0-30cm) is very important when studying soil emissions. Oduor *et al.,* (2018) and Rotich *et al.,* (2018) studied the distribution of SOC with depth in the topsoil and sub-soil and under different grazing practices. Although there is a missing link between the contribution of grazing practices and different land cover types on both SOC fractions and soil emissions. Besides, the correlation between SOC fractions and soil emissions is poorly understood and whether the relationship is positive, negative, or neutral.

1.3 Justification

Kenyan semi-arid rangelands are used solely for both livestock production and wildlife conservation hence they can't be overlooked since they contribute to the national GDP. Habitats grazed by herbivorous species influence the sensitive fraction of total organic carbon, labile carbon fraction. Studying labile fraction, which is a soil indicator of land degradation or sustainable land use under different grazing practices enhance understanding of how management has a significant effect on soil organic carbon over a short period. This will contribute to the adaption of proper grazing practices in semi-arid rangelands, enhance carbon sequestration, and improve soil quality. In the long run, it will help in securing the livelihoods of sedentarized pastoralists.

1.4 Research Objectives

Broad objective

To contribute to existing knowledge on the effects of grazing practices on vegetation attributes, soil carbon fractions, and greenhouse gas emissions in Kenyan semi-arid rangeland

Specific objectives

1. To determine the effect of grazing practices on species richness, composition, diversity, relative abundance, and tree density.
2. To determine the effect of grazing management practices, topographic positions, and land cover on soil mineral-associated organic carbon (MAOC) and particulate organic carbon (POC).
3. To evaluate the effect of grazing practices and vegetation composition on carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) emissions.

1.5 Hypotheses

1. Grazing practices and topographic positions had a significant effect on species richness, composition, diversity, relative abundance, and tree density.
2. Grazing practices, topographic positions, and land cover interaction have a significant effect on soil mineral-associated organic carbon (MAOC) and particulate organic carbon (POC).

3. Grazing management practices and land cover have a significant effect on carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) emissions.

1.6 Study site Description

1.6.1 Location

Two study sites, Ilmotiok community group ranch and Mpala Ranch and Conservancy are found in the Kenyan semi-arid rangelands. Ilmotiok community group ranch forms part of the Naibunga Conservancy of the Northern Rangelands Trust Central (NRT 2015). Mpala Ranch and Conservancy, on the other hand, manage wildlife and livestock together for conservation and animal products (Veblen *et al*., 2016). River Ewaso Nyiro separates the two ranches. Ilmotiok ranch is a community group ranch that mimics open grazing regime thus anybody is allowed to graze their animals in this land while Mpala practices holistic grazing (Lalampaa *et al.,* 2016).The stocking density for livestock in Mpala Ranch ranges between low and moderate which is 0.10–0.15 cattle/ha (Veblen *et al.*, 2016). The area experiences an average rainfall of 600±50 mm and a high temperature that ranges between 25-30°C and low from 12-17°C (Mureithi *et al*., 2012; Veblen *et al*., 2016).

1.6.2 Vegetation

The dominant vegetation in Kenyan semi-arid rangelands includes *Brachiaria lachnantha*, *Pennisetum mezianum, Pennisetum stramineum, Setaria sphacelata*, and *Themeda triandra* (Butynski and De Jong 2014). Areas dominated by vertisols have bushlands and woodlands which are composed of *Acacia drepanolobium* (whistling thorn) and *Euclea divinorum* (Butynski *et al.*, 2014). Areas with scattered riparian forests tend to have a variety of tree species which is dominated mainly by *Acacia xanthophloea*. Other tree species found in the riparian forests include *Acacia gerrardii*, *A. gracilior, Syzygium guineense, Syzygium cordatum, Calodendrum capense*, *Warburgia ugandensis*, and figs *Ficus spp*. (especially sycamore fig, *F. sycomorus*).

1.6.3 Agro-economic activities

The main economic activities in Kenyan semi-arid rangelands include but not limited to; livestock production, tourism, private and public conservancies, ranching, small and large scale farming, horticultural farming, sand harvesting and quarrying (Porensky *et al.,* 2013).

1.6.4 Main wildlife

The wildlife in the Kenyan semi-arid rangelands is found outside of the gazetted protected areas in the country (Graham *et al.,* 2013). The common wildlife species can be found in the private ranches with a few found in community group ranches. The elephant is the most abundant species in the ranches (Graham *et al.,* 2013). Other major species include Burchelles zebras, rhinoceros, Thompson gazelles, impalas, buffaloes, lions, elands and Grevy zebras. (Mureith *et al.,* 2012)

1.6.5 Experimental design

Two parallel experiments were carried out in two ranches namely Mpala Research Centre and Conservancy and Ilmotiok Community Group Ranch. The management in both ranches is distinct in that Mpala Ranch practicing controlled grazing with a consistent stocking density of 10-12TLU/km^2. Ilmotiok Community Group Ranch practices Continuous grazing and stocking density of 25TLU/km^2. A complete randomized block design was set up in Ilmotiok community group ranch and Mpala Ranch whereby plots of 200m by 150m were demarcated into representative topographical positions namely mid-slope, foot slope and bottom. The GPS coordinates were taken using a Garmin GPS gadget. for each topographical zones under both grazing management practices for each demarcated plot as described in section 1.6.5.1. Ellipsoidal height was also produced by the Garmin GPS gadget which was recorded as elevation/altitude (masl) (Table 8). Land cover types, bare ground, patches of grass and mosaic of trees, were selected randomly and samples on vegetation attribute, soil and GHG emissions were collected in each plot.

1.6.5.1 Topographical positions classification

Topographical positions were first classified as described by Eric *et al.,* (2002). A permanent point of reference was defined within the gradient point (A-F) and the coordinates and altitude of this point were recorded using a GPS gadget (Table 8). Topographical positions within the study area were point sampled as shown in Figure 1 below.

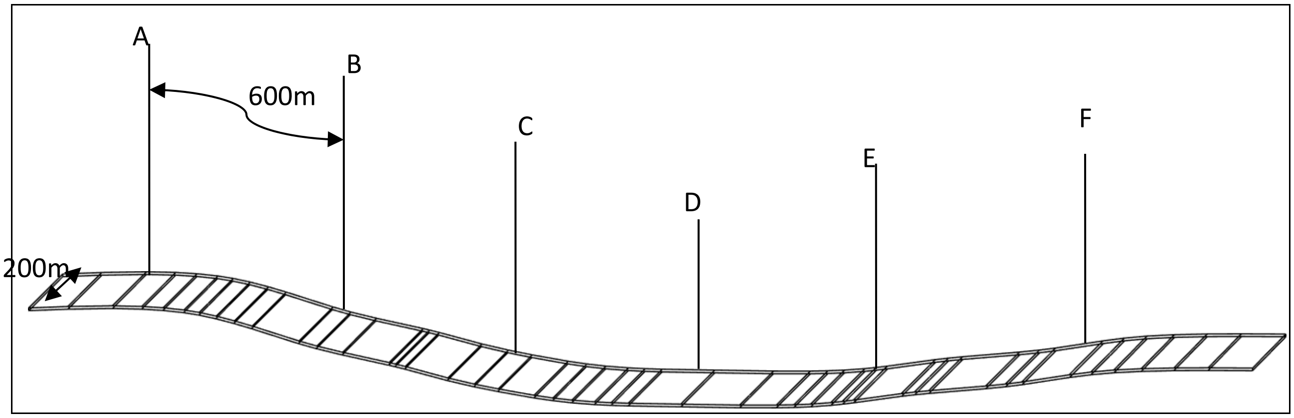

Figure 1:Topographical classification (Source: Eric *et al.*, 2002)

Topographical positions within each grazing management practices were point sampled using a clinometer and two rods marked at equal height. At the starting point (A), reference point, the first rod was held vertically and the second rod was held parallel 30 m from the first rod as shown in figure 1. Variation in topographical points was determined using Equation 1 below.

$$\Delta\ \text{Topographical point} = \ \text{distance between sampling point} \times \text{clinometer reading} \quad \text{Equation 1}$$

A cloth tape was used to demarcate the length of each transect line. 10 of the points were marked either as bottom-land, mid-slope, or foot slope if 33 percent of the length of the transect (200 m) was considered to be bottom-land, mid-slope, or foot slope. The ratios of each topo-class within each transect and the total length of all contour lines were calculated out of these values. At each topographical location, depending on the elevation of neighboring topographical positions, it was graded as mid-slope, foot slope, or bottomland.

1.6.5.2 Land cover types

Land cover types were selected based on the most dominant vegetation as shown in figure 2 below.

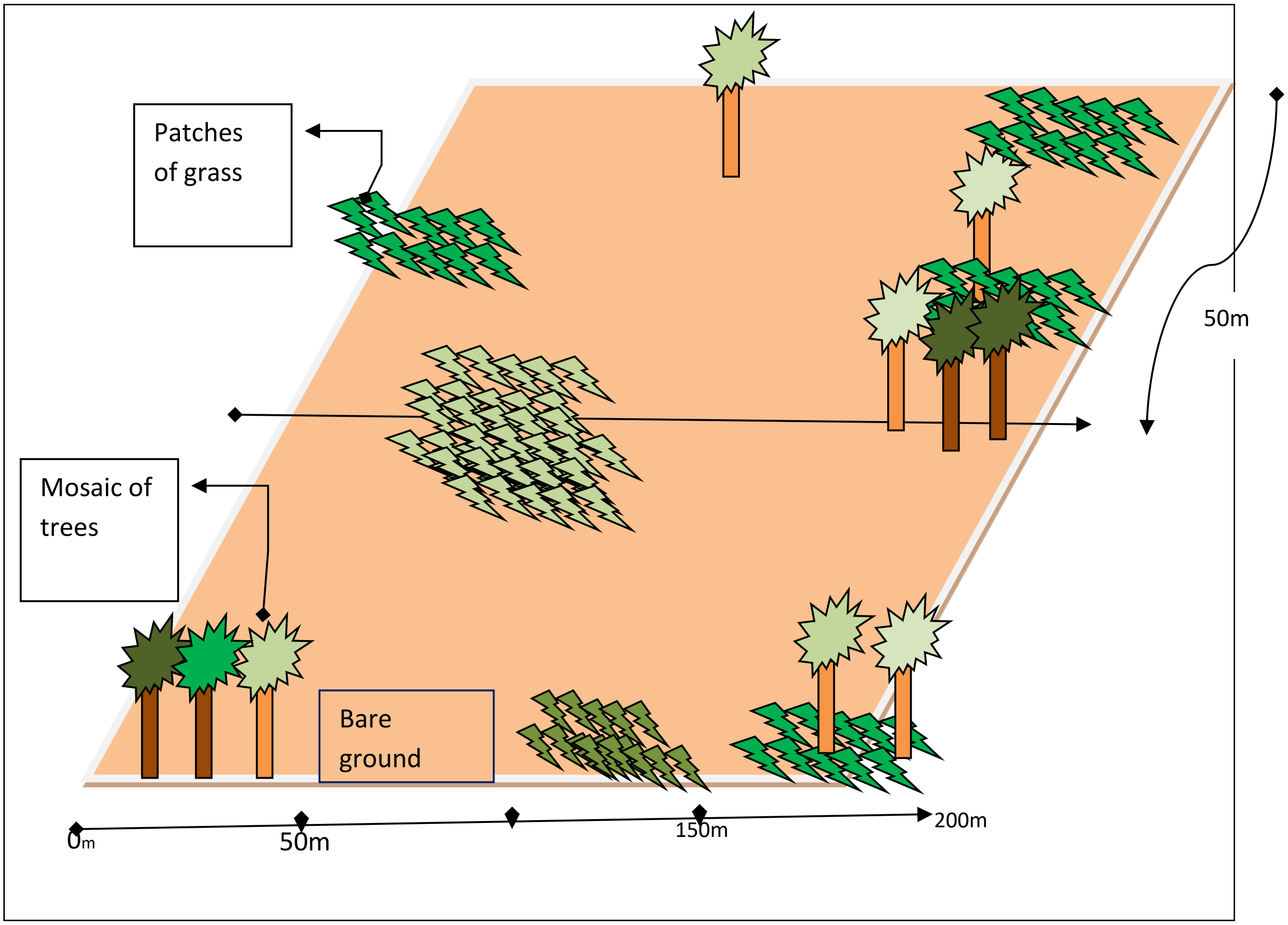

Figure 2: Sketch of dominant land cover types selected in each demarcated plot in all the topographical positions under both grazing management practices

1.6.6 Statistical analysis

Vegetation attributes measured, such as species richness, diversity, and relative abundance were subjected to various packages in R software (R Core Development Team 2013) to derive ANOVA tables. Agricolae package was used to do post hoc analysis with Tukey HSD test for mineral-associated organic carbon (MAOC) and particulate organic carbon (POC). Carbon dioxide (CO2), nitrous oxide (N2O), and methane (CH4) emissions data were subjected to a one-way ANOVA in R to derive means and error type at 0.05 level of significance. Tukey HSD post hoc test was used to separate the means.

1.7 Structure of the thesis

This thesis is divided into three parts. The first part describes the background of the study and defines the scope of the study (objectives and research hypotheses) in *Chapter 1*. *Chapter 2* is on the literature review of previous studies that looked at Continuous grazing and controlled grazing as a management tool in semi-arid rangelands. The second part is the reporting on results on the influence of grazing management practices had on semi-arid rangelands and is comprised of three ongoing papers (*chapters 3, 4,* and *5*) that have their own literature review and methodology sections. Hence, some sections of this thesis may appear replicated with chapters 1 and 2, but it was all considered important for a better understanding of this entire research. *Chapter 3* assesses the influence of grazing practices and topography on vegetation attributes in a semi-arid rangeland of Laikipia County. *Chapter 4* points out the effect of grazing management on total soil organic carbon, mineral-associated organic carbon, and particulate organic carbon in semi-arid rangelands of Laikipia County while *Chapter 5* assesses the short term effect sporadic rainfall, grazing management practices and land cover types had on CO2, N2O and CH4. *Chapter 6*, is the third part, covers the general discussion, conclusions, and recommendations of the thesis.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview of semi-arid rangelands of Kenya

Semi-arid rangelands experience climate variability with a rainfall range between 300-1200mm annually and dry spells of 5-10months (FAO, 2000; Ndegwa *et al.*, 2016). They provide ecosystem services that are essential to social economics (Pote *et al*., 2006; Kalema *et al.*, 2015; Ndegwa *et al.*, 2016). The ecosystem services provided by semi-arid rangelands are such as controlling desertification, regulating climate stability through carbon sequestration, controls flows of the river and fresh water, and biodiversity conservation (Maass *et al*., 2005; Grace *et al*., 2006; Becknell *et al*., 2012).

These fragmented ecosystems are mainly used for livestock production, charcoal and woodfuel production with the majority of the livestock population found in the arid and semi-arid regions of Kenya (Roy *et. al*., 2010). Livestock production supports over 90% of the workforce in the ASALs and is contributing to 95% of household income and the majority depend on woodfuel as a primary source of energy for domestic use (Njenga *et al*., 2016; Luvanda 2014; Roy *et. al*., 2010). Most of the livestock is owned by smallholder farmers who are vulnerable to climate change (Kumar *et. al*., 2015). Livestock production in the rangelands has led to ecosystem fragmentation which has reduced the frequent movement of pastoralists (Harris et al. 2009; Ogutu *et al*. 2009; Western *et al.*, 2009; Craigie *et al*. 2010; Fynn *et al.*,2011).

Various grazing practices in the Kenyan semi-arid rangelands have come about as a result of land fragmentation and ownership (Ogutu 2009). The types of grazing practices practiced in Laikipia include open land grazing, bunched grazing, enclosed grazing, holistic grazing, and rotational grazing. Open land grazing is the continuous grazing by herbivores and is common in semi-arid rangelands (Wissman 2006). This type of grazing is practiced in areas where the land is owned by the community. Enclosure grazing system is an intentional type of grazing that is seasonal and there is controlled grazing and stocking density (Mureithi *et al.*, 2012).

2.2Effect of grazing on species composition, richness, diversity and tree density

Grazing is the act of biting and chewing by herbivorous animals that defoliate palatable herbaceous plant species. Herbivorous grazing in semi-arid rangelands alters the structure and composition of flora (Stern et al. 2002, Kikoti *et al.,* 2015). This affects half of the net primary productivity of above-ground biomass and quarter below ground productivity. Above and below ground productivity depends on the grazing intensity which changes vegetation composition from palatable herbaceous species to non-palatable forbs and shrubs as has been reported globally (Sun et al. 2011, Zatout 2014, Bakker et al. 2003; Koerner *et al.,* 2014, Cingolani et al. 2013). This makes the emergence of mosaics of habitats with varying plant species richness as a response to grazing practices (Deng *et al.,* (2014). The gradual equilibrium of vegetation decreases competition for limited environmental resources due to the mosaics which have developed (Bakker et al. 2003). Defoliation in continuous grazing accelerates the percentage of ground cover of bare soil. This leads to daily constant variation and maximum temperatures. Other factors affected are spatial heterogeneity of light availability, soil fertility, and vegetation diversity.

Effect of grazing tends to influence vegetation composition both spatially and temporally and consequently livestock production. The defoliation by herbivorous species may have a massive effect on net forage abundance than trampling (Curll and Wilkins, 1983). This may accelerate degradation and invasion of woody species in semi-arid rangelands depending on the grazing intensity. Grazing intensity significantly alters the population of forbs species with higher abundance recorded during the wet season and low in the dry season. Heavily grazed areas tend to host species commonly found in degraded areas while in conserved areas have a positive effect on the diversity of vegetation and abundance (Kanga *et al.,* 2013; McSherry *et al.,* 2013). This creates a slight variation in grass species spatially. The tall grass found in conserved areas is attributed to low forage quality with little diversity and the herbivores are prone to be captured by predators. Herbivores tend to avoid such areas thus serving as important contributors to grassland conditions (Coppolillo *et al.,* 2004). This variance in grazing makes semi-arid rangelands distinct in that they have spatial heterogeneous vegetation (McGranahan *et al.,* 2012). The heterogeneous vegetation depends on the type of herbivores grazing the area, the number of herbivores, soil type, elevation, and grazing practices (Allred *et al.,* 2011). Furthermore, there is a correlation between the animal anatomy in terms of the digestive system, dental anatomy, mass weight, and species breed and functional traits, and diversity of vegetation (Rook *et al.,* 2004).

Previous studies show that the effects of grazing on plant production are variable, but most have a negative influence on aboveground production (Porensky *et al.,* 2013;). Grazing intensity tends to be higher in areas with high tree density, unlike the open grassland. The height of grass will significantly vary along an elevation with a correlation to the grazing regime being utilized (Hopcraft *et al.,* 2010). Grazing intensity influences the most palatable vegetation species, which may reduce depending on grazing practices. This has a paradigm shift on vegetation floristic composition, and vertical canopy structure (Sala et al., 1986). The action of biting by herbivores influences the amount of carbon input (Raiesi *et al.,* 2014). Species with a short height are classified to capture C unlike trees with enormous canopy (Nyawade *et al.,* 2015). This may divert the reallocation of C between above and below ground (He *et al.,* 2017). This leads to the dominance of C4 plants which have a higher root C compared to soil carbon pool and this triggers the shift of fixing C belowground (McSherry *et al.,* 2013).

2.3Grazing practices and soil organic carbon (SOC)

The existence of both wildlife and livestock contributes greatly to spatial variation in grazing practices thus influencing the distribution of carbon in semi-arid rangelands (Niamir *et al.*, 2012; Graham *et al.,* 2013; Fynn *et al.,* 2015; Ogutu *et al*., 2016). Soil organic carbon (SOC) is the main constituent of soil organic matter (SOM), which has a huge ability for storing atmospheric carbon dioxide (CO2) through plant photosynthesis (FAO 2017). Generally, SOC is reported to either increase, decrease, or remains constant under different grazing conditions (Pineiro *et al.*, 2010; McSherry *et al.*, 2013; Chen *et al*., 2015; Xiong *et al.,* 2016; Qasim *et al.,* 2017; Zhou *et al.*, 2017; Abdalla *et al.,* 2018). Though it's unclear for which carbon fractions contribute to such results across different edaphic properties and precipitation gradients. Aboveground vegetation, soil moisture, and SOM have a positive correlation to the content and distribution of SOC in temperate regions though it's unclear in tropical regions (Shang *et al.*, 2014). Studies have indicated that grazing during the dry season, increased SOC in areas with short grasses and decreased in areas that are humid and have tall grasses (Derner *et al.* 2006; Abdalla *et al.,* 2018). This influences SOC in various ranches containing perennial grass, annual herbs, and annual grass (Ritchie 2014). In conserved areas, C is significantly high compared to the areas where there is intensive grazing and human settlement (Ritchie 2014). Grazing also influences the topsoil and carbon decreased with increase in soil depth, this is attributable to root biomass, root turnover rate and root production though this may vary depending with the vegetation type (Waldrop *et al*., 2006; Chatterjee *et al.,* 2011; Chen *et al.,* 2015). Moreover, the trampling of animals reduces the size of soil macropores thus influencing bulk density but with variable and largely unknown effects through the deposition of dung (Eldridge *et al.,* 2015).

Effect of grazing on Particulate, stable and inert organic matter

Soil organic carbon has two main fractions, which are studied according to its chemical stability and turnover times. Soil organic carbon can be divided into two main fractions, according to its chemical stability and turnover times that is the particulate organic matter or labile carbon fractions which is readily decomposable and is an indicator of soil health (Nyawade *et al.,* 2015; Zhang *et al.,* 2018). Physically, it is classified as POC and MAOC. The POC is the labile fraction and is further classified into light POC and heavy POC. POC is normally high in the macro-aggregates which is sand while MAOC which is stable is associated with the micro aggregate mainly clay. On the other hand, stable carbon fractions are less degradable since they have undergone soil mechanisms transformation by the microbes to form highly stable fractions which are not easily chemically decomposable. It is essential to study the carbon fractions to understand the carbon cycle and the contribution of human-induced activities such as grazing influences carbon fractions. For instance, it is unclear whether grazing and defoliation of vegetation influence labile carbon or it is animal trampling. On the other hand, the concentration of stable carbon fractions depends on precipitation, land management, the nature of the soil, grazing intensity, and vegetation composition (McSherry *et al.,* 2013; Abdalla *et al.,* 2018). However, it’s unclear how various grazing practices, if they will have any influence on stable carbon fractions (Yusuf *et al.,* 2015).

Most studies look at SOM in form of total C and total N at the topsoil hence not much is told on the various forms of carbon fractions and their density beyond 0.3m when accounting for GHG emissions; there is a need for measuring carbon fractions beyond 1m depth (IPCC 2006). Moreover, there is need for proper understanding on the correlation between grazing effect, vegetation cover and soil texture on soil organic carbon particle size distribution and density fractions to enhance knowledge on soil mineralization and carbon sequestration with varying soil depth in the tropical regions (Shang *et al.,* 2015; Eldridge et., al., 2015; LAI *et al*., 2014; Shang *et al.,* 2014; Di Bene *et al*., 2011).

2.4 Effect of grazing on GHG emissions

Grazing convert's stable carbon into CO2 and other non-CO2 emissions but several studies have shown that it can reduce net ecosystem carbon emissions and boost the potential of grasslands to sequester carbon (Wilsey 2002; Allard *et al.,* 2007). Globally, grasslands and pastures, in general, can be used to mitigate global warming if they are managed sustainably (Oertel *et al.,* 2016). This can be achieved through proper grazing practices which will help to curb climate change (Chen *et al.,* 2015). Also, these grasslands tend to have high CO2 evolution of (3.09 ± 0.23 mol CO2 m−2 s−1) during the dry season and rates reduced greatly to (1.26 ± 0.15 mol CO2 m−2 s−1) during the wet season (Peng *et al*.,2011). In contrast, another study conducted in Asia showed that such semi-arid areas tend to sequester less due to continuous heavy grazing resulting to soil erosion which affects vegetation composition, diversity and abundance (Su *et al*., 2005; Pei *et al*., 2008; Zuo *et al*., 2008; Golluscio *et al*., 2009). Conservancies in Kenya majorly target to reduce GHG emissions of 54 million tons of CO2 and non-CO2 equivalents within a 30-year time frame (NRT 2015) thus and ways of increasing the potential of grasslands to sequester carbon (UNFCCC 2015). Castaldi *et al.,* 2006, noted pastures that were managed acted as sources of CH4 emissions during the wet season and as a sink during the dry season. Though it's not clear the correlation between grazing management practices and different land covers on soil CO2, N2O, and CH4 fluxes. According to Tang *et al.,* (2019), grazing management practices and precipitation indirectly influences CO2, N2O, and CH4 fluxes by altering microbial activity and root respiration. Furthermore, grazing has been associated to reduce root biomass since photosynthate C allocation to the roots is reduced which in extent influences root respiration (Bai *et al.,* 2015; Liu *et al.*, 2015).

Also, in the context of measuring, reporting and verifying (MRV) on GHG, Kenya phases technical challenges thus relying on emission factors to account for GHG emissions (Hickman et al., 2014; Pelster et. al., 2017). These emission factors have been derived from developed countries that have different agroecosystem conditions compared to Kenya (Rosenstock et. al., 2013). This has led to overestimation or underestimation of GHG emissions especially in developing countries that are faced with technical challenges when it comes to MRV on GHG emissions (IPCC 2006; Richards *et. al*., 2016).

CHAPTER THREE

Effect of Grazing Practices and topography on Vegetation attributes in Semi-Arid Rangeland of Laikipia County, Kenya

Abstract

Vegetation composition of semi-arid rangelands has become of interest. More so the impact of grazing practices on species richness, diversity, and relative abundance of both herbaceous and woody vegetation. Vegetation attributes respond to different grazing practices hence a study was carried out in semi-arid rangeland of Laikipia County to elucidate the effect of grazing practices on vegetation composition, diversity, richness, relative abundance, and density in different topographical positions. A complete randomized block design was used to collect data on vegetation attributes whereby two grazing practices, controlled grazing, and continuous grazing, together with topographic positions, mid-slope, foot slope, and bottomland were selected and vegetation attributes determined along 200m transect replicated thrice. Both grazing practices and topographical positions had a significant ($p<0.05$) effect on the relative abundance of trees as well as grass while it was highly significant ($p<0.001$) on herbs and forbs. Effect of grazing practices and topographical positions on species diversity was significant ($p<0.01$) on herbs cover. Tree density responded to grazing practices significantly ($p<0.05$). Under controlled grazed zones, bottomland recorded high species composition. Moreover, in controlled grazed areas vegetation composition was dominated in the sequence of grass>shrubs>trees>forbs>herbs. Under continuously grazed zones, the dominance of species based on relative abundance attribute was grass>herbs>trees>shrubs>forbs. Across the three topographical positions, the trend of the dominance of species relative abundance was forbs<trees<shrubs<herbs<grass for both mid-slope and bottomland. Foot slope had a different trend of species relative abundance which was observed to be forbs<trees<herbs<shrubs<grass. Under continuously grazed zones at the bottomland, species diversity was observed to be higher relative to other plots. Controlled grazing should be used as a mechanism to enhance the diversity of palatable species in semi-arid rangelands. Destocking should be done under continuously grazing management practice. This will allow vegetation to recover from grazing activities and be able to regenerate.

Keywords: continuous grazing, controlled grazing, relative abundance, composition, diversity, richness

3.1 Introduction

Several grazing managements are practised in semi-arid rangelands which have different stocking density (Kibet *et al*., 2016; Oduor *et al*., 2018; Rotich *et al*., 2018). Grazing in semi-arid rangelands alters the structure and composition of flora (Stern *et al*., 2002, Kikoti *et al*., 2015). Vegetation can be monitored by studying various stocking densities (Crawford *et al*., 2018). Livestock grazing in humid rangelands has shown to have a positive effect on species diversity (Hanke *et al*., 2014; Ondier *et al*., 2019). However, in semi-arid rangelands, species diversity is poorly understood due to varying stocking densities and also the co-existence of wildlife and livestock animals which have different grazing patterns. Moreover, quantifying species richness and abundance have been attributed to species diversity.

Richness tries to capture the variety of vegetation whereas abundance explains the distribution of the identified species for a given area and the composition of patches. In semi-arid rangelands, along with topographical positions they are characterized to be sensitive to varying temperature and moisture availability (Dorji *et al*., 2014). Topographical positions contribute to vegetation devilment and establishment (Begum *et al*., 2010). Defoliation due to continuous grazing accelerates the percentage of ground cover of bare soil whereas for controlled grazing there is insufficient information. Different grazing pressures indirectly influence the stability of vegetation distribution and functioning (Herrero-Jáuregui *et al*., 2018). This may lead to either a positive or negative effect on plant community structure (Niu *et al*., 2016). There is a need to understand how different stocking densities influence plant community composition and diversity in semi-arid rangelands of Kenya in different topographical positions. The heterogeneous vegetation depends on the type of herbivores grazing the area, the number of herbivores, soil type, elevation, and grazing practices. Some studies have shown that stocking density had significant effects on graminoid species composition and diversity (Adler *et al*., 2001; Allred *et al*., 2011). It is hence essential to compare vegetation diversity indices of continuous grazing practice and controlled grazing to provide information on their sustainability against vegetation fluctuation. This will help in managing and rehabilitating overgrazed semi-arid rangelands. When it comes to forbs composition and distribution countable studies with insufficient information arises especially in grazing gradients (Pennington *et al*., 2016)

Grazing influences the most palatable vegetation species, which may reduce depending on grazing practices. Moreover, grazing tends to modify herbivore distribution whereby wild herbivores tend to graze in areas with low bush encroachment. Livestock animals, on the contrary, have wide use of the semi-arid rangelands thus influencing the distribution of unpalatable herbaceous species and woody species. The influence of grazing practices on tree density is not clear in different topographical positions. This study was carried out to elucidate the effects of different grazing practices on vegetation structure and was measured by determining vegetation relative abundance, composition, diversity, richness, and tree density.

3.2 MATERIALS AND METHOD

3.2.1 Study site description

The main economic activities in Laikipia County include but not limited to, livestock production, tourism, private and public conservancies, ranching, small- and large-scale farming, horticultural farming, sand harvesting, and quarrying. The elevation of Laikipia County varies between 1,500 m above sea level at Ewaso Nyiro basin in the North to a maximum of 2,611m above sea level around Marmanet forest. The northern part of the County is an ASAL consequently making it difficult to support crop farming for commercial purposes. This has made the entire region to be dependent on pastoralism and charcoal production. Under controlled grazing, which is practised at Mpala Research Centre, the livestock stocking density normally ranges between 10 – 12

TLU/km2and has been practised for the past 30 years. Continuous grazing, on the other hand, has been characterized to have a stocking density of 25 TLU/Km2 and tends to increase depending on rainfall patterns (Kibet *et al*., 2016).

3.2.2 Experimental design and data collection

Assessment of vegetation community structure to determine species richness, diversity, and tree density under both grazing practices was carried out during the dry season of 2018. Vegetation sampling was carried out during the dry season of 2018. Under both grazing practices, macro-plots were demarcated in each topographic position, mid-slope, foot slope, and bottomland. Vegetation was sampled according to the topographic positions in Ilmotiok community group ranch (continuous grazing) and Mpala Ranch and Conservancy (controlled grazing). Transects were treated as units of replicates and established based on the areas grazed by both livestock and wildlife. Each transect was 200m long and replicated three times.

Species identification was done after every 1m, along transects by classifying and tallying individuals of each plant species in each plot. Species richness is the number of vegetation varieties identified in a place (Jawuoro *et al*., 2017). Species richness was determined by tallying the identified species in each transect for all topographical positions under both grazing management practices. Plant specimens that were hard to identify in the field were stored in a plant press and taken to the lab for further identification following the British Columbia Ministry of Forests (1996) plant nomenclature.

Plant species composition, diversity, tree density, and relative abundance were determined using equations 2, 3, 4, and 5.

Species composition was calculated as the percentage of the total amount of each species divided by the total number of species (Equation 2)

$$\textbf{Species composition percentage} = \frac{n}{N}$$ (Equation 2)

Where: n_i = total number of individual species

N= total population of all species combined

Shannon weiner formula was used to determine species diversity (Equation 3) as described by Krebs (1989).

$$H' = -\Sigma\{\mathbf{ni}/N\} \times LN\{\mathbf{ni}/N\}$$ (Equation 3)

Where: H'= Shannon weiner index

n_i = number of each individual species identified in each transect

N = total number of all the species found in all the transects

LN= natural log of the number

Tree density was determined using the Point Centred Quarter Method(PCQM) as described by Silva *et al.,* (2017). Along transect for each tree encountered, four dimensional distances were measured from the tree to the next nearest tree and recorded. This was used to calculate the tree density (Eqn4).

$$\textbf{Tree density } (\boldsymbol{\lambda}) = \frac{\mathbf{4(4n - 1)}}{\boldsymbol{\pi}\Sigma(\boldsymbol{r}_{ij^2})}$$ (Equation 4)

Where: λ is estimated tree density (trees/ha)

n is the sample size of trees tallied in each transect

Π is pie (3.142)

r_{ij}^2=distance from random point i to closest individual in quarter j

R.A is a comprehensive representation of species diversity. To understand species diversity comprehensively, relative abundance distribution is determined using equation 5 to explain the composition of species and how relative they were from each other (Veech 2018).

$$\boldsymbol{Relative\ abundance} = {}^{\mathbf{ni}}/_{\sum_{1}^{S}\boldsymbol{ni}}$$ (Equation 5)

Where: n_i= abundance of each individual species i

$\sum_{1}^{S} = \text{Total summation from all individual speciesfrom 1 to S}$

3.2.3 Statistical analysis

R software version 3.5.3 (R core team 2018) was used to carry out Analysis Variation of the observed species richness between grazing management practices and topographic positions by comparing 95% confidence intervals derived by multiple sample rarefaction (Colwell, 2009). Species composition, diversity, and tree density were analyzed using one-way ANOVA and the means were separated using Fischer's protected test at 5% significance level.

3.3 Results

3.3.1 Effect of grazing practices on species richness and diversity

Under both grazing practices and all the topographical positions combined, 1942 observations of species were made. A total of 52 species were detected in general in the 18 transects (Figure 3) in all the topographical position under the two grazing management practices.

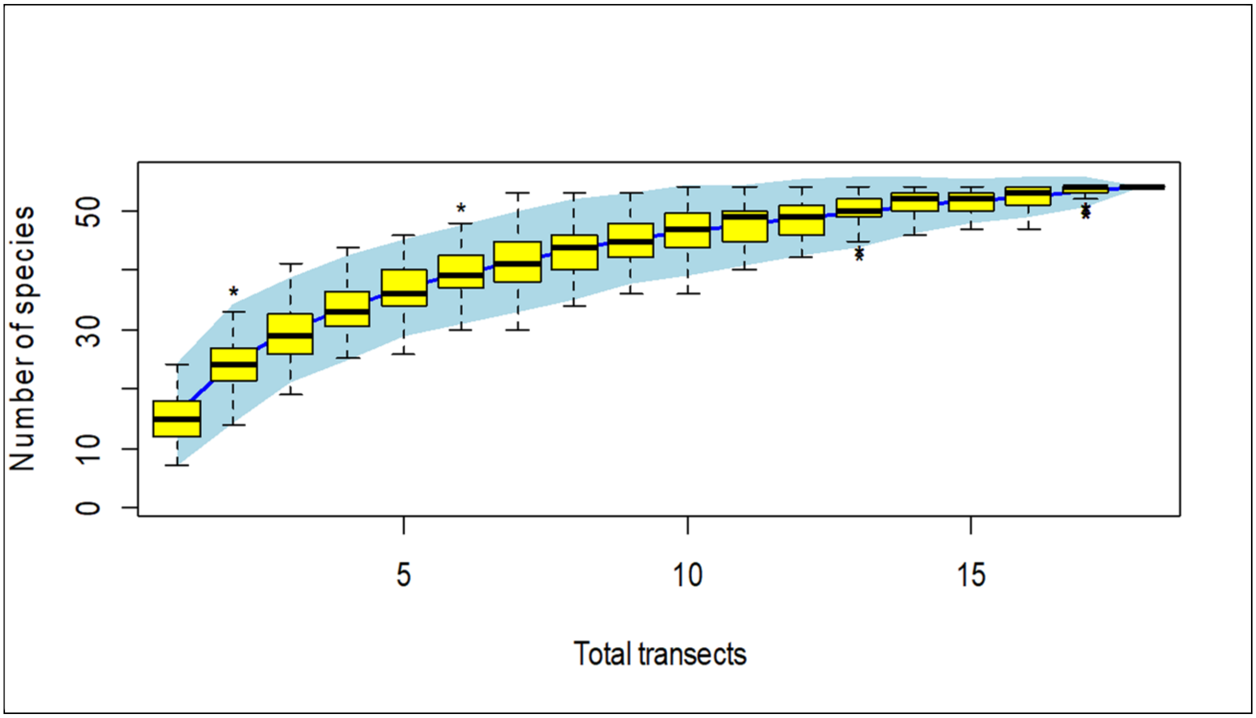

Figure 3: Total observed number of species richness

Species richness was evenly distributed showing regardless of the grazing pattern the various species were not affected. The vegetation species were further categorized into herbaceous and woody vegetation groups. The effect of continuous and controlled grazing at different topographical positions had varying responses (Table 1).

Table 1: species richness response to two razing management practices in different topographical positions

Grazing management practice	Topographical position	Grass	Forbs	Herbs	Shrub	Trees	Bare counts
Continuous grazing	Mid-slope	4.67^{b}	1.67^{a}	1^{b}	1.33^{a}	2^{ab}	68.33^{ab}
	Foot slope	4.67^{b}	1.33^{a}	1.67^{ab}	2.33^{a}	1.67^{ab}	87.00^{a}
	Bottomland	4^{b}	0.33a	4.33^{a}	5^{a}	3^{a}	96.67^{a}
Controlled grazing	Mid-slope	4.67^{b}	2.67^{a}	1.33^{ab}	3^{a}	0.67^{b}	17.00^{b}
	Foot slope	3.67^{b}	0.67^{a}	2^{ab}	4^{a}	2.33^{ab}	36.33^{ab}
	Bottomland	8.33^{a}	2.67^{a}	1^{b}	4.67^{a}	3.33^{a}	78.67^{a}
F value		7.68	1.926	3.567	3.03	4.98	5.874
P value		0.0019 **	0.16	0.033 *	0.054	0.0106 *	0.00569**

Signif. Codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1; means with different letters in each column indicate significant difference, Tukey HSD test

Bottomland under controlled grazed zones recorded significantly ($p<0.01$) the highest species richness relative to the other plots.

Controlled and continuous grazed zones significantly influenced herbs species (Table 2).

Table 2: Effect of grazing practices and topographic positions on species diversity

Grazing management practice	Topographical position	Grass	Forbs	Herbs	Shrub	Trees
Continuous grazing	Mid-slope	0.70^{a}	0.01^{ab}	0.07^{b}	0.02^{a}	0.03^{ab}
	Foot slope	1.10^{a}	0.02^{ab}	0.08^{b}	0.02^{a}	0.01^{b}
	Bottomland	0.29^{a}	0.00^{b}	0.27^{a}	0.01^{a}	0.05^{a}
Controlled grazing	Mid-slope	2.45^{a}	0.02^{a}	0.00^{b}	0.02^{a}	0.00^{b}
	Foot slope	2.19^{a}	0.00^{b}	0.01^{b}	0.11^{a}	0.01^{b}
	Bottomland	0.51^{a}	0.01^{ab}	0.01^{b}	0.04^{a}	0.01^{b}

Means with different letters in the same column show significant difference; Tukey HSD test

Herbs diversity increased down the topographical gradient. Bottomland under continuously grazed zones recorded the highest Shannon-wiener diversity index (H´=0.27). Mid-slope under controlled grazed zones had no herb diversity (H´=0).

3.3.2 Effect of grazing practices and topographical positions on species composition

The community structure under both grazing management practices along with the three topographic positions, mid-slope, foot slope, and bottomland exhibited varying dominance and precedence of species composition. Some species exhibited to be dominant or semi-dominant whereas others were either absent, dominant, or rare and were presented as percentages in Figure 3 below.

Table 3: Percentages of species composition for controlled and continuous grazing practices along topographical positions

	Controlled grazing			Continuous grazing		
Species	Mid-slope	Foot slope	Bottom slope	Mid-slope	Foot slope	Bottom slope
Abutilon_mauritianum	NP	NP	NP	NP	NP	0.551
Acacia_brevispica	2.65	0.85	0.97	0	0.97	0.55
Acacia_etbaica	0*	0*	0.56*	0.39*	1*	5.6*
Acacia mellifera	1.08*	1.01*	NP	4.69*	0.34*	8.55*
Acacia tortilis	0	0.38	1.41	2.14	1.79	2.41
Aloe vera	0.397	NP	NP	NP	NP	NP
Alternanthera sp	NP	NP	NP	NP	NP	0.221
Aristida keniensis	NP	1.21	NP	NP	NP	NP
Balanites aegyptiaca	NP	0.628	0.556	NP	NP	NP
Barleria acanthoides	3.02	10.97	1.67	8	NP	2.08
Boscia angustifolia	NP	1.71	0.72	NP	NP	NP
Cenchrus ciliaris	6.4*	0.61*	4.55*	10.08*	8.19*	NP
Chloris roxburghiana	NP	NP	11.99**	NP	NP	NP
Commelina benghalensis	NP	0.61	1.29	NP	NP	1.86
Croton dichogamus	0.4	1.21	1.98	NP	NP	NP
Cynodon dactylon	51.2	50.5	16	0.4	1.5	3.3
Digitaria macroblephara	7.3	8.1	NP	2.57	1.01	NP
Enteropogon macrostachyus	2.7*	1.59*	28.12*	0.32*	NP	NP
Eragrostis tenuifolia	0.8	0	0.1	25.5	3.3	26.2
Euphorbia bussei	NP	NP	0.716	NP	NP	NP
Euphorbia heterochroma	2.82	NP	0.95	0.39	0.48	0.99
Euphorbia heterophylla	0.397	0.628	NP	NP	NP	NP
Euphorbia kibwezensis	1.43	NP	0.42	0.39	2.94	NP
Euphorbia septentrionalis	NP	NP	NP	2	1.01	NP
Euphorbia tirucalii	NP	NP	0.146	NP	NP	NP
Euphorbia volkensii	0.397	NP	NP	NP	NP	NP
Glycine clandestina	NP	NP	NP	NP	NP	9.43*
Grewia similis	NP	0.61	0.58	NP	NP	0.33
Heteropogon contortis	NP	NP	0.682*	NP	NP	NP
Hibiscus diversifolus	NP	NP	NP	NP	NP	0.221
Hibiscus micranthus	NP	1.21	NP	0.39	0.34	NP
Hypoestes forskaolii	0.344	0.379	NP	NP	NP	NP
Indigofera arrecta	0.34	0.61	NP	NP	NP	NP
Indigofera schimperi	0.397	NP	NP	NP	NP	NP
Indigofera spinosa	NP	0.61	NP	NP	0.97	0.55

	Controlled grazing			Continuous grazing		
Species	Mid-slope	Foot slope	Bottom slope	Mid-slope	Foot slope	Bottom slope
Kleinia odora	0.397	NP	NP	NP	NP	NP
Lintonia nutans	NP	NP	NP	NP	NP	3.19
Lycium shawii	0.69	NP	NP	NP	NP	NP
Ocimum suave	NP	0.628	NP	NP	NP	NP
Opuntia vulgaris	NP	NP	NP	NP	4.09*	0.22*
Panicum maximum	NP	NP	0.14	0.97	NP	NP
Pennisetum mezianum	NP	NP	1.4**	30.8**	48.7*	2*
Pennisetum stramineum	3.97**	0.98**	16.83**	NP	5.8**	NP
Pupalia lappacea	NP	0.61	NP	NP	NP	0.22
Sanseveira purva	NP	NP	NP	NP	NP	23.57**
Sanseveira volkensii	NP	NP	NP	10.59*	13.44*	NP
Setaria sp	NP	NP	NP	NP	NP	0.221
Sida acuta	NP	NP	NP	NP	NP	0.548
Sida cuneifolia	NP	0.61	NP	NP	NP	NP
Sida ovata	NP	0.379	NP	NP	NP	NP
Solanum incanum	0.74	0.25	3.72	1.28	0.5	1.43
Themeda triandra	0.397	NP	0.146	NP	NP	NP

Significance level: '**' 0.001, '*' 0.05, 'NP 'Not Present';

Grazing practices and topographical positions influence *Acacia mellifera* and *Acacia etbaica* significantly (p=0.05). *Cenchrus ciliaris* was significantly (p≤0.05) relatively pronounced in all plots except in bottomland under controlled grazing which was dominated significantly (p<0.001) by *Chloris roxburghiana*.

Enteropogon macrostachyus and *Heteropogon contortis* were significantly (p=0.05) influenced by grazing management practices and topographical positions. Bottomland under controlled grazed zones compared to other sites recorded the highest quantity of *Enteropogon macrostachyus* (composition=28.12%). *Heteropogon contortis* was only present at the bottomland under controlled grazed zones.

Pennisetum mezianum and *Pennisetum stramineum* were significantly (p<0.001) influenced by grazing practices and topographical positions. Foot slope recorded the highest *Pennisetum* *mezianum* (composition=48.7%) compared to the other sites. Bottomland under controlled grazed zones recorded the highest *Pennisetum stramineum* (composition= 16.83) when compared to other sites.

Sansevieria purva was significantly ($p<0.001$) more at bottomland under continuously grazed zones whereas *Sanseviera volkensi* was significantly ($p<0.05$) common in foot slope and bottomland under continuously grazed areas. The herb was absent under controlled grazed areas.

3.3.3 Interaction of grazing and topographic positions on species relative abundance

The response of grass and tree composition to grazing practices and the topographic position was significant at $p<0.05$ while forbs and herbs composition were significant at $p<0.001$ as shown in Table 4 below.

Table 4: Means of species relative abundance to grazing practices and topographic positions

Grazing practice	Topographical position	Grass	Forbs	Herbs	Shrubs	Trees
Continuous grazing	Mid-slope	2.29	0.11	0.45	0.144	0.13
	Foot slope	2.6	0.18	0.6	0.234	0.34
	Bottomland	2.67	0.05	2.27**	0.379	0.96*
Controlled grazing	Mid-slope	2.85	0.04	0.07	0.361	0.05
	Foot slope	3.54	0.22	0.11	0.685	0.18
	Bottomland	9.83*	0.29**	0.16	1.136	0.41
Grazing management practices		*	*	**	*	*
Topographic positions		*	NS	*	*	**
Grazing management x topographic positions		*	**	**	NS	*

Significant codes: ‘**’ 0.001 ‘*’ 0.05; NS ‘Not significant’

The response of herbs to the interaction between grazing practices and the topographical position was observed to be significantly ($p<0.001$) different. Areas under continuous grazing at the bottom slope zone had the highest relative abundance of herbs relative to the other treatments. The response of herbs to the interaction between grazing practices and the topographical position was observed to be significantly ($p<0.001$) different. Areas under continuous grazing at the bottomland had significantly ($p<0.001$) the highest relative abundance of herbs relative to the other treatments. Bottomland under continuously grazed zones recorded a high relative abundance of herbs which was significantly composed of Glycine clandestine, *Pupalia lappacea*, *Sanseveira purva*, and *Sansevieria volkensii*. The response of grass relative abundance to both grazing practices and the topographical positions was observed to be averagely 7.04 times higher under controlled grazing in the bottomland zone compared to the other treatments (Table 2). Besides, grass species was more relatively abundant compared to the other relative abundance of trees, shrubs, forbs, and herbs. The relative abundance of forbs under both grazing practices in all the topographical positions had a significant ($p<0.001$) difference. Down the gradient under continuous grazing, the forbs decreased whereas under controlled grazed zones it increased.

3.3.4 Effect of grazing practices and topographic positions on tree density

The interaction of grazing practices and topographic positions had a significant ($p<0.001$) effect on tree density (Table 5).

Table 5: Means of tree density (trees/ha)showing effect of grazing practise and topographic positions

Topographic position	Grazing practice	
	Continuous grazing	Controlled grazing
Mid-slope	173.3^{c}	95^{a}
foot slope	349.4^{e}	127.4^{b}
Bottomland	1506.1^{f}	314.1^{d}

Means with different letters show statistical significant difference between means at (P <.001), S.E 8.22, C.V 13.3

Under both grazing practices, tree density was more pronounced at the bottomland. Bottomland under continuously grazed areas recorded 88%, 77%, 94%, 92%, and 79% more tree density relative to mid-slope and foot slope under continuously grazed zones as well as mid-slope, foot slope, and bottomland under controlled grazed zones.

3.4 Discussion

3.4.1 Effect of grazing and topographical positions on species diversity and richness

Effect of grazing practices and topographical position on species diversity and richness was insignificant for woody species as well as herbaceous species except for herb cover. This was due to the low composition of the species observed over a small area. Herbs had a significant response to grazing management and topographical positions due to the continuous grazing pattern which reduces dominant grass patches. This paves way for invasive herbs which have low dispersal rate and do well in soil with low TN SOC, and soil moisture. Moreover, bottomland under continuous grazing the species richness of herbs was observed to be relatively higher compared to bottomland under controlled grazed zones (table 4). According to Wang *et al*., (2019) grazing intensity tends to influence plant diversity whereby low grazing intensity leads to high dominance of grass patches. This reduces the possibility of invasive species occurring while under heavily grazed zones low grass patches are outcompeted by vegetation species with minimal soil nutrient requirement (Yan *et al*., 2016, Wang *et al*., 2019). On the contrary, Ombega *et al*., (2017) observed management practice and topographical positions had a significant effect on the diversity of perennial grasses. Effect of grazing management on grass diversity and forbs had no significant effect and this corroborates Mureithi *et al*., (2014) findings.

Moreover, according to Rutherford *et al*., (2013), the increase in species richness influences the species diversity. Herbs richness was observed to be half that of grass richness. Hence agreeing with Rutherford *et al*., (2013) that low species richness to some extent contributed to a significant response of species diversity. Moreover, the species rarefaction was not affected by the grazing pattern. This contradicts the findings of Rutherford *et al*., (2013) who observed under heavy grazing the species are poorly distributed with some species occurring in some points and others missing.

3.4.2 Effect of grazing and topographical positions on species composition

Species composition varied across species with some species being significantly detected while others were absent. This is due to the varying grazing practices under the two grazing practices. Under both grazing practices, there is the existence of grazers, browsers, and mixed feeders. The varying feeding behavior in the two grazing practices influences the composition of vegetation with some species being found in some zones and others being non-existent. Studies such as Murray *et al*., (2002), Kempel *et al*., (2015), and Dostál *et al*., (2018) have associated the variation in species to have been brought about by species being prone to herbivory, susceptive to pathogens in the soil, poor generative reproduction, and vegetal growth or interspecific competition.

Chloris roxbughiana was significantly present in areas under controlled grazing in bottomland and absent in the other plots because it is very sensitive to intense grazing pressure and frequency (Mnene *et al*., 2005). This is in agreement with other studies such as Ogillo (2010). The absence of the grass species in the other plots was caused by the persistent grazing in the other plots except in zones where there was controlled grazing at the bottomland. In drought-prone semi-arid rangelands, controlled grazing practices at the interface of wildlife and livestock gives room for *Chloris roxburghiana* to exist and be used as forage. Moreover, drought is another major contributing factor to the diminished existence of *Chloris roxburghiana* in the semi-arid rangelands of Kenya (Mnene *et al*., 2005, Waweru *et al*., 2013). The percentage composition of Chloris *roxburghiana* was higher compared to other studies such as Mureithi *et al*., (2014) and Ombega *et al*., (2017) which was less than 5%. On the other hand, 42% of *Chloris roxburghiana* was observed in areas that were frequented by both wildlife and cattle (Wawer *et al*., 2013). Continuous grazing has been associated with heavy grazing which depletes pure stands first of Chloris *roxburghiana*. This explains why under continuously grazed zones *Chloris roxburghiana* was absent.

The percentage composition of *Cenchrus ciliaris* was significantly ($p \leq 0.05$) relatively higher under continuous grazing contrary to other species due to its ability to tolerate high grazing intensity along a gradient. Tegegn*et al*., (2011) associated livestock especially cattle, sheep, and camels tend to graze in areas with *Cenchrus ciliaris*. According to Koech (2014), *Cenchrus ciliaris* does well in areas exhibiting low soil moisture which was common up the topographical gradient. *Chloris roxburghiana* was dominant at bottomland under controlled grazing zones which were observed to have high soil moisture and low grazing pressure. Furthermore, Akram (2008) attributed *Cenchrus ciliaris* to its natural ability to exist in areas with low soil moisture, as well as high N, P, K+, and Ca+. The major macro-elements together with micro-elements strengthen the species productivity in areas with low soil moisture (Koech 2014).

Heteropogon contortis was significantly ($p<0.05$) relatively abundant under controlled zones at the bottomland. This is due to the varying grazing pressures. *Heteropogon contortis* is a perennial grass that thrives under low grazing intensity. Under heavy grazing stress, the perennial grass has a short life span. Thus, livestock opts to feed on it as the priority. On the contrary, the low relative abundance of *Heteropogon contortis* has been attributed to the presence of *Cynodon plectostachyus* and *Arisitida spp* which out-compete the perennial grass under heavy grazing (Orr *et al*., 2004). Arisitida spp, Cynodon plectostachyus, and *Digitaria macroblephara* are tolerant of heavy grazing such as continuous grazing hence tend to be dominant (Sollenberger 2008, Fatima *et al*., 2018). *Enteropogon macrostachyus* was relatively most at the bottomland under controlled grazed zones due to high clay content. Similar observations were made by Kavana *et al*., (2005) who explained that *Enteropogon macrostachyus* does well in black soils and the grass is preferred by young calves.

The composition of Sansevieria purva ($p<0.001$) and *Sansevieria volkensii* ($p<0.05$) was observed in areas under continuous grazing because it out-competes palatable species. Under controlled grazed areas the herb was absent because it had less bare patches and more of *Chloris roxburghiana*, a species which is palatable and dominant at the bottomland. The percentage composition of *Sanseveira sp* ranged between 16-31% which was close to Kibet *et al*., (2016) findings in the same study area. According to King *et al*., (2011), vegetation tends to shift from palatable herbaceous species to areas densely covered with Sansevieria sp. The herb forms patches and inter-patches with bare ground and other beneficial forage species are sparsely distributed. Kibet *et al*., (2016) pointed out that *Sanseveira sp* rapidly increases under intensive grazing patterns and areas with low soil TOC and TN and away from homesteads. Moreover, Kibet *et al*., (2016) pointed out a decrease in relative abundance and richness contributes greatly to ecological niches being colonized by Sansevieria sp. Moreover, the herb was present under continuously grazed zones due to its ability to thrive in soils with low soil moisture, highly compacted soils, and has a well-established root system (Kibet *et al*., 2016).

3.4.3 Effect of grazing and topographical positions on species relative abundance

Species relative abundance varied along topographical gradients and under both grazing practices. This is a result of varying soil properties across the topographical positions. Moreover, the co-existence of wildlife and livestock which have different feeding patterns influences the abundance of species along with the topography. This has been attributed to varying life forms and the density of species (Hoshino *et al*., 2009, Jawuoro *et al*., 2017). Furthermore, this finding concurs with Mudongo *et al*., (2016) who observed continuous grazing contributed to the decrease of herbaceous cover and increase of woody vegetation in Botswana's Kalahari rangeland. Herbs dominated at the bottomland under continuously grazed areas because it does well in soil depleted of nitrogen and limited in soil moisture. This observation is in agreement with Warren *et al*., (20008) who explains that herbs tend to do well at the bottom of the slope facing north unlike the south-facing slope. Furthermore, it is more of soil moisture and irradiation of sun and not the dimension of the topographical position face that influences herbs (Giladi 2004, Diez and Pulliam 2007, Warren 2007, Warren 2008). The effect of both grazing and topographical position had no significant effect on shrubs. This may have been due to self-limitation of shrubs which resulted in the two grazing practices in various topographical positions having no significant effect. This is in contradiction with other studies Zhang *et al*., (2019) who found that controlled grazing practices contributed to the increase of shrubs whereas continuous grazing reduced shrub density by feeding on them. Topography has been documented to be a key shaper of shrub distribution (Li *et al*., 2015). Regardless of the grazing pattern, tree relative abundance increased down the slope. The bottomland under continuous grazing was observed to have the most tree composition compared to mid-slope and foot slope under both grazing management as well as bottomland under controlled grazing. This is because the population of browsers, which feed on trees, under continuous grazing is less compared to areas under controlled grazing (Kibet *et al*., 2016). Moreover, Elephants were the most common browsers encountered at the bottom of the slope in controlled grazing during the survey. Goats and dik-diks were the most predominant browsers in continuous grazing though they have been classified as mixed feeders. Mid-slope and the foot slope in both grazing practices were observed to have a significant ($p<0.05$) difference in tree relative abundance. This is because despite the two topographic positions, being close to each other they are on different dimensions as well as elephants have been attributed to shaping woody vegetation of African savannas and this finding was also observed by Messinia *et al*., (2018).

Forbs responded to both grazing practices and topographic position significantly ($p<0.001$). Moreover, forbs such *Euphorbia sp* tends to increase in areas where the grass relative abundance is low and was observed under continuous grazing in mid-slope and foot slope. Forbs have been attributed to be high under heavy grazing with low soil moisture environments (Wu *et al*., 2011, Dorji *et al*., 2014). According to Dorji *et al*., (2014), forbs distribution along a gradient was observed to have no pattern. Bottomland under both grazing practices had relatively more soil moisture compared to mid-slope. Under continuously grazed zones, herbs' relative abundance at the bottomland was 98% more than the forbs composition. The most dominant unpalatable herb was the *Sanseveira sp* which was replacing grass under continuous grazing management practices especially at the bottomland. Under controlled grazed zones, the second dominant species composition was shrubs after grass. The percentage composition of *Baleria ancathoides* was significantly the most dominant shrub in all plots. This is in contradiction to Jawuoro *et al* (2017), who observed forbs relative abundance tends to dominate over grass relative abundance especially in areas with high moisture. Also, Mureithi *et al*., (2010) observed forbs tend to be persistent than grass species especially under high grazing pressure areas which contradicts the findings of this study.

The relative abundance of grass was comparatively higher regardless of the grazing pattern due to the high percentage composition of various grass species which included *Cenchrus ciliaris, Chloris roxburghiana, Cynodon plectostachyus, Eragrostis tenuifolia*. Similar observations were made for continuously grazed zones in Tiamamut while zones under conservation grazing, a type of controlled grazing management practice, grass species occurred frequently hence leading to higher counts (Mureithi *et al*., 2014). Bottomland under controlled grazed zones recorded the highest grass relative abundance due to high-frequency counts of *Chloris roxburghiana, Cynodon plectostacchyus,* and *Cenchrus ciliaris*. Moreover, the relative abundance of grass cover at the bottomland is high and this finding corroborates those of Ombega *et al*., (2017).

3.4.4 Effect of grazing and topographical positions on tree density

Bottomland has been reported to have less gravity erosion, deposition of sediments rich in soil nutrients compared to mid-slope, and foot slope. This enhances the growth of vegetation. These findings are like those observed by Riginos *et al*., (2008) who pointed out that grazers tend to graze in open areas for easy detection of predators. Foot slope and mid-slopes have been observed to be open grasslands which tend to have low tree density and have grass <10cm in height. Hence foot slope and mid-slope are open areas and tree density was observed to be less relative to bottomland. Under both grazing practices, mid-slope and foot slope recorded low tree density relative to bottomland hence grazers prefer open grasslands while browser except for giraffes prefer areas with high tree density since they feed on trees and is the habitat to elephants. On the contrary, high tree density in semi-arid rangelands has been strongly associated with high rainfall episodes (Sankaran *et al*. 2005, Good and Caylor 2011, Lehmann *et al*. 2014, Axelsson and Hanan 2017, Axelsson and Hanan 2018). Also, deep-rooted trees in soils that have low clay content in semi-arid rangelands have an upper limit relative to areas with high clay content (Ji *et al*., 2019). These results contradict the findings of Kibet *et al*., (2016) who observed highly stocked areas (continuous grazing) to have a low tree density while low stocked areas acted as controlled grazing to have a higher tree density.

3.5 Conclusion and Recommendation

Controlled grazing contributes to high grass richness and low herb richness. On the other hand, continuous grazing contributes to high herb richness and low grass richness. Controlled grazing should be used to restore grass richness in continuously grazed zones. Furthermore, controlled grazing down the gradient enhanced the dominance of some species and at the same time reduced diversity. Continuous grazing down the gradient increased diversity and tolerant unpalatable species. Interaction of grazing management practice and topographic positions shapes vegetation composition niche with grass composition having the dominant species. Controlled grazing should be utilized to enhance vegetation characteristics since it alters the feeding habit of livestock and decreases the selectivity of species grazed. This leads to animals moving less and grazing more in one spot unlike under continuous grazing which has less vegetation and higher stocking density. This forces livestock to walk for long distances and accelerates bare ground.

Continuous grazing management should be destocked to a suitable number of animals with the carrying capacity of the land in mind. Further studies should be carried out on herb species such as *Sansevieria sp,* which is an invasive herb species, and how the land can be restored in areas it has colonized. Moreover, the species was spotted in areas with bare ground or close to *Acacia sp* trees. Research should be carried on the ecological niche of *Sansevieria sp,* its dispersion as well as gene-phenotype to understand how it colonizes patches and interpatch of vegetation mosaics.

CHAPTER FOUR

Effect of Grazing Management on Mineral-Associated Organic Carbon and Particulate Organic Carbon in Semi-Arid Rangelands of Laikipia County

Abstract

This study set out to elucidate the effect of two types of grazing management on mineral-associated organic carbon (MAOC) and particulate organic carbon (POC) in the soil. The study was carried out in two ranches, Mpala Research Centre (controlled grazing) and Ilmotiok community Group Ranch (continuous grazing). The experimental design was a completely randomized block design. The main plots were the grazing practices, controlled grazing and continuous grazing; and topographic positions; mid-slope, foot slope, and bottomland. The land covers, bare ground, patches of grasses, and mosaics of trees, were randomly selected and replicated three times. Soil depth was used as a blocking factor and soil samples were collected at intervals of 10cm (0-10cm, 11-20cm, and 21-30cm). The samples were tested for POC and MAOC and data were analyzed using Agricolae package in R software. The highest level of interaction, grazing management practices, topographical positions, and land cover types had a significant ($P<0.0001$) effect on POC fraction at depth intervals of 0-10cm and 11-20cm. The interaction had no significant effect on MAOC fraction in any soil depth interval. Under controlled grazed (POC= 0.887% CC SD=0.49) zones it was significantly different compared to zones under continuous grazing (POC = 0.718% CC SD=0.3) . Mosaic of trees (POC =1.15% CC, SD = 0.22) recorded the highest concentration of carbon followed by patches of grass (POC = 0.87% CC, SD= 0.37) and bare ground (POC = 0.38% CC SD = 0.12) had the least. Topographical position had a increasing trend of carbon concentration down the gradient that is mid-slope (POC = 0.59% CC, SD =0.4)< foot slope (POC = 0.84% CC, SD =0.34) < bottomland (POC = 0.98% CC, SD = 0.41). This study shows that grazing practices, topographical positions as well as land cover types have a significant effect on particulate organic carbon.

Keywords: continuous grazing, controlled grazing, particulate organic carbon, land cover types, topographical positions

4.1 Introduction

Semi-arid rangelands have been managed for the past centuries by grazing leading to an increase in tree density (Kibet *et al*., 2016). This has made this type of biome to be incapable of providing critical ecosystem services like fodder for both domestic and wild animals, suitable habitat for wildlife and supporting services like carbon cycling among others. The indication and magnitude of how grazing practices influence soil characteristics depend on land cover and grazing management (Celik 2005, Yimer et a., 2015). The two distinct grazing management practices in the semi-arid rangelands of Kenyan are continuous and controlled grazing practices. Continuous grazing is characterised as grazing throughout the year with no rest period for vegetation to recover. Controlled grazing is practised in private ranches whereby land allocation, for forage, prioritization is given to both livestock and wildlife with taking into account drought scenarios with a rest period (Kibet *et al*., 2016). The grazing intensity in the two practices is heavy grazing intensity for the former and light to moderate grazing intensity in the latter.

Grazing practices have a significant effect on soil carbon fractions on the surface which is correlated to species composition and functioning (Alvarez *et al*., 1998; Personeni and Loiseau 2004). Soil labile and stable carbon forms part of the SOC reserve with the former being very sensitive to management and can act as a huge source of atmospheric CO2 if mismanaged through anthropogenic activities like grazing (Handayani, 2004; Sequeira *et al*., 2011). As it has been suggested as a good soil indicator of the effect of grazing management practices, it is essential to understand the sources and components of labile carbon fraction. Sources of labile carbon include vegetation and animal droppings. Urine and faecal matter from herbivorous animals have a high content of labile carbon and highly decomposable which act as hot spots and hot moments of sources of greenhouse gases (Bardgett *et al*., 1998; Frank *et al*., 2000; Bakker *et al*., 2004).

Grazing directly influences vegetation composition and litter hence either reducing or increasing the quantity of evapotranspiration and shading (Naeth and Chanasyk, 1995; Krümmelbein *et al*., 2009). Furthermore, it indirectly influences decomposition and mineralization rate of labile carbon by directly affecting the amount of soil moisture, oxygen availability and temperature (Sierra, 1997; Kiehl *et al*., 2001; Theodose and Martin, 2003). It has been observed that grazing in the temperate regions which experience freezing and thawing increases the quantity of labile carbon which is used as a source of energy by denitrifying microbes which can serve as a source of nitrous oxide to the atmosphere (Frank *et al*., 1998a; Frank *et al*., 2000; Le Roux *et al*., 2003). The active labile carbon pool is indirectly influenced by grazing through the species richness and functioning (Alvarez *et al*., 1998; Personeni and Loiseau 2004; Gosling *et al*., 2013). Studies on Continuous grazing, for instance in Ethiopia, showed that it has a negative effect on soil properties like total nitrogen, phosphorous and CEC unlike in controlled though it is unclear for the carbon pool as depth increases in semi-arid rangeland where there is co-existence of both grass and trees (Sankaran *et al*, 2005; Mekuria *et al*. 2011).

Most studies on soil carbon in Kenya report on soil organic carbon for the top 0.3m depth and not much is documented on various forms of carbon fractions and its trend down the soil profile. Depth tells us the trend of carbon and how much has been stored with time (Chandler 2016). It also reflects on the history of how various aspects like weather, land management and environmental factors influence SOC over time (Hobley *et al*. 2016). Several studies show that SOC reduces as depth increases and it is more stable in the sub-soil compared to the topsoil. Most studies on soil carbon in Kenya concentrate on the topsoil i.e. 0-30cm and not much is documented on the subsoil which is 30cm and beyond. It is essential to study TOC, MAOC and POC with depth since it is a source of ecosystem services which is dependent on its availability and the nature it exists in the soil. The topsoil tends to have high concentrations of carbon compared to the sub-soil and clay tend to isolate it and abiotic factors such as precipitation and temperature catalyse the process (Jackson *et al*., 2017).

Against this backdrop, the current study was carried out to elucidate the quantity and trend of TOC, MAOC and POC fraction concentration up to 120cm in different topographic positions and land cover changes associated with grazing practices. This will help to demystify how different grazing management practices, topographic positions and land cover types influence soil carbon with depth.

4.2MATERIALS AND METHODS

4.2.1 Site description

Two parallel experiments were carried out in two adjacent ranches Mpala Research Centre and Ilmotiok Community group ranch Laikipia county, Kenya. Laikipia County experiences an average rainfall of 600±50 mm per annum and a high-temperature range from 25-30°C and low from 12-17°C. Controlled grazing is practised in Mpala ranch and has been characterized to practice low to moderate grazing intensity is with a stocking density of wildlife and cattle with the exclusion of elephants to be 24TLU/Km2. IIlmotiok community group ranch has been classified to have a stocking density of 37TLU/Km2 (Table 6) and categorized as heavy grazing intensity (Kibet 2016).

Table 6: Grazing practices description of study site

Site	**Land Ownership**	**Total Livestock biomass (TLU)**	**Total livestock and wildlife (TLU)**	**Land area (Ha)**	**Stocking density (TLU/Km^2)**
Mpala Research Centre	Private	2074	4572.7	19000	24
Ilmotiok community group ranch	Community	897	1334.4	3651	37

Source: Kibet *et al.,* (2016)

The elevation of Laikipia County varies between 1,500 m above sea level at Ewaso Nyiro basin in the North to a maximum of 2,611 m above sea level around Marmanet forest. The dominant soil type is vertisols followed by red sandy soils (Lalampa *et al*., 2016). The main economic activities in Laikipia County includes but not limited to, livestock production, tourism, private and public conservancies, ranching, small and large scale farming, horticultural farming, sand harvesting and quarrying. The northern part of the County is an ASAL consequently making it difficult to support crop farming for commercial purposes. This has made the entire region to be dependent on pastoralism and charcoal production.

4.2.2 Soil properties of grazing practices in different topographic positions of semi-arid rangeland of Laikipia County

Some of the soil chemical and physical characteristics of topographic position were measured at the beginning of the experiment. The soil properties under each grazing management practice were summarized in Table 7.

Table 7: Soil properties for semi-arid rangelands of Mpala Research Centre and Ilmotiok Community Group Ranch

Grazing practice	Topographic position	pH	EC	Sand	Silt	Clay	Textural class	BD	TN	CN Ratio
			ds/m		%			g/cm3	g/kg	
Continuous grazing	Mid-slope	6.9	0.17	61.55	25.32	13.13	SCL	1.52	0.939	5.03
	Foot slope	7.09	0.13	61.13	28.53	10.35	SCL	1.47	1.081	5.03
	Bottom land	7.2	0.10	64.08	27.13	8.80	SCL	1.44	1.314	5.50
Controlled grazing	Mid-slope	6.98	0.08	64.6	21.44	13.96	SCL	1.53	1.128	4.87
	Foot slope	6.68	0.07	63.38	25.07	11.75	SCL	1.52	1.556	5.05
	Bottom land	6.23	0.05	38.49	50.23	11.29	C	1.48	1.844	5.24

SCL- Sandy clay loam, C- Clay; BD- bulk density; TN- Total nitrogen

4. 2.3 Experimental design and treatment

The experimental design was a completely randomized block design with a split plot. The treatments were the grazing management practices, topographic positions, and land cover types. Soil depth was used as a blocking factor. Land cover types were selected randomly based on the most dominant cover that is bare ground, patches of grass and mosaic of trees. The topographical positions were classified into mid-slope, foot slope and bottom land (Figure 1) as described by Eric *et al* (2002). GPS coordinates for each topographic position were recorded for both grazing practices as shown in Table 8.

Table 8: Grazing practices and topographic positions description

	Grazing	**Coordinates**		**Altitude**	**Position on**
SITE	**practice**	**N**	**E**	**(masl)**	**catena sequence**
Mpala Research centre	Controlled grazing (LS-MS)	36.86	0.467	1671.25	Mid-slope
		36.86	0.491	1646.75	Foot slope
		36.87	0.479	1629.24	Bottomland
Ilmotiok community group ranch	Continuous grazing (HS)	36.92	0.471	1649.25	Mid-slope
		36.92	0.469	1647.62	Foot slope
		36.91	0.471	1634.5	Bottomland

LS- Light stocking, MS- Moderate stocking, HS- Heavy stocking

In each topographic positions, land cover types, bare ground, patches of grasses and mosaics of trees were randomly selected and used to plot, a 200m transect and replicated 3 times. In each land cover type, soil samples were collected up to 30cm soil depth at intervals of 10cm. The soils were later tested for TOC, MAOC and POC.

4.2.4 Soil Sampling and analysis

Soil samples were collected from a flat surface which had been cleared of roots and grass. a calibrated soil auger was used to sample soils at depth intervals of 10cm from the surface (0cm) up to 30cm soil depth. A total of 162 (1kg) soil samples were collected i.e

2 grazing management practices * 3 topograpgrphical positions * 3 land cover types * 3 soil depths * 3 replicates = 162 soil samples

The samples were tested for POC, and MAOC.

Fractionation of Organic Carbon

SOM was classified into various C fractions (Dubeux Jr. *et al.*, 2006). 50g of fresh soil was weighed and dispersed with 10% calgon solution. Sieves with a mesh size of 2mm, 250 and 50 µm were arranged in that order and the dispersed soil sample was placed on the 2mm sieve and the process of wet sieving was carried out. After 20 minutes had elapsed, the fractions that were in each sieve was collected and oven dried at 65ºC for 24 hours. The weight of the dried samples was recorded and used to determine the percentage of carbon fractions in terms of 2mm - 0.05mm POC, and >53 µm MAOC carbon. C concentration in each fraction i.e. POC and MAOC was further classified using the Walkley-Black method described by Nelson and Sommers (1975). Conc. of C/kg of soil was calculated as quantity of OM recovered multiplied by C concentration in the SOM per unit of each particle size and then multiplying the result by the proportion of each given particle size in the soil particle size distribution.

Organic Carbon

Total organic carbon was determined by wet oxidation method using modified Walkley-Black method described by Nelson and Sommers (1975). Soil was sieved through a 0.5 mm sieve and 0.5g weighed. The weighed sample was placed into a conical flask in duplicates. Potassium dichromate, 10 ml was added to the conical flask followed by addition of 20ml of conc. Sulphuric acid and left to rest for 20 minutes. This was followed by adding 150ml of distilled water to the aliquot. This was done also for a blank sample i.e no soil in the conical flask.

After the aliquot had cooled off, Orthophosphoric acid and Barium were added and followed by titration of the aliquot with Ferrous sulphate. The titre values were recorded and used to calculate the percentage of Carbon content using equation 6.

$$\%\boldsymbol{C} = \left\{\frac{\textbf{M.e dichromate—m.e FeSO4}}{\textbf{Weight of soil in grams}}\right\} * \mathbf{0.3} \qquad \text{(Equation 6)}$$

4.2.5 Statistical analysis

R software version 3.5.3 (R Core development Team 2013) was used to carry out a one-way ANOVA for POC, and MAOC data. Agricolae package was used to do post hoc analysis with Tukey HSD test for POC, and MAOC to separate the means at 5% significance level.

4.3 Results

Soil Organic Carbon fractions in grazing practices, topographical positions and land cover types at various soil depths

4.3.1 Particulate Organic Carbon (POC) fraction and Mineral-associated Organic Carbon (MAOC) fraction

The POC fraction had a significant (p<0.001) response to grazing practices, topographical positions and across different land cover types at a soil depth of 0-10cm and 11-20cm but was insignificant between 21-30cm (Table 9).

Table 9: Means of carbon content (CC) % under different grazing practices at different topographical positions and various land cover types at 0_30cm soil depth

			Land cover types POC		
Soil depth	**Grazing practice**	**Topographical positions**	**Bare ground**	**Patches of grass**	**Mosaic of trees**
0_10cm	Continuous grazing	Bottom land	0.41^{i}	0.98^{de}	1.05^{d}
		Foot slope	0.41^{i}	0.84^{f}	0.9^{ef}
		Mid-slope	0.18^{k}	0.74^{g}	0.94^{ef}
	Controlled grazing	Bottom land	0.55^{h}	1.39^{b}	1.49^{b}
		Foot slope	0.44^{i}	1.07^{d}	1.35^{b}
		Mid-slope	0.31^{j}	0.2^{k}	1.18^{c}
11_20cm	Continuous grazing	Bottom land	0.33^{j}	0.76^{ef}	0.81d^{e}
		Foot slope	0.31^{jk}	0.67^{g}	0.69f^{g}
		Mid-slope	0.16^{l}	0.57^{h}	0.74f^{g}
	Controlled grazing	Bottom land	0.45^{i}	1.09^{b}	1.24^{a}
		Foot slope	0.36^{j}	0.83^{cd}	1.05^{b}
		Mid-slope	0.24^{k}	0.17^{l}	0.9^{c}
21_30cm	Continuous grazing	Bottom land	0.19^{hi}	0.52d^{e}	0.55^{cde}
		Foot slope	0.18^{hi}	0.44^{ef}	0.46^{ef}
		Mid-slope	0.1^{i}	0.36^{fg}	0.5^{def}
	Controlled grazing	Bottom land	0.28^{gh}	0.67^{abc}	0.8^{a}
		Foot slope	0.21^{hi}	0.57^{cde}	0.75^{ab}
		Mid-slope	0.12^{i}	0.12^{i}	0.63^{bcd}

Means with similar letters are insignificant.

Agricolae HSD test specifically under continuous grazing, POC means respectively at mid-slope (POC=0.84% CC, SD=0.015) and foot slope (POC =0.74% CC, SD=0.017) in patches of grass indicated significant difference. Under controlled grazed zones, the post hoc test showed POC means at bottom land in bare ground (POC =0.55% CC, SD=0.041) and mosaic of trees(POC =1.49% CC, SD=0.031) as well as in mid-slope bare ground (POC =0.31% CC, SD=0.026) and mosaic of trees(POC =1.18% CC, SD=0.061) had a significant difference. Grazing practices, topographical positions, land cover types, and soil depth had a significant ($p<0.001$) effect on MAOC fraction. Although the HSD test indicated there was no significant difference between the MAOC means at all soil depths (Table 10).

Table 10: Means of Mineral Associated Organic Carbon (MAOC) Content under different grazing practices at different topographical positions and various land cover types at 0_30cm soil depth

			Land cover types MAOC		
Soil depth	**Grazing practice**	**Topographical positions**	**Bare ground**	**Patches of grass**	**Mosaic of trees**
0_10cm	Continuous grazing	Bottom land	0.50^{ab}	0.29^{efg}	0.32^{def}
		Foot slope	0.45^{abc}	0.23^{gh}	0.34^{def}
		Mid-slope	0.51^{ab}	0.27^{efgh}	0.2^{h}
	Controlled grazing	Bottom land	0.4^{cd}	0.3^{efg}	0.24^{gh}
		Foot slope	0.44^{bc}	0.325^{fgh}	$0.24f^{gh}$
		Mid-slope	0.52^{a}	0.45^{abc}	0.28^{efg}
11_20cm	Continuous grazing	Bottom land	0.5^{ab}	0.29^{efg}	0.32^{def}
		Foot slope	0.45^{abc}	0.23^{gh}	0.34^{de}
		Mid-slope	0.51^{ab}	0.27^{efgh}	0.2^{h}
	Controlled grazing	Bottom land	0.4^{cd}	0.3^{efg}	0.24^{gh}
		Foot slope	0.44^{bc}	0.25^{fgh}	0.24^{fgh}
		Mid-slope	0.52^{a}	0.45^{abc}	0.28^{efg}
21_30cm	Continuous grazing	Bottom land	0.37^{ab}	0.36^{abc}	0.39^{a}
		Foot slope	0.3^{abc}	0.28^{bc}	0.38^{ab}
		Mid-slope	0.35^{abc}	0.29^{abc}	0.27^{c}
	Controlled grazing	Bottom land	0.32^{abc}	0.36^{abc}	0.36^{abc}
		Foot slope	0.33^{abc}	0.33^{abc}	0.37^{ab}
		Mid-slope	0.37^{ab}	0.3^{abc}	0.37^{abc}

Means with similar letters are insignificant.

4.4 Discussion

4.4.1 Particulate Organic Carbon

Grazing practices had a significant effect on POC. This is attributable to the varying stocking density in the two grazing management practices. Under continuous grazing practice, the stock density varied and has been classified to have a high grazing intensity (Kibet 2016). High grazing intensity has been associated to decrease POC in the active soil depth layer. According to Zhang *et al.*, (2016) grazing practices had no significant effect on POC. In other studies, grazing has been associated to decrease POC through trampling which loosens the soil and also reduces the plant cover which is a major source of POC in form of litter (Sainepo *et al.*, 2017).

The POC content was observed to be 38% which is within the range observed in other studies in semi-arid rangelands such as Chan (1997), Gill *et al*., (1999), Kaye *et al*., (2002), and Oduor *et al*., (2018). According to Cao *et al*., (2013), Riggs *et al*., (2015) and Eze *et al*., (2018) POC was detectable because it is sensitive to human-induced practices with grazing management being one of them. On the other hand, a study carried out in Switzerland was able to detect less than 20% of POC content and the rest of the CC was linked to MAOC (Leifeld and Fuhrer, 2009). This was due to the nature of the grassland which consisted of clay loamy soil.

The high CC under mosaics of tree cover was attributable to variation of tree species which have different amounts of carbon input in form of leaf litter, shoots and twigs which are rich in cutin, suberin and lignin. Land cover types had a significant effect because of the variation in species composition. Mosaic of trees recorded the highest followed by patches of grass. Bare ground recorded the least CC. Patches of grass and mosaics of trees are the main source of POC through the leaf litter. According to Kurgat *et al*., (2014) variation in vegetation covers types in semi-arid areas protects the soil surface from direct sunlight. Canopies of trees, such as Acacia species which is common in semi-arid rangelands, have been linked to having high soil moisture (Kurgat *et al*., 2014). This, in turn, enhances soil decomposition in the root zone.

Moreover, vegetation species have different C content especially trees like Boscia spp and Balanities spp have high quality and quantity of leaf litter lignin with high mineralization and the C: N ratio input unlike Acacia species (Gower *et al*., 1992; Feral *et al*., 2003; Wang *et al*., 2009; Wang *et al*., 2013). Rabbi *et al*., (2014) had similar findings and explained besides patches of land cover being sources of nutrients; they have a microclimate which slows down the decomposition of SOC in the soil thus influencing the physiochemical nature of carbon in the soil. On the contrary, Gili *et al*., (2010) associated high POC under tree canopies to the existence of herbaceous cover which was characterized to be unpalatable and hard. Also, under mosaics of trees and patches of grass, they have been characterized to have saturated hydraulic conductivity which enhances SOC content (Wang *et al*., 2009). According to Hibbard *et al*., (2003) and Gili *et al*., (2010) they associated high clay content to accrue POC under herbaceous and woody cover.

Besides, the drastic loss of POC as the depth increased was due to the high sand percentage at 0_10 soil depth which was observed to range between 65-70%. The sand was higher at 0_10cm compared to 21_30cm soil depth in the bare ground land cover type. Sandy soils have been associated to have weak van der Waal forces which enable microbes to easily access POC (Damien *et al*., 2015; Jackson *et al*., 2017; Chen *et al*., 2018; Gabriel *et al*., 2018). Also, sandy soils make POC prone to wind and water erosion.

4.4.2 Mineral-associated organic carbon

Grazing system, topographical position and land cover type do not influence soil MAOC. This is attributed to the similarity in clay content across all the grazing systems and topographical positions. MAOC is strongly associated with fine silt and clay particles (Zhao *et al*., 2006). In this, the silt and clay particles are uniformly distributed across all land cover types suggesting that the grazing systems and topographical positions had similar capacities to accumulate MAOC. These results corroborate with studies conducted in the drylands of South-west Kenya and Northern China (Yu *et al*. 2017; Sainepo *et al*. 2018). According to Eze *et al*., (2018) Furthermore, MAOC was unaffected with depth and similar observations were made by Ward *et al*., (2016) under grassland cover type.

4.5 Conclusion and recommendation

Controlled grazing management should be adopted under continuous grazed areas to curb further loss of particulate organic carbon. Regardless of the grazing management practice and topographical position, mosaic of trees having recorded high particulate organic carbon content, more trees should be planted to increase soil organic carbon. This will help to reduce bare ground cover and restore soils deprived of soil organic carbon. Controlled grazing should be used to reduce overgrazing of vegetation which is the main source of particulate organic carbon in the form of litter. SOC should be studied for the first 0-20cm soil depth under various land cover types under different grazing management in each topographical position as shown this study despite IPCC recommendation of sampling more than 30cm soil for carbon studies.

CHAPTER FIVE

Influence of grazing practices and land cover types on CH_4, CO_2 and N_2O fluxes in semi-arid rangelands of Laikipia County, Kenya

Abstract

Grazing management practices and land cover types may influence short term fluxes of CH_4, CO_2, and N_2O fluxes. A field experiment was conducted to measure the three major soil greenhouse gas emissions under three land cover types; bare, patches of grass, and a mosaic of trees in two grazing systems (continuous and controlled). Grazing management practices significantly ($p<0.001$) influenced CO_2 and N_2O fluxes although on CH_4 flux it was insignificant ($p>0.05$). Mean CO_2 emission under continuous grazed areas was observed to be 21.5 and 83.2 $mg.m^{-2}h^{-1}$ under controlled grazed zones while mean N_2O emission was 19.4 and 3.4 $\mu g.m^{-2}h^{-1}$ under controlled and continuous grazed zones respectively. Similarly, under different land cover types, there was a significant ($p<0.05$) effect on CO_2 and N_2O but insignificant ($p>0.05$) in CH_4. Bare ground had 27.86 $mg.m^{-2}h^{-1}$ CO_2- C flux, 0.007 $mg.m^{-2}h^{-1}$ CH_4-C flux and 3.71 $\mu g.m^{-2}h^{-1}$ N_2O- N fluxes. Tree had 66.57 $mg.m^{-2}h^{-1}$ CO_2- C emission -0.005 $mg.m^{-2.}h^{-1}$ CH_4-C fluxes and 11.43 $\mu g.m^{-2}h^{-1}$ N_2O- N fluxes. Grass exhibited 61.88 $mg.m^{-2}h^{-1}$ CO_2- C fluxes, -0.034 $mg.m^{-2.}h^{-1}$ CH_4-C fluxes and 18.81 $\mu g.m^{-2}h^{-1}$ N_2O- N fluxes. The CO_2 emission means were significantly different when compared to patches grass and tree cover while there was no significant difference between patches of grass and tree cover. There was a significant difference between bare ground and patches of grass but tree cover N_2O emission means was insignificant relative to bare ground and patches of grass. The GHG emissions in the three land cover types followed the order of tree>grass>tree, bare>tree>grass and grass>tree>bare for CO_2, CH_4, and N_2O respectively. Soil total nitrogen, total organic carbon, water-filled pore space, CN ratio CH_4, and N_2O were the main controlling significant ($p<0.01$) factors on CO_2 flux. Continuous grazing emits less CO_2, CH_4, and N_2O fluxes, unlike controlled grazing.

Keywords: TOC, TN, greenhouse gases, patches of grass, bare ground, mosaic of trees, CO_2, CH_4, and N_2O fluxes

5.1 Introduction

Semi-arid rangelands are normally utilized for livestock production and wildlife tourism due to limiting factors for crop production like low soil fertility, unpredictable rainfall patterns and landscape position (Kibet *et al*., 2016). Overgrazing in continuously grazed rangelands is a perennial problem that has reduced the availability of pasture thus affecting the livelihood of the pastoral community (Ribeiro *et al*., 2016). Studies on grazing effects on vegetation and soil properties have been carried out for semi-arid rangelands but there is insufficient information on soil greenhouse gas emissions. Hundreds of research have been conducted in temperate regions on GHG emissions whereas in Sub-Sahara it is still insufficient (Rosenstock *et al*., 2016). Most studies on greenhouse gases (GHG) are based more on crop production whereas the impact of grazing management practices and land cover types on GHG emissions is poorly understood (Oduor *et al*., 2018). Also, there is insufficient information on the contribution of semi-arid rangelands, which receive low rainfall and have low off-farm nutrient input, to GHG emissions.

Grazing patterns have been depicted to have different effects on the three major soil greenhouse gases, CO_2, CH_4, and N_2O. Grazing management influences CH_4 directly through urine and animal droppings and indirectly through soil moisture (Wang *et al*., 2012; Oduor *et al*., 2018). Previous studies have left out the contribution of vegetation to methane flux since it is insignificant (Ciais *et al*. 2013). The principal cause of N_2O emission in pasture lands has been attributed to animal droppings, urine, and denitrification process in the soil. In semi-arid rangelands, N_2O is emitted during denitrification of NO^{-3} in the soil (Yan *et al*., 2016). The main source of CO_2 emissions in natural environments is from soil respiration which has been associated with microbial activity and root respiration (Graham *et al*., 2012). It is essential to study all three GHG's because they interact in the soil pores and influence each other depending on soil carbon and nitrogen. A study carried out in the semi-arid rangeland of Kenya showed that CO_2 and CH_4 emissions had a positive correlation (Oduor *et al*., 2018). Also due to high periods of drought, the soil emits less CO_2 but upon birch effect, the fluxes from root respiration are three-fold (Borken *et al* 1999).

Many studies have been carried out on GHG for temperate regions but there is a dearth of information for the tropics and precisely for semi-arid rangelands (Rosenstock *et al*., 2016). Moreover, in Kenya, most studies have been based on livestock enteric emissions yet there is insufficient information on the contribution of stocking density and land cover types to GHG fluxes. Based on the hypothesis that grazing management practices and land cover types influence GHGs emission, a field experiment was conducted to measure CO_2, CH_4, and N_2O in continuous and controlled grazing zones under three land cover types (bare ground, patches of grass and mosaic of trees) in a semi-arid rangeland of Laikipia County.

5.2Materials and method

5.2.1 Site description

Two areas that is under controlled grazing and has a stocking density of 10-12TLU/km^2 while under continuous grazing it is 25TLU/km^2 and has been exhibited to be increasing over the years were used to set up the experiment for greenhouse gas emission. The area experiences an average rainfall of 600±50 mm per annum and a high temperature range from 25-30°C and low from 12-17°C. The elevation varies between 1,500m above sea level at Ewaso Nyiro basin in the North to a maximum of 2,611m above sea level around Marmanet forest (Mureithi *et al.*, 2014).

5.2.2 Experimental design

A completely randomized block design was used to set-up the experiment. The treatments were grazing management practices (Table 6) and the land cover types (Figure 2). The grazing management practices that were assessed included continuous grazed zones in Ilmotiok community group ranch and the controlled grazed zones in Mpala Research Centre. Topographical positions classified in Chapter 1, were used as a blocking factor. In each topographical position, mid-slope, foot slope and bottomland there was a 200m transect. The 200m transect was further blocked into 50m long 4 times. This was in order to distinguish the distinct land cover type after every 50m stake and setup the static chambers. Three land cover types were assessed under each grazing management practice and topographical position, namely; bare ground, patches of grass and mosaic of trees. Three cylindrical opaque static chambers measuring 29.2cm in diameter and 15cm in height were installed 10cm deep in each land cover type making a total of 36 sampling points (3 chambers x 3 land cover types x 4 replicates) in each grazing management practice and topographical position. The chambers were installed three weeks prior to the first gas sampling. Data on surface soil properties (0-10cm) described in Chapter 3 was used to establish the relationship with the GHG emission rates.

5.2.3 GHG Gas sampling and laboratory analysis

Soil emissions were sampled as from 24th January 2018 up to 28th February 2018 for each subplot. Gas samples were collected for 5 weeks consecutively from both sites one day per week, generally between 0800hrs and 1200hr local time. To avoid the influence of time, the last sub-plot to sample was the first to be sampled in the subsequent sampling event, and vice versa. Sampling was done immediately after fitting the lid (d=29.2cm) with an aluminium tape, rubber sealing, fan, 50cm non-forced vent, a Einstich TFA thermometer model and a sampling port was fitted to the base frame using metal clamps for 30 min. Gases were collected at 4 time intervals i.e. at time zero (T0), after 10 minutes (T1), 20 minutes (T2) and lastly after 30 minutes (T3). Once the systems were operational and set i.e., thermometers and chamber leads, gases were collected using 60ml syringe with a luer lock and stored in 20ml evacuated vials. The samples were transported to the lab to be measured for CO_2, CH_4 and N_2O. Other measurements taken included; surface compaction, soil moisture, temperature of soil, air and chamber, air pressure and chamber height. A total of 1440 samples were collected (5 weeks x 4 time intervals x 3 vegetation types x 4 reps x 2 grazing practices x 3 topographical positions). CH_4, CO_2 and N_2O were analyzed at Mazingira Centre (ILRI) using a gas chromatograph (GC) which was equipped with ^{63}Ni electron capture detector for N_2O while a flame ionization detector was used to detect CH_4 and CO_2. CH4, CO2 and N_2O fluxes were calculated depending on the peak areas detected by the GC relative to peak areas determined from the calibrated gas standards. Linear regression of standard concentrations as described by Qui *et al.,* (2006) was used to calculate CH_4, CO_2 and N_2O fluxes versus chamber closure time and corrected for soil moisture and temperature using equation 7 below.

$$F= (P/Po) \times (M/Vo) \times (dc/dt) \times (To/T) \times H \qquad \text{(Equation 7)}$$

Whereby: F= for CO_2- C Linear flux (mg.m-2.h-1), CH_4-C Linear flux (mg.m-2.h-1) and N_2O- N Linear flux (μg.m-2.h-1)

P= atmospheric pressure of study site (Pa)

P_o= atmospheric pressure (Pa)

M= gas mass (g/mol)

V_o= molar volume (ml)

dc/dt = rate of change in concentrate

T_o = absolute chamber temperature (°C)

T= absolute chamber temperature at time of sampling (°C)

H= height of static chamber at the time of sampling

Above ground air temperatures at 1.5 m and inside the base chamber were measured concurrently in each gas sampling event using a Einstich—TFA digital probe thermometer. Soil temperature (°C) and soil moisture content (SM, %v/v) were measured at 5 cm surface soil depth using a probe sensor model 5MT, Decagon Devices Inc which measured both soil moisture and temperature. Water filled pore space (WFPS) was determined as described by Zhang *et al.*, (2012) using extra parameters measured in the field like soil moisture and bulk density. It was calculated using equation 8 below.

$$WFPS\,\% = \frac{Soil\ moisture\ (\%)}{[1-\left\{\frac{Bulk\ density\left(\frac{g}{cm^3}\right)}{2.65}\right\}]} \qquad \text{(eq 8)}$$

5.2.4 Statistical analysis

R software version 3.5.3 was used to derive ANOVA tables and separate means using Agricolae package for CH4, CO2 and N2O fluxes to test the effect of grazing practices and land cover types on soil emissions. Linear regression model was used to determine the relationship between grazing practices, land cover, WFPS, total organic carbon, total nitrogen and CN ratio to CH4, CO2 and N2O.

5.3 Results and Discussion

5.3.1 Soil temperature, TOC, TN, CN ratio and WFPS

Under grazing management practice and varying land cover types the soil had varying responses as shown in Table 11.

Table 11: Soil chemical and physical characteristics under both continuus grazing and controlled grazing in different land cover types

Grazing system	**Land cover**	**TOC**	**TN**	**CN Ratio**	**WFPS**	**Soil temperature**	**Textural class**
		g/kg	**g/kg**		**%**	**°C**	
Continuous grazing	Bare ground	9.04	1.00	9.08***	8.47	31.4	LS
	Patches of grass	11.69^{**}	1.15	10.15	9.67	34.8	SCL

Grazing system	Land cover	TOC	TN	CN Ratio	WFPS	Soil temperature	Textural class
		g/kg	g/kg		%	°C	
	Tree mosaics	12.98^{**}	1.22	10.72	7.53	26.5	SL
Controlled grazing	Bare ground	9.36	1.1	8.67***	13.31	32.7	SL
	Patches of grass	13.36^{**}	1.32^{**}	10.17	15.35	33	SCL
	Tree mosaics	16.49^{**}	1.71^{**}	9.71	8.47	35.3	SCL

Significance level: '**' 0.001, '*' 0.05, 'LS' Loamy sand, 'SCL' Sandy clay loam, 'SL' sandy loam

Interaction of grazing practices and land cover types had a significant ($p<0.05$) effect on TOC, TN and C:N ratio. The interaction had no significant ($p=0.05$) effect on soil temperature, WFPS and soil texture. Under both grazing management, mosaics of tree recorded higher TOC and TN and bare ground had the least while patches of grasses being in between. Tree cover recorded the highest TOC and TN because the source of litter had quality and quantity of substrates.

5.3.2 Carbon dioxide (CO_2) soil flux

Continuous grazed areas had a significant effect ($p<0.001$) on CO_2 shown in Table 12.

Table 12: Effect of grazing practices and land cover types on CO_2-C flux

Variable	Treatment	Cumulative CO_2- C Linear flux (mg.m-2.h-1)
Grazing practice	Continuous grazing	21.5^{***}
	Controlled grazing	83.2
Land cover types	Bare ground	27.86*
	Patches of Grass	61.88
	Mosaic of Tree	66.57

Significant codes: ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

Continuous grazing management emitted 288% less CO_2-C flux relative to controlled grazing management. Land cover types had significant ($p<0.05$) effects on CO_2-C flux with bare ground emitting significantly less CO_2-C flux relative to patches of grass and mosaic of trees. There was no significant difference between patches of grasses and mosaic of tress.

5.3.3 Nitrous oxide (N_2O) soil flux

Grazing management practices had a significant ($p<0.001$) effect on N_2O- N flux as shown in Table 13.

Table 13: Effect of grazing practices and land cover types on N_2O- N flux

Factor	Treatment	Cumulative N_2O- N Linear flux (µg.m-2.h-1)
Grazing practice	Continuous grazing	3.4^{***}
	Controlled grazing	19.4
Land cover types	Bare ground	3.71
	Patches of Grass	18.81
	Mosaic of Tree	11.43

Significant codes: ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

Continuously grazed zone emitted 471% on N_2O- N flux less compared to controlled grazed zones. Although, land cover types had a significant effect on N_2O- N flux, there was no significant difference between the treatments (Table 13). Patches of grass recorded the highest N_2O- N flux relative to bare ground and mosaic of trees.

5.3.4 Methane (CH_4) soil flux

Grazing management practices and land cover types had no significant effect on CH_4-C flux (Table 14).

Table 14: Effect of grazing practices and land cover types on CH_4-C flux

Factor	Treatment	Cumulative CH_4-C Linear flux (mg.m-2.h-1
Grazing practice	Continuous grazing	-0.037
	Controlled grazing	0.016
Land cover types	Bare ground	0.007
	Patches of Grass	-0.034
	Mosaic of Tree	-0.005

Significant codes: ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

Continuously grazed areas acted oxidized CH_4-C flux where as under controlled grazed zones they acted as sources of CH_4-C flux. Patches of grasses and mosaics of trees enhanced oxidation of CH_4-C flux where as under bare ground cover emitted CH_4-C fluxes.

5.3.5 Regression analysis of grazing management practices, land cover types and soil chemical and physical properties on CO_2 flux

The factors influencing CO_2 flux was assessed and was observed to have an adjusted R^2 of 0.6 677. The relationship with coefficients is shown in Table 15 below.

Table 15: Regression analysis of precipitation, grazing management practices, land cover types and soil chemical and physical properties for CO_2 flux

	CO_2 Flux			
Coefficients:	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
(Intercept)	835.3664	279.0897	2.993	0^{**}
Grazing management practices	29.6058	10.3544	-1.79	0.08^{**}
Land cover type	4.6035	18.7839	0.245	0.81
WFPS	1.4944	0.4222	3.54	0^{***}
TOC	702.0136	200.737	3.497	0^{***}
TN	-6500.98	2066.192	-3.146	0^{**}
Soil texture	-48.2962	11.5338	-4.187	0^{***}
Soil temperature	-0.4005	0.5329	-0.752	0.45
CN ratio	-87.875	27.7759	-3.164	0^{**}
CH_4 flux	35.3684	13.1076	2.698	0.01^{**}
N_2O flux	1.9792	0.1178	16.808	0^{***}

Significant codes: ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05

The effect of controlled grazing (29.61mg.m-^{2}h-^{1} CO_2- C linear flux being emitted into the atmosphere from the soil. WFPS and TOC significantly ($p<0.001$) contributed to increase in CO_2- C flux. Increase in TN lead to reduction of CO_2- C flux significantly. Methane and nitrous oxide emissions significantly lead to an increased rate of CO_2- C flux. Soil texture had a significant negative effect on CO_2- C flux as a result of areas with high soil clay content.

5.4 Discussion

5.4.1 Carbon dioxide (CO_2)

Grazing had a significant effect on CO_2-C emissions. Controlled grazing emitted more CO_2-C emissions because of the high TOC concentration and WFPS than continuous grazing. The high soil TOC under controlled grazing ranged between 9.36-16.49g/kg of soil and this enhanced the diffusion of CO_2-C flux into the atmosphere. Also, WFPS which had a positive relationship (Table 14) with CO_2-C emissions was estimated to range between 8.56-14.65% which increased flux of CO_2 under both grazing managements. This is in corroboration with another study on enclosures which is a form of grazing practice (Oduor *et al*., 2018). Although, according to Wachiye *et al*., (2019) grazing practices has no significant effect on CO_2-C emissions. According to Oduor *et al*. (2018), enclosure, which is another example of controlled grazing practice, increases CO_2-C emissions indirectly by influencing soil TOC and soil moisture. Moreover, both controlled grazing and continuous grazing practices had relatively low CO_2-C emissions when compared to other studies in Chepararia, Kenya and Tanzania which was greater than 200 mg C m^{-2} h^{-1} (Oduor *et al*. 2018, Lal *et al*., 2015). Continuous grazing (21.5 mg C m^{-2} h^{-1}) had low CO_2-C emissions while controlled grazing (83.2 mg C m^{-2} h^{-1}) closely emitted the same amount when compared to croplands in savanna ecosystems of Kenya unlike the studied grazed lands (Wachiye *et al*., 2019). A study in savanna ecosystems compare six different land-use types and the conservation lands (75±6 mg CO_2-C m^{-2} h^{-1}) emitted closely similar amounts of CO2-C flux when compared to controlled grazing (83.2 mg C m^{-2} h^{-1}) (Wachiye *et al*., 2019). On the other hand, when grazed lands (50±5 mg CO2-C m^{-2} h^{-1}) of the savanna ecosystem of Kenya are compared to the two grazing management practices, continuous grazing (21.5 mg C m^{-2} h^{-1}) emitted on the lower side whereas controlled grazing was on the upper side (Wachiye *et al*., 2019). Tree and grass had 1.39 times and 1.21 times higher CO_2-C emissions respectively relative to bare soil. This is attributable to the fact that bare grounds were observed to be either resting glades for wild animals in semi-arid rangelands. In some cases, bare ground occurs because of overgrazing or footpaths created during transit in search of pasture by livestock. Theses glades had traces of animal droppings during gas sampling hence have high concentrations of urine and animal droppings which may have acted as a source of CO_2-C emissions. Bare ground was highly compacted and had a bulk density of 1.43g/cm^3 this contributed to less CO_2-C emissions. According to Kong *et al*., (2013) land cover type with high tree abundance have a high microbial carbon and nitrogen content relative to grass which results in more emission of CO_2-C flux. Grass patches tend to have a closed cover, unlike bare ground, whereas mosaic of trees provides shade which influences the quantity of soil moisture. Below ground under patches of grass has a very active network of roots which enhances root respiration and the quantity of litter (Yan *et al*., 2016). Moreover, this explains under patches of grasses and mosaic of trees there was high CO_2-C flux (Wachiye *et al*., 2019).

5.4.2 Nitrous oxide (N_2O) soil flux

Controlled grazing emitted more N_2O relative to continuous grazing. This is in agreement with previous studies, Oenema *et al*., (1997), Yamulki *et al*., (1998), Ma *et al*., (2006), Saggar *et al*., (2007). On the other hand, according to Oduor *et al*., (2018), who studied enclosures, a form of grazing management practice, it had no significant effect on N2O-N emission. On the other hand, controlled grazing (19.4 µg.m-2h-1) emitted similar quantities of N2O- N flux like enclosure grazing practice (18.6 µg N m^{-2} h^{-1}) in Chepararia, West Pokot and smallholder farms (<20 µg N m^{-2} h^{-1})located in the western tropical highlands of Kenya (Oduor *et al*., 2018, Pelster *et al*., 2017). Controlled grazing produces more emissions while continuous grazing leads to less by influencing vegetation composition and density of a landscape. This is because under controlled grazing it had light stocking rate. According to Yan *et al*., (2016), high grazing intensity and rate decrease N_2O-N flux. Furthermore, the landscape had high tree density, vegetation composition and diversity hence the soil moisture was higher while the counterpart was degraded of vegetation attributes hence there is less soil moisture which is a function of N denitrification. On the contrary, land cover types had no significant effect on N_2O-N emission. Patches of grass recorded the highest N_2O-N flux relative to bare ground and mosaic of trees due to the nature of the soil. Areas with grass cover have been observed to have higher water content compared to woody vegetation (Acharya, *et al*., 2017). Furthermore, grazing influences vegetation cover which in turn influence soil moisture and quality of the litter. Bulk density and compaction have been observed to be high under high grazing intensity because of animal trampling (Yan *et al*., 2016, Oduor *et al*., 2018). This, in turn, reduces the diameter of the soil pore which directly influences the amount of moisture stored and diffusion of N_2O-N flux in the soil. Moreover, trampling creates anaerobic zones in the soil pores where denitrifying bacteria thrive. This increases the denitrification potential of converting nitrates in the soil by denitrifying bacteria release of N_2O-N (Yan *et al*., 2016).

5.4.3 Methane (CH_4) soil flux

Controlled grazing emitted -331.25% more CH_4compared to continuous grazing and this was in agreement with other studies, Chen *et al*.,(2011); Zhu *et al*.,(2015), but also contradicts with previous findings of Cardoso *et al*., (2016) whereby grazing was observed to have a significant effect on methane. Continuous grazing acted as a sink while controlled grazing was a source. This is because; in controlled grazing, the stocking density of wildlife, with heavy body mass, exceeds that of continuous grazing which caused compaction. The two grazing practices are practised adjacent to each other thus have varying microclimates and according to Zhu *et al*., (2015) varying microclimates and difference in the two practices whereby the former has heavy stocking rate while the former has been consistently practicing light to moderate stocking rate leads to oxidation and emission of CH_4 respectively.

Trees and grasses were observed to have negative CH_4-C fluxes (table 22) hence acting as a sink and are in agreement with Colmer (2003) findings whereby roots accelerate the oxidation of CH_4-C to produce CO_2-C and hydrogen gas. Moreover, the land cover tends to have a microclimate and habitat characteristics which influence WFPS. Oduor *et al*., (2018) linked grazing enclosure to Under tree and grass vegetation the WFPS was observed to be 49% and 46% respectively higher compared to bare patches (Table 10) which implies that they had higher soil moisture content relative to bare grass. This prompted oxidation of CH_4-C flux into the soil in the two vegetation types. Moreover, the strong correlation between CH_4 and CO_2 fluxes in the soil.

5.4.3 Soil temperature, TOC, TN, CN ratio and WFPS

Grazing indirectly influences soil fluxes by directly influencing habitat characteristics in terms of species diversity and tree density which was observed to be 0.89 and 178.8 trees/ha for controlled grazing and 0.96 and 676.3trees/ha for continuous grazing. This directly influences TOC, TN, CN ratio, WFPS and bulk density. Under continuous grazing the stocking density was high which increased species diversity and tree density when compared to areas under controlled grazing. In turn, the vegetation which acts as the main source of TOC and TN directly influenced N_2O, CH_4 and CO_2. The soil under woody vegetation such as Boscia sp has been reported to have high C content (Kassa *et al.*, 2010). This explains why under a mosaic of trees under both grazing managements had high carbon content. Mosaics of trees under both grazing managements recorded the most TN followed by patches of grass and the bare ground had the least. The bare ground had the least TN relative to mosaics of trees and patches of grass because it had high sand percentage which has been attributed to causing little storage of mineralized N. According to Boutton and Liau (2010) woody and herbaceous cover tend to have high silt and clay content with strong electromagnetic forces which prompt slow decomposition and accumulation of TN in the soil.

The CN ratio was generally low because the quality of the substrate was low. Grasses recorded higher CN ratio compared to tree cover because it contains recalcitrant content of lignin and suberins which take long to decompose in the soil.

Under controlled grazing management, TOC, TN and WFPS were 16%, 22%, and 66% respectively higher compared to continuous grazing. While bulk density and CN ratio under controlled grazing management was 2% and 5% less relative to continuous grazing. High TOC, TN and WFPS and low bulk density and CN ratio under controlled grazing, reversed the role of this SCL soils from sinkers to emitters of CO_2, CH_4 and N_2O. Increased levels of TN under controlled grazing inhibited atmospheric methane oxidation in the soil hence explaining why under controlled grazing N_2O-N flux was high.

5.4.5 Relationship between CO_2 flux and grazing management practices, land cover types, and soil chemical and physical properties

Stepwise regression analysis showed that CO_2 flux was driven by TOC, TN, WFPS, precipitation, and CN ratio. Increase in TOC led to accelerated emission of CO_2 flux. Rise in CO_2 flux on the surface may have been as a result of increased substrates during decomposition of plant litter to stable TOC by microbes. Moreover, Xiao *et al*., (2007) further associated CO_2 flux occurred during decomposition of TOC which enhances root growth thus accelerating root respiration.

Increase in WFPS accelerated CO_2 flux and the reverse is true. This has been attributed to soil moisture and bulk density whereby soil which is highly compacted have a low bulk density thus the soil pores store less moisture (Yan *et al*., 2016, Oduor *et al*., 2018). The C: N ratio had a negative significant ($p<0.01$) relationship to CO_2 flux. Low CN ratio leads to high CO_2 flux which was as a result of vegetation litter whose quality of residue was poor. Similar findings were observed by Toma and Hatano (2007). Moreover, CH_4 and N_2O had a significant positive correlation to CO2 emission. In Hungarian soils, N_2O significantly contributed to CO_2 emission (Kong *et al* 2013). Regression analysis indicated CH_4 led to high CO_2 (35.3684mg CO_2-C $m^{-2}h^{-1}$) respiration in the soil whereas N_2O though a driver of CO_2 (1.9792 mg CO_2-C $m^{-2}h^{-1}$) emission it was low. According to Zhao *et al* (2019), respiration of CO_2 in the microsites enhanced uptake of CH_4 though the two fluxes had a negative relationship.

5.5 Conclusion and recommendation

Controlled grazing having a consistent low stocking rate significantly emitted more CO_2 and N_2O fluxes whereas continuous grazing with accelerated stocking rate significantly emitted less. This creates room for further research on ways to practice sustainable grazing practices which will contribute to lower soil emission. Land cover type significantly influenced CO_2 and N_2O fluxes. Further research should be conducted to determine the biochemical composition of semi-arid trees mainly Acacia trees which were observed to be the dominant tree species in both grazing practices and how they accelerate or enhance oxidation of CO_2, N_2O and CH_4. This will help to understand the relationship of biochemical content of vegetation litter and how they influence CO_2, N_2O and CH_4 flux in semi-arid rangelands.

CHAPTER SIX

GENERAL CONCLUSION AND RECOMMENDATIONS

6.1 General Conclusion and recommendation

Controlled grazing and continuous grazing had a significant effect on POC. controlled grazing had less impact on POC when compared to continuous grazing practice. Controlled grazing should be used to manage vegetation composition, diversity and relative abundance of species and tree density. This practice is sustainable since fodder is available to both livestock and wildlife and at the same time reducing soil erosion, surface runoff and recycling of litter in the form of POC.

Controlled grazing is a strategic grazing management which boosts habitat characteristics and balances the population of wildlife and livestock hence should be adopted to reduce the loss of POC. Also, controlled grazing exhibited oxidation of CH_4 in the soil during long dry seasons at the expense of CO_2 and N_2O.

Controlled grazing showed it is suitable for grazing management and should be adopted since it puts into consideration both livestock and wildlife. This type of grazing showed its enhanced species composition compared to continuous grazing management practice. Moreover, it acted as a reservoir of POC fraction. It also enhances habitat structure by controlling woody species by replacing with herbaceous species thus improving land cover patches as well as reducing further land degradation since it had less bare ground contrary to continuously grazed areas. There is also a need for revegetation of bare ground with palatable grass species which can grow in soil with low or deficient in N and at the same time oxidizes N_2O from the atmosphere. This will enhance the decomposition of carbon and reduce denitrification. Moreover, destocking should be carried out under continuously grazed zones to reduce the loss of vegetation cover and SOC fractions. Continuous grazing in this study has shown to proliferate herb cover especially Sansevieria sp which is an invasive species in heavily grazed areas.

For controlled grazing to be used as a climate-smart tool, further research should be carried out to understand the main source of CO_2, N_2O and CH_4 by identifying and marking the isotopes of the fluxes. Moreover, nitrogen acts as a regulator of methane oxidation and reduction; hence there is need for proper understanding on how to acquire equilibrium between increasing soil C and N to improve soil fertility while at the same time being able to oxidize both N_2O and CH_4.

Strategies such as reseeding together with controlled grazing patterns should be used to recover bare ground, especially under continuously grazed zones. This will help to restore bare land cover and control degradation and further loss of the topsoil.

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APPENDICES

```
richness <- read.csv("Richness.csv")
attach(richness)
df <- specaccum(richness, "random")
df2 <- specaccum(richness, "random")
plot(df, ci.type = "poly", col = "blue", lwd=2, ci.lty = 0, ci.col = "ligh
tblue",
     ylab = "Number of species", xlab = "Total transects")
boxplot(df2, col="yellow", add = TRUE, pch="*",legend=TRUE, legend.pos="to
pright")

detach(richness)

speciesRich <- read.csv("arranged_richness.csv")
attach(speciesRich)
site <- factor(SITE)
topo <- factor(T.ZONE)
h1 <- aov(Grass~SITE*T.ZONE)
summary(h1)

##             Df Sum Sq Mean Sq F value  Pr(>F)   
## SITE         1  5.556   5.556    5.00 0.04512 * 
## T.ZONE       2 13.000   6.500    5.85 0.01685 * 
## SITE:T.ZONE  2 24.111  12.056   10.85 0.00204 **
## Residuals   12 13.333   1.111                   
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

rish <- with(speciesRich, interaction(site,topo))
h2 <- aov(Grass~rish)
summary(h2)

##             Df Sum Sq Mean Sq F value Pr(>F)   
## rish         5  42.67   8.533    7.68 0.0019 **
## Residuals   12  13.33   1.111                  
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

h3 <- aov(Trees~rish)
summary(h3)

##             Df Sum Sq Mean Sq F value Pr(>F)  
## rish         5 13.833  2.7667    4.98 0.0106 *
## Residuals   12  6.667  0.5556                 
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

h4 <- aov(Shrubs~rish)
summary(h4)

##             Df Sum Sq Mean Sq F value Pr(>F)  
## rish         5  30.28   6.056   3.028 0.0538 .
## Residuals   12  24.00   2.000                 
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

h5 <- aov(Herbs~rish)
summary(h5)

##             Df Sum Sq Mean Sq F value Pr(>F)
## rish         5  23.78   4.756   3.567  0.033 *
## Residuals   12  16.00   1.333
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

h6 <- aov(Forbs~rish)
summary(h6)

##             Df Sum Sq Mean Sq F value Pr(>F)
## rish         5  14.44   2.889   1.926  0.163
## Residuals   12  18.00   1.500

detach(speciesRich)

df_diversity <- read.csv("theo.csv")
attach(df_diversity)
invent <- with(df_diversity, interaction(Site,Topographical.position))
df4 <- aov(Grass~invent)
summary(df4)

##             Df Sum Sq Mean Sq F value Pr(>F)
## invent       5  12.34   2.468    2.66 0.0766 .
## Residuals   12  11.14   0.928
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

df5 <- aov(Forbs~invent)
summary(df5)

##             Df    Sum Sq   Mean Sq F value  Pr(>F)
## invent       5 0.0008357 1.671e-04   5.551 0.00708 **
## Residuals   12 0.0003613 3.011e-05
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

df6 <- aov(Trees~invent)
summary(df6)

##             Df   Sum Sq   Mean Sq F value  Pr(>F)
## invent       5 0.005570 0.0011140   6.422 0.00399 **
## Residuals   12 0.002082 0.0001735
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

df7 <- aov(Herbs~invent)
summary(df7)

##             Df  Sum Sq Mean Sq F value   Pr(>F)
## invent       5 0.15598 0.03120   12.14 0.000236 ***
## Residuals   12 0.03084 0.00257
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

df8 <- aov(Shrub~invent)
summary(df8)

##               Df  Sum Sq  Mean Sq F value Pr(>F)
## invent         5 0.01854 0.003708   1.369  0.303
## Residuals     12 0.03251 0.002709

detach(df_diversity)

Abundance <- read.csv("Relative_abundance.csv")
attach(Abundance)
together <- with(Abundance, interaction(Grazing.practice, Topographical.po
sitions))
df_shrub <- aov(shrub~together, data = Abundance)
summary(df_shrub)

##               Df Sum Sq Mean Sq F value Pr(>F)
## together       5  1.843  0.3685   4.161   0.02 *
## Residuals     12  1.063  0.0886
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

df_tree <- aov(tree~together)
summary(df_tree)

##               Df Sum Sq Mean Sq F value   Pr(>F)
## together       5 1.5835  0.3167   14.75 9.08e-05 ***
## Residuals     12 0.2576  0.0215
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

df_grass <- aov(grass~together)
summary(df_grass)

##               Df Sum Sq Mean Sq F value   Pr(>F)
## together       5 126.55  25.309   11.02 0.000373 ***
## Residuals     12  27.55   2.296
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

df_forbs <- aov(FORB~together)
summary(df_forbs)

##               Df  Sum Sq  Mean Sq F value   Pr(>F)
## together       5 0.10184 0.020368   15.56 6.96e-05 ***
## Residuals     12 0.01571 0.001309
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

df_herbs <- aov(HERB~together)
summary(df_herbs)

##               Df Sum Sq Mean Sq F value   Pr(>F)
## together       5 10.395  2.0790   21.74 1.24e-05 ***
```

```
## Residuals   12  1.147  0.0956
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
detach(Abundance)
```

```
tree_density <- read.csv("Bare_count_data.csv")
attach(tree_density)
intact <- with(tree_density, interaction(Grazing.practice, T.ZONE))
df_density <- aov(Tree.density~intact)
summary(df_density)
```

```
##             Df  Sum Sq Mean Sq F value Pr(>F)
## intact       5 4342891  868578    4280 <2e-16 ***
## Residuals   12    2435     203
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
detach(tree_density)
```

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```
TEN <- read.csv("ten.csv")
attach(TEN)
intent <- with(TEN, interaction(Grazing.mgt,Topographic.positions,Land.cov
er.types))
df2 <- aov(POC~intent)
summary(df2)
```

```
##             Df Sum Sq Mean Sq F value Pr(>F)
## intent      17  8.896  0.5233   480.6 <2e-16 ***
## Residuals   36  0.039  0.0011
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
detach("TEN")
```

```
Twenty <- read.csv("twenty.csv")
attach(Twenty)
concern <- with(Twenty, interaction(Grazing.mgt,Topographic.positions,Land
.cover.types))
df10.1 <- aov(POC~concern)
summary(df10.1)
```

```
##             Df Sum Sq Mean Sq F value Pr(>F)
## concern     17  5.471  0.3218   523.5 <2e-16 ***
## Residuals   36  0.022  0.0006
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
detach("Twenty")
```

```
Thirty <- read.csv("thirty.csv")
attach(Thirty)
food <- with(Thirty, interaction(Grazing.mgt,Topographic.positions,Land.co
ver.types))
```

```
df3.1 <- aov(POC~food)
summary(df3.1)
```

```
##             Df Sum Sq Mean Sq F value Pr(>F)    
## food        17 2.6314 0.15479   75.85 <2e-16 ***
## Residuals   36 0.0735 0.00204                   
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
detach(Thirty)
```

```
flux <- read.csv("GHG.csv")
attach(flux)
variables <- with(flux, interaction(SEASON, RANCH,vegetation.cover))
carbon <- aov(CO2.Linear.flux...mg.m.2.h.1.~variables)
summary(carbon)
```

```
##              Df  Sum Sq Mean Sq F value   Pr(>F)    
## variables    11  676945   61540   9.764 3.91e-14 ***
## Residuals   204 1285805    6303                     
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
nitrous <- aov(N2O.Linear.flux...ug.m.2.h.1.~variables)
summary(nitrous)
```

```
##              Df Sum Sq Mean Sq F value   Pr(>F)    
## variables    11  54988    4999   5.163 3.83e-07 ***
## Residuals   204 197503     968                     
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
methane <- aov(CH4.Linear.flux...mg.m.2.h.1.~variables)
summary(methane)
```

```
##              Df Sum Sq Mean Sq F value Pr(>F)
## variables    11  0.719 0.06538   0.863  0.578
## Residuals   204 15.464 0.07580
```

```
water <- aov(WFPS~variables)
summary(water)
```

```
##              Df Sum Sq Mean Sq F value Pr(>F)    
## variables    11   8374   761.2   13.63 <2e-16 ***
## Residuals   204  11393    55.8                   
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
soc <- aov(TOC~variables)
summary(soc)
```

```
##              Df Sum Sq Mean Sq F value Pr(>F)    
## variables    11 13.036  1.1851   37.91 <2e-16 ***
## Residuals   204  6.378  0.0313                   
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
Total_nnitrogen <- aov(TN~variables)
summary(Total_nnitrogen)

##                Df  Sum Sq  Mean Sq F value Pr(>F)    
## variables      11 0.10519 0.009563      39 <2e-16 ***
## Residuals     204 0.05002 0.000245                   
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

CN_ratio <- aov(C.N.ratio~variables)
summary(CN_ratio)

##                Df Sum Sq Mean Sq F value Pr(>F)    
## variables      11  111.3  10.123   17.86 <2e-16 ***
## Residuals     204  115.6   0.567                   
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

df <- lm(CO2.Linear.flux...mg.m.2.h.1. ~SEASON+RANCH+vegetation.cover+WFPS
+TOC+TN+C.N.ratio+
      Texture+soil.temperature+Air.temperature+Air.pressure)
summary(df)

## 
## Call:
## lm(formula = CO2.Linear.flux...mg.m.2.h.1. ~ SEASON + RANCH + 
##     vegetation.cover + WFPS + TOC + TN + C.N.ratio + Texture + 
##     soil.temperature + Air.temperature + Air.pressure)
## 
## Residuals:
##     Min      1Q  Median      3Q     Max 
## -159.62  -40.25   -9.43   22.40  375.85 
## 

df2 <- lm(N2O.Linear.flux...ug.m.2.h.1. ~SEASON+RANCH+vegetation.cover+WFP
S+TOC+TN+C.N.ratio+
            Texture+soil.temperature+Air.temperature+Air.pressure)
summary(df2)

## 
## Call:
## lm(formula = N2O.Linear.flux...ug.m.2.h.1. ~ SEASON + RANCH + 
##     vegetation.cover + WFPS + TOC + TN + C.N.ratio + Texture + 
##     soil.temperature + Air.temperature + Air.pressure)
## 
## Residuals:
##     Min      1Q  Median      3Q     Max 
## -58.964 -11.343  -2.463   6.561 275.113 
## 


## 
## Residual standard error: 30.58 on 203 degrees of freedom
## Multiple R-squared:  0.248,  Adjusted R-squared:  0.2035 
## F-statistic: 5.578 on 12 and 203 DF,  p-value: 3.107e-08
```

```
df3 <- lm(CH4.Linear.flux...mg.m.2.h.1. ~SEASON+RANCH+vegetation.cover+WFP
S+TOC+TN+C.N.ratio+
            Texture+soil.temperature+Air.temperature+Air.pressure)
summary(df3)

##
## Call:
## lm(formula = CH4.Linear.flux...mg.m.2.h.1. ~ SEASON + RANCH +
##     vegetation.cover + WFPS + TOC + TN + C.N.ratio + Texture +
##     soil.temperature + Air.temperature + Air.pressure)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -2.42982 -0.03521  0.00872  0.06501  1.90651
##

detach(flux)
```