EFFECTS OF HOLISTIC GRAZING MANAGEMENT ON SOIL PHYSICO-CHEMICAL PROPERTIES AND HERBACEOUS VEGETATION PRODUCTION IN NAIBUNGA CONSERVANCY, LAIKIPIA COUNTY, KENYA

BY

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A thesis submitted to the Board of Postgraduate Studies in partial fulfilment of the requirements for the degree of Master of Science in Range Management in the Department of Land Resource Management and Agricultural Technology, Faculty of Agriculture, University of Nairobi

DECLARATION

THIS THESIS IS MY ORIGINAL WORK AND HAS NOT BEEN PRESENTED FOR A DEGREE IN ANY OTHER UNIVERSITY.

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DEDICATION

This thesis is dedicated to my Mum, Brothers and sisters**.**

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ABBREVIATIONS AND ACRONYMS

HGM	Holistic grazing management
CEC	Cation Exchange Capacity
UNCCD	United Nations Convention to Combat Desertification
FAO	Food and Agriculture Organization
NRT	Northern Rangeland Trust
TNC	The Nature Conservancy
LWF	Laikipia Wildlife Forum
IPCC	Intergovernmental Panel on Climate Change
GHGs	Green House Gases
HCL	Hydrochloric Acid
USDA	United States Department of Agriculture
NRCS	Natural Resource Conservation Service
SOM	Soil Organic Matter
Kpa	Kilogram Pascal

ABSTRACT

This study evaluated the effects of holistic grazing management (HGM) on biomass production and soil properties under holistic and non-holistic grazing sites. The study was conducted in two Group Ranches namely, Koija and Il Motiok in Naibunga Conservancy, Laikipia County, Kenya. Vegetation attributes and soil parameters were determined in four plots randomly sited and established within the Il Motiok Ranch, which is under HGM, and in the same number of plots sited and established in Koija Ranch which is under free-range grazing system. Herbaceous vegetation and soil parameters were determined along two transects placed diagonally across each plot. Along each transect, soil samples were collected at two depths 0-10cm and 10-20cm using a standard soil auger. The results of the analyses show that herbaceous standing biomass and yield was higher ($P \leq 0.05$) in holistic than non-holistic grazing sites. Mean organic carbon and moisture content, pH, total nitrogen, cation exchange capacity (CEC), potassium, phosphorus, aggregate stability, hydraulic conductivity, and water content were significantly higher ($P < 0.005$) under holistic grazing than non-holistic grazing sites. Conversely, soil bulk density and penetration resistance were greater under holistic grazing regimes. This study has demonstrated that holistic grazing management has the potential to significantly improve the soil properties and range productivity. These results are attributed to the beneficial effects of grazing that includes hoof action on soil and fertilization from animal dung and manure that occur when grazing animals are congregated together to assert maximum impact on soil and pasture for a short duration followed by adequate rest durations to allow post-grazing pasture recovery. However, monitoring of the study sites would be helpful in determining the long-term effects of holistic grazing management in pastoral rangelands.

KEY WORDS: Vegetation attributes, Organic matter, Livestock grazing, Semi-arid lands

CHAPTER ONE

INTRODUCTION

1.1 Background information

Rangelands, primarily comprising savannas and shrub-lands occur within the arid, semi-arid and dry sub-humid zones, covering about 41% of the global landmass (UNCCD, 2006). Rangelands occur extensively in Africa, making up 43% of the total land surface area. In general, rangelands are characterized by low, spatially and temporally variable rainfall. In addition, these areas are characterized by high temperatures leading to high levels of evapotranspiration. Rangelands also experience high runoff leading to floods (Mwangi and Dohrn, 2006) which make them more susceptible to degradation (Reid *et al*., 2008).

Despite the natural limitations, rangelands are important social-economically and ecologically. Specifically, because these areas support the livelihoods of over 40% of the world's population (De Jode, 2009), there is growing recognition of their importance in meeting the global food security as well as other needs of the inhabitants (Mortmore *et al.,* 2009). In terms of ecological significance rangelands provide habitats for wildlife, and acts as catchments or watersheds for large river systems (Lund, 2007). In addition, rangelands are important areas for carbon storage. It is estimated that rangelands store up to 30 % of the world's soil carbon (FAO, 2009).

Livestock production and wildlife conservation are the major land uses in arid and semi-arid rangelands (FAO, 2009, Odadi *et al*., 2011). Livestock production in rangelands is primarily carried out through pastoralism, and ranching. Pastoralism has been viewed as the most viable production system in arid and semi-arid rangelands (Schareika, 2010, Galvin, 2009). Because of the high spatial and temporal variation in rainfall in these areas, pastoralism responds to the heterogeneous distribution of forage and water resources across the landscape through increased livestock mobility. However, this traditional mobility has been compromised in many pastoral rangelands due to loss of grazing land to agriculture, and urban centers, drying up of water point, conflicts and insecurity, and socioeconomic changes necessitated by changing aspirations and economic needs (De Jode, 2009).

Degradation of pastoral rangelands has been associated with restricted livestock mobility, poor grazing management practices and the ensuing overgrazing (WISP, 2008 and Li *et al*., 2011). Rangeland degradation has serious negative consequences for pastoral livestock production, wildlife conservation and pastoral livelihoods. It undermines the ability of pastoral communities to cope with the challenges of a complex and dynamic system.

African pastoral rangelands are some of the most degraded rangelands in the world (Galvin, 2009, Ritchie *et al*., 2012, Kioko, 2012, Kamau, 2004). This situation has been attributed to the increasing tendency towards sedentarization occasioned by many factors, including land privatization and fragmentation of former communal grazing lands (Olson, 2006) which reduces the land available for grazing. When plants are exposed to intensive grazing for extended periods of time without sufficient recovery periods, the land is overgrazed. This leads to land degradation through increased soil erosion and spread of invasive plant species and reduces the ability of the land to support biodiversity and livestock production (Conant *et al.*, 2001). Exposure of the soil to the sun, wind, water and other environmental elements, as a result of reduced herbaceous ground cover, generally increases soil erosion, which reduces soil depth and soil organic carbon (Li *et al*., 2008, McClaren *et al*., 2008) that ultimately affects range productivity.

The on-going degradation of African pastoral lands has been largely associated with inappropriate grazing practices (Maraseni *et al.*, 2008). Consequently, restoration and improvement of the productivity of these rangelands require innovative approaches to grazing management. Holistic grazing management (HGM), which involves, planned grazing, rest rotation and bunched herding, has been suggested as a tool for restoring and enhancing rangeland health (Savory and Butterfield, 1999, Wolf 2011, Ritchie *et al*., 2012). However, the efficacy of this grazing management approach in improving rangeland health remains to be validated, especially in African pastoral grazing lands. Scientific assessment of the effects of holistic grazing management on pastoral rangeland health is necessary given the ongoing efforts aimed at expanding this grazing approach across African pastoral rangelands

1.2 Research problem

Healthy rangelands are capable of providing a wide range of ecosystem services necessary for survival of wildlife, livestock and human beings. For centuries, pastoralism has been a dominant livestock production system in tropical rangelands and especially in sub-Saharan Africa. Before the advent of colonialism in Africa, pastoralists and their livestock extensively traversed rangelands, often switching between wet and dry season grazing areas and, in the process, ensured sustained livestock productivity and healthy rangelands (Galvin, 2009). Over the past one century, however, this extensive livestock mobility has been seriously impaired, leading to increased overgrazing and land degradation, with negative consequences on the ecosystem.

Consequently, there is urgent need to restore and improve rangeland productivity through sustainable grazing management methods. One such approach which is currently being piloted in parts of northern Kenyan is HGM system. However, there is insufficient information on the effect of this system on the soil physical and chemical characteristics as well as the herbaceous biomass yield.

1.3 Justification

Holistic grazing management is gaining popularity among private commercial ranches in Zimbabwe (Abel 1989), in USA (Strauch 2009), and South Africa, Botswana and Namibia (Oba 2000) as an emerging means of restoring degraded rangelands. The beneficial effects of HGM have been linked to the hoof action of the animals that break down the hard crusts in the compacted soil, thereby improving the soil structure and subsequent increase in vegetation production (Dore 2001). In Kenya, the Northern Rangeland Trust has been promoting the adoption of the holistic grazing system mainly in the group ranches in Laikipia County. However, its recent promotion under pastoral production systems is guided by lean empirical evidence. There is a paucity of information about the model's ability to improve vegetation cover and herbaceous production, as well as soil physical and chemical properties in the arid and semi-arid pastoral ecosystems.

This study investigated the performance of holistic grazing management under the pastoral production system by determining its effect on the herbaceous biomass production and the soil physical and chemical properties. The results of this study are expected to guide development of appropriate grazing management plans and monitoring of their performance to ensure sustainable utilization of communal pastoral ecosystems. Specifically, the results will be useful to several stakeholders in the pastoral rangelands, including the organizations spearheading the adoption of HGM system such as the Northern Rangelands Trust (NRT), The Nature Conservancy (TNC), Laikipia Wildlife Forum (LWF), communal group ranches, and conservancies, among others. In addition, these findings will contribute towards guiding policy formulations for sustainable rangeland management at both county and national levels of governance.

1.4 Broad objectives

The overall objective of this study was to assess the effects of HGM on soil physical and chemical characteristics and forage production in northern Laikipia rangelands of Kenya. The ultimate aim of the study was to inform development of sustainable grazing management plans and specifically out-scaling of HGM system to other areas with similar socio-ecological conditions.

1.5 Specific objectives

The specific objectives of this study were to determine the effects of HGM on:

1. Herbaceous biomass production and utilization
2. Soil physical properties (aggregate stability, soil moisture content, bulk density, penetration resistance, hydraulic conductivity and available water content)
3. Soil chemical properties (soil organic carbon, carbon density, CEC, nitrogen, phosphorous, potassium)

1.6 Hypotheses

This study hypothesized that:

1. Holistic grazing management has no effect on herbaceous biomass production.
2. Holistic grazing management has no effect on physical properties of the soil.
3. Holistic grazing management does not affect the chemical properties of the soil.

CHAPTER TWO

LITERATURE REVIEW

2.1 Extent and importance of rangelands

Rangelands make about 40% of the globe (Sutie *et al.*, 2005) and are approximately 69% of the world's agricultural land (FAO, 2009). They are important habitats for wild flora and fauna as well as for domestic livestock (du Toit *et al.*, 2010, Galvin, 2009). The dry lands are predominantly used for livestock production, mainly through pastoralism. In sub-Saharan Africa alone, 25 million pastoralists and 240 million agro-pastoralists depend on livestock for their primary income (FAO, 2009).

Movement of livestock herds is a central component of land management (Galvin, 2009). Traditional mobility within the pastoralist system is compromised by declining access to rangeland resources, with some of the obstacles to pastoral mobility being: loss of grazing land to agriculture, poor watering point management, conflicts and insecurity, shifting boundaries (county, national and regional), and social change necessitated by changing human aspirations and economic needs (De Jode, 2009, Gao *et al.*, 2009).

Rangeland degradation undermines the ability of dry land communities to cope with the challenges of a complex and dynamic system. Rangelands and the associated natural pastures are experiencing rapid degradation, thus reducing their contribution to livestock feed. Pastoral systems are losing resilience as traditional coping mechanisms are failing due to increasing environmental degradation coupled by absence of national policies to address the problem (Kassahun *et al.*, 2008). Grazing animals influence species composition, biomass yield and distribution of biodiversity (Oba *et al,* 2001, Zerihun & Saleem, 2000)

2.2 Holistic Grazing Management

Holistic grazing management is based on strategies that aim to tackle the formidable task of bringing life back to bare grounds/patches, and increasing the health and productivity of the grasslands (Savory and Butterfield, 1999). It involves, high intensity, short duration rotational grazing.The proponents of holistic grazing management argue that when animals are concentrated in small areas for short periods of time, they break the ground, allowing for water and nutrient flow, whilst sowing seeds and adding fertilizer through dung and urine (Strauch, 2009, Savory, 1983). This, coupled with the rotation of the concentrated herd, ensures that plants regenerate, making the rangeland healthier and more productive (Abel, 1989 Savory, 1978).

Holistic grazing management differs from the traditional rotational grazing in that, with the latter, animals are not moved on the basis of plant responses, but the grazing periods set aside for each paddock (Jacobo, 2006,Wolf, 2011). The movement of animals is more flexible in HGM depending on the prevailing weather conditions, plant growth or the changing animal needs (Wolf, 2011). In continuous grazing where holistic grazing is not practiced, animals are grazed on the same piece of land for a very long period of time. This does not give the grazed plants adequate time for recovery leading to the loss of vigor in the defoliated plants, resulting in declining productivity (Kioko et al., 2012, Jacobo, 2006).

Holistic grazing management is gaining popularity among private commercial ranches in Zimbabwe (Abel 1989), in USA (Strauch 2009), and South Africa, Botswana and Namibia (Oba 2000) as an emerging means of restoring degraded rangelands. This beneficial effect has been linked to the action of the hooves of the animals that break down the hard crusts in the compacted soil, thereby improving the soil structure and subsequent increase in vegetation production (Dore 2001). In Kenya, the Northern Rangeland Trust has been promoting the adoption of the holistic grazing system in many parts of the Laikipia County (Ritchie *et al.,* 2012). This has led to its adoption by various community ranches. However, its recent promotion in pastoral production systems that are characterized by low external input is guided by lean empirical evidence. There is a scarcity of information about the model's ability to improve vegetation cover and herbaceous production, as well as soil physical and chemical properties in the arid and semi-arid pastoral ecosystems. There is therefore need to assess the performance of HGM in pastoral set-up to guide its adoption and out-scaling to other areas with similar ecological conditions.

2.3 Effects of grazing on aboveground biomass production

Land-use has a major impact on rangeland ecosystems (Conant *et al.*, 2001), and can therefore have a significant effect on the global environment. Rangelands largely exploited through livestock grazing (Bilotta *et al*., 2007) and grazing intensity influences the sustainability of grazing lands (Mphinyane *et al.,* 2008, Kioko *et al.,* 2012, Ilan *et al.,* 2008, Radford *et al.,* 2008, Steffens *et al.,* 2008). Specifically, high grazing intensity affects the botanical composition and species diversity of the grazed pasture by depressing the vigor of dominant species. This results in colonization by highly competitive and tolerant plant species (Kgosikoma *et al.,* 2013 Sternberg *et al*., 2000).

High intensity, short duration rotational grazing can improve the state and health of the range and also biomass production because when the frequency and duration of grazing and the rest periods are controlled, repeated defoliation of palatable plant species is avoided (Oba *et al*., 2001, Jacobo *et al.,* 2006). Proper utilization increases forage quality by creating environmental conditions that prevent the survival of invasive weed species, while favouring recruitment and survival of palatable forage/browse species. High utilization, especially in continuous grazing systems that are not controlled is highly detrimental to the survival and production of the plants (Steffens *et al.,* 2008, Kinyua *et al*., 2009).

Oba *et al*., (2001) demonstrated that when a range is properly utilized it economically provides quality forage to meet the animal's nutritional requirements, while maintaining forage in a healthy vegetative state. Adler *et al*., (2001) and Fuhlendorf and Engle (2001) observed that when an area is severely utilized to an extend that does not allow regrowth after defoliation, the incidences of undesirable forage species increase at the expense of more palatable forage species.

Herbivore essentially affects the composition and productivity of plants through change of plant nativity, recruitment, and mortality (Adler *et al*., 2005, Bergman *et al.*, 2001) This may cause changes in community structure and function (Fortin *et al.*, 2003). An ecosystem may be relatively stable and resistant to changes produced by grazing, up to a certain threshold beyond which further changes are rapidly being accentuated by stochastic abiotic factors such as rainfall.

The ability of plants to replace tissues lost through herbivory and withstand continued defoliation is a function of the rate at which stored carbohydrates are utilized during the dormant or slow-growing season and subsequently replenished during rapid regrowth period (Adler (2001). This above ground plant growth dynamic is transmitted to the roots. Root growth declines when plant shoots are heavily defoliated because most of the carbohydrate reserves are mobilized and the leaf surface which has the photosynthetic capacity is limited after being grazed upon (Bergman *et al*., 2001, Fuhlendorf and Engle, 2001, Holechek *et al*., 2001).

Therefore, management of plant communities for sustainable livestock production requires seasonal integration of information on plant species composition and production across the expansive and often heterogeneous rangelands. The planning horizon must be clearly identified and well-linked to time and community landscape so as to ensure there is sufficient forage across the seasons. If the structural and functional aspects of grazing ecosystems are to be understood at spatial and temporal scales, appropriate for long-term sustainability, key plant parameters must be known in relation to grazing which includes utilization that this study focused on.

2.4 Effect of grazing on soil chemical properties

It is still not quite clear how grazing which is a key land use activity affects the bio-physical characteristics of the soils which support the plants above them (Trumper *et al.,* 2008). Increased grazing intensity may result in removal of above ground biomass and loss of vegetation cover. This reduces the total leaf area exhibited by plants which results in reduced primary production (Dong *et al.,* 2014). In other words, below ground biomass which contributes the bulk of soil organic matter is also reduced.

Soil erosion, land degradation and conversion of the land to crop lands characterize most rangelands today (Reid *et al.,* 2003). This essentially reduces carbon storage and the trend can only be reversed through proper land use systems which will enhance species diversity and mix, thereby arresting land degradation (Conant *et al.,* 2001, IPCC, 2000, Trumper *et al.,* 2008).

Soil erosion, which occurs due to the loss of ground cover, is the main cause of soil carbon loss (Maraseni *et al*., 2008). Much research work has acknowledged the greatest potential of rangelands to store carbon (IPCC, 2007). Lal, 2001 noted that different land uses have different potential of offsetting atmospheric carbon dioxide emissions through carbon storage in the soils depending on their effects on vegetation cover. Similarly, Debasso *et al.,* (2014) and Pineiro *et al.,* (2010) reported that inappropriate grazing systems eventually reduce plant species composition in the affected area, which reduces the primary production and ultimately reduces the amount of carbon which is stored at any point in time.

One of the roles of soil organic carbon (SOC) is to increase the CEC and water holding capacity of the soil (Mureithi *et al*., 2014). It plays a key role in binding of soil particles into aggregates which improve the structural stability of the soil. It is part of the SOM which holds the nutrient cations and trace elements that are essential for the plant growth (McClaran *et al.,* 2008). In addition, it prevents nutrient leaching and produces an organic acid that promotes the availability of minerals to plants. It also buffers the soil from strong changes in soil PH (Mureithi *et al.,* 2014)

The effect of livestock grazing on biomass production, and soil organic matter which binds soil particles together may have a direct influence on aggregate stability of the soil especially when the grazed area remains bare. Continuous grazing may reduce vegetation cover of the soil resulting in the increased bear ground that significantly affects the stability of soil aggregates. Aggregate stability of soils is their ability to resist any disintegration when external forces are applied to them (Wasonga, 2009). The way the soil particles stick to each other has a direct influence on soil erosion, soil, water movement and the ability of the plant roots to grow in that particular soil (USDA, 1996). Stable aggregates are resilient to any kind of disruption be it from rain drops or movement of water through the soil (Zziwa *et al.,* 2012). When aggregates break down, especially when struck by rain drops or any other external forces, the individual particles are dispersed in the soil and basically seal the soil surface and close the pores (McClaran *et al.,* 2008). The closure of the soil pores through which water and air percolate into the soil makes it difficult for the seedlings to emerge from the soil. The ideal situation is to have large pores between the aggregates and smaller pores within the aggregates (Zziwa *et al*. 2012). The pores that are usually found between the soil aggregates are very important for the entry and exchange of both water and air. The spaces between the aggregates provide channels through which the plant roots interact with the soil.

2.5 Effects of grazing on soil physical properties

The wise use of the land resource requires a basic understanding of soil, water as well as the standing crop. Any volume of soil consists of four parts: mineral matter, organic matter, water, and air (Paul, 2014). The mineral and organic matter components store nutrients required by plants (Neitsch *et al.*, 2011). Changes in land use practices result in changes in soil makeup. The relative amounts of mineral and organic matter determine the physical properties of soil (Donkor *et al.*, 2002). The remaining volume of soil, composed of spaces between the mineral and organic matter, is the pore space**.** The pore spaces are filled with varying amounts of water and air. Livestock grazing may compact the soil, reducing the soil pores and increasing soil bulk density, which is a key determinant of soil compaction and health (Maitima, 2009). It determines infiltration, rooting depth, available water capacity, soil porosity, plant nutrient availability and soil micro-organic activity. High bulk density is an indicator of low soil porosity and compaction (Azarnivand, *et al*. 2010). When soil compaction increases, the bulk density also increases, which reduces biomass production and vegetative cover available to protect the soil from erosion.

Bulk densities of most soils lie between 1.0 g/cm^3 and 2.0 g/cm^3. According to Azarnivand, *et al*., (2010) root penetration is severely constrained by bulk densities higher than 1.6g/cm^3. Soils of low bulk density exhibit high water infiltration rates, which minimize runoff, improve water quality, and reduce storm-water flow. The increased penetration resistance (PR) by compacted soil reduces the penetration the soils by plant roots. Da Silva *et al*., (2003) reported that trampling of soils by animals exerts high pressure which results in soil deformation. According to Donkor *et al*., (2002) compaction of the soil, which is caused by the grazing animals impedes root growth and water infiltration through reduction of soil porosity. Inappropriate grazing systems cause soil compaction, which increases the penetration resistance of the soil. Gomez *et al.,* (2005) reported that spatial variability of BD and PR is highly affected by soil management practices. A proper grazing system should be one that minimizes the penetration resistance of the soil and enhances range productivity. Excessive cattle trampling on the soil increases the soil bulk density and penetration resistance (Stankovicova *et al.*, 2008).

Utilization of rangeland plants by livestock has had concurrent consequences on the soil, especially in terms of moisture retention. Soil moisture is an important soil component and a major determinant of productivity (Chaichi, 2005). Soil moisture holding capacity plays a very significant role in the establishment, growth and development of vegetation cover in the dry-lands. Amiri *et al*., (2008) reported that the reestablishment of range plants and root development is guaranteed when the management practices adopted in the rangelands ensures adequate moisture holding capacity of the soil.

A number of studies have been conducted to determine the impact of grazing on the physical characteristics of soils in the rangelands under different grazing regimes (Kamau, 2004, Tate, 2004, and Igwe, 2005). However, only a few of them have investigated the effects of HGM on these soil attributes. In the northern Kenya rangelands where HGM is being practiced on trial basis, no study has been done to determine the effectiveness of HGM in restoration of soil physical properties.

CHAPTER THREE

3.1 Study area

3.1.1 Location

This study was conducted in Il Motiok and Koija Group Ranches located in Laikipia County (Figure 3.1), situated on the leeward side (rain shadow) of Mt. Kenya. These group ranches are part of the larger Naibunga Conservancy, located in the Mukogodo division of Laikipia North District and comprising seven other group ranches. The Koija group ranch is approximately 7,555 ha, while Il Motiok is 3,650ha

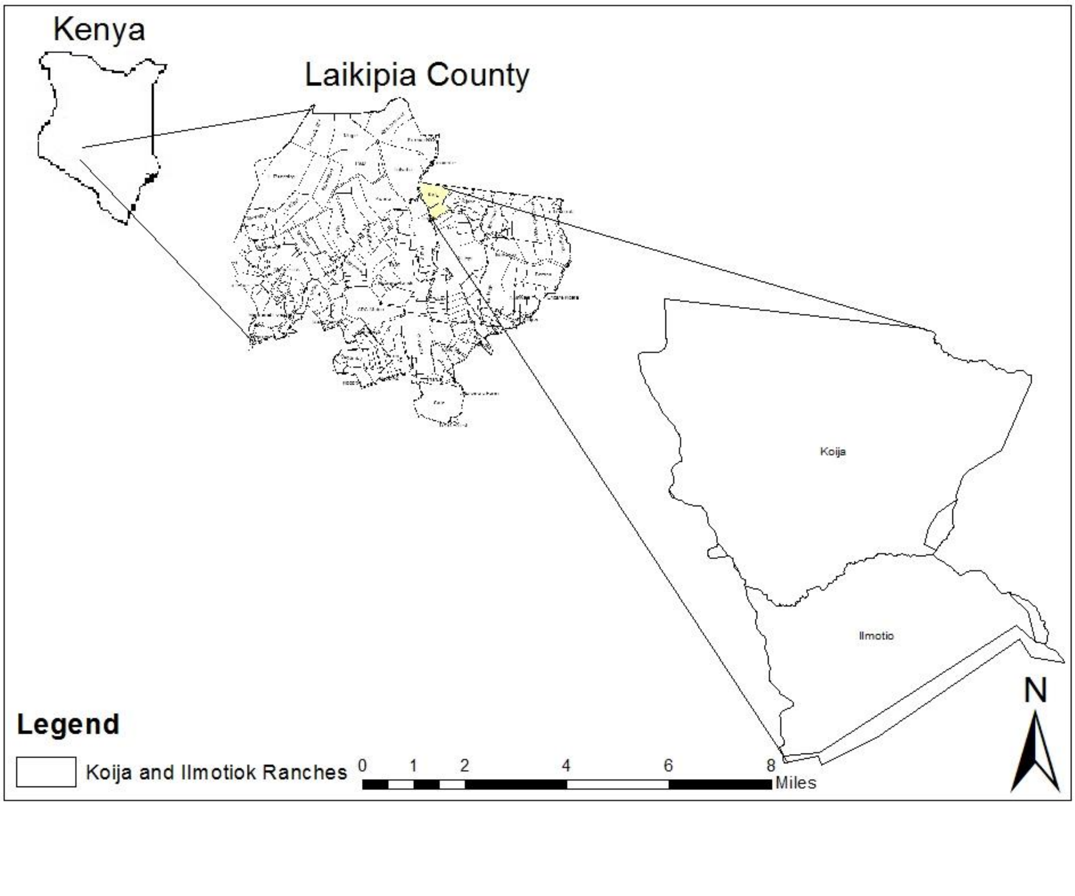


Figure 3. 1: The map of study area (Koija and IImotiok group ranches)

3.1.2 Climate of study area

Laikipia County experiences a cool temparate climate, with mean annual temperatures of between 16°C and 26°C (Georgiadis *et al*., 2007, Heath, 2000). The county receives an average of 400mm and 750mm rainfall annually (Figure 3.2). Rainfall is highly variable both spatially and temporally. The seasonal distribution of rainfall is mainly influenced by the Northeasterly and Southeasterly winds and the Inter –Tropical Convergence Zone (ITCZ). The long rains occur between March and May, short rains in between October and November, and the 'Continental rains' in between July and August.

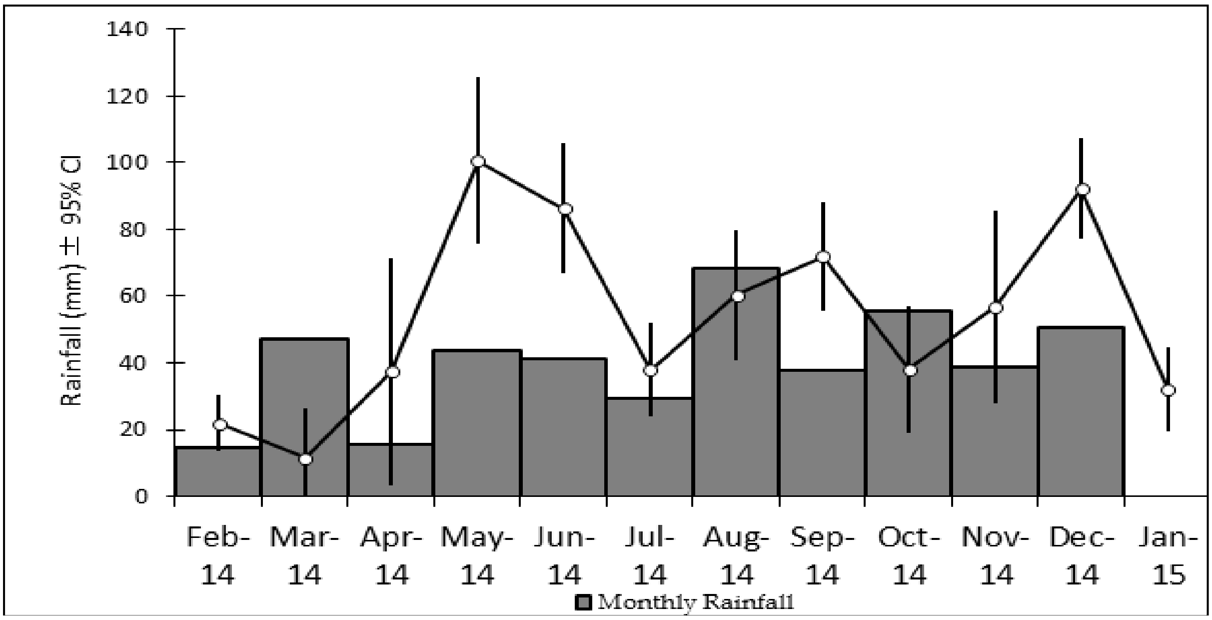


Figure 3. 2: Rainfall data for the year 2014 in the study area

3.1.3 Soils and vegetation

There are two main soil types in Laikipia County, sandy well-drained red soils (oxisols) and poorly drained black cotton soils (vertisols). The oxisols are found on the eastern part of the County, mainly on the steep slopes and areas of high elevation. Vertisols, are characterized by impeding drainage, high clay content and high levels of calcium carbonate, and are mainly found in the western part of the County.

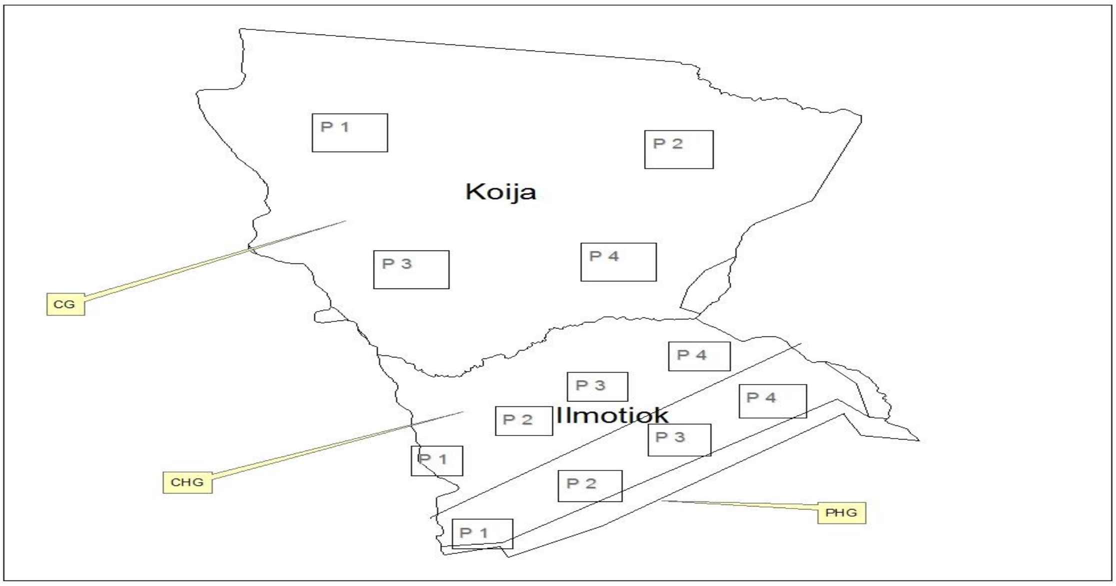
The central and northern parts of Laikipia falls within ecological zone V and VI (Heath, 2000). They are dominated by *Themenda–Pennisetum* grassland and Acacia bush land. Open thickets dominated by *Acacia brevispica* and arid zone Acacia bushlands dominated by *Acacia mellifera* and *Acacia nilotica* are commonly found on the well-drained red soils in zone VI. IL Motiok and Koija group ranches are characteristic of semi-arid African savannas, predominantly grassy savanna bushland with patches of woodland and open grassland. The herbaceous layer of vegetation is dominated by perennial grasses and forbs.

3.1.4 Economic activities

Laikipia County is known for its big open ranches which provide a significant source of beef for local consumption and export (Heath, 2000). The county also benefits from tourism due to the many wildlife conservancies and ranches. Laikipia County hosts some of the largest wildlife population in Kenya (Heath, 2000, Georgiadis *et al.*, 2007). Some of the most common large herbivores include the African elephant, giraffe, Burchell's zebra, Grevy's zebra, impala, Grant's gazelle and Thompson's gazelle (Odadi *et al.*, 2011). Cattle are the dominant livestock species in Laikipia comprise 85% of the total livestock biomass density (Georgiadis *et al.*, 2007*)*.Other livestock species include sheep, goats, camels and donkeys.

3.2 Study design

The experimental design was completely randomized design (CRD) involving three grazing systems: complete holistic grazing (CHG), partial holistic grazing (PHG) and non-holistic grazing (control). Vegetation and soil attributes were measured across three study sites (Figure 3.3). HGM was initiated 2 years prior to the commencement of this study. Complete holistic grazing management differs from the traditional rotational grazing in that, in the latter, animals are not moved on the basis of plant responses, but on the basis of grazing periods set aside for each paddock (Jacobo, 2006, Wolf, 2011). The movement of animals is more flexible depending on the prevailing weather conditions, plant growth or the changing animal needs (Wolf, 2011). Partial holistic grazing is where the movement of animals is only based on the available forage. Animals are bunched together and moved to areas where plants have regenerated, but this does not factor in the prevailing weather conditions as well as the animal's needs as it is in complete holistic grazing. In non-holistic grazing management, animals are grazed on the same piece of land on almost continuous basis with no specific rotation schedule. This grazing system does not give the grazed plants adequate time for recovery resulting in loss of vigor in the defoliated plants, and therefore decline in productivity (Kioko *et al*., 2012, Jacobo, 2006).



CHG- Complete holistic grazing; PHG-Partial holistic grazing; and CG-Non-holistic grazing (Control)

Figure 3. 3: The study layout

3.3 Data collection

Herbaceous vegetation and soil samples were obtained at 10m intervals along two diagonal transects in four 20x20m plots. At every 10m interval, soil sampling points were established and sampling was done during the wet and dry seasons of 2014.

3.3.1 Soil sampling and analyses

Soil samples were collected at 10cm and 20cm depths using a standard soil auger. The soil samples from each plot were then composited by depth into a single sample. Each composite soil sample was then sieved to remove foreign materials like plant roots, stones and organic residues using a 2 mm mesh. The sieved composite soil sample was then divided into two sub-samples. One sub-sample was used for soil carbon/organic matter analysis, while the other was air dried and used to estimate moisture content, pH, CEC, nitrogen, phosphorus and potassium content. These analyses were done at the University of Nairobi Soil Science laboratory.

3.3.2 Determination of aboveground biomass

Sampling of aboveground herbaceous biomass was conducted at the beginning of the wet and dry seasons. Along each of the two diagonal transects, a 0.5m x 0.5m quadrat was placed at 2m intervals and all the standing aboveground plant material within the quadrat clipped to the ground level. The harvested material was then sorted into grasses and forbs and stored in separate sampling bags after which they were oven dried for 24 hours at 80^{o}C to determine the dry matter. The sample dry matter content was then converted to dry matter yield per hectare (Kg/ha). (Jones, *et al.,* 2000)

3.3.3 Estimation of herbaceous biomass yield

At the beginning of the sampling period, a movable cage measuring 1m x 1m x 1m was randomly placed within each plot. Concurrently, a 0.5m x 0.5m quadrat was placed adjacent to the cages, and all the standing biomass inside the quadrat clipped to ground level and placed into separate paper bags. At the end of the sampling period a 0.5m x 0.5m quadrat was randomly placed inside each cage and all the herbaceous vegetation clipped and separated into grasses and forbs. The study area comprised a mosaic of patches of herbaceous plants and bare ground of varying proportions. Because biomass cages were only placed on vegetated patches, the proportion of each plot covered by these patches was estimated in order to ensure more accurate estimation of herbage production across the landscape. To do this, the width of the vegetated patches traversing a given number of line transects at each site was measured to give the percentage of the landscape covered by vegetated patches. This proportion was multiplied by total biomass production to determine the actual amount of herbaceous biomass produced. Herbage production was estimated in kg/ha as:

$$p = c(b - insidet_1) - (b - outsidet_0)$$

Where p is the production during the sampling period, $\boldsymbol{c}$ is the estimated percentage cover of vegetated patches; $b\text{-}inside_{t1}$ is the herbaceous biomass inside the cage at the end of the sampling period and $b\text{-}outside_{t0}$ is the herbaceous biomass outside the cage at the start of the sampling period.

3.3.4 Estimation of herbage utilization

To estimate herbage utilization, a 0.5m x0.5m quadrat was randomly placed within the plots and all herbage within it clipped at ground level. The harvested herbage was sorted into grasses and forbs, after which they were oven dried for 24 hours at 80^{o}C to determine dry matter weight. Percent utilization was estimated as follows:

$$u = \frac{(b - insidet_1) - (b - outsidet_1\,)}{b - insidet_1}\; x100$$

Where: u is percent utilization, $b\text{-}inside_{t1}$ is the herbage biomass inside the cage at the end of the sampling period and $b\text{-}outside_1$ is the herbage biomass outside the cage at the end of the sampling period.

3.3.5 Determination of soil carbon

The Walkley-Black method was used to determine soil organic carbon (Walkley and Black, 1934). A 1.00g soil sample was weighed into a 500 ml flask and A10 ml of 1N potassium dichromate solution and 20ml of sulphuric acid were added and mixed by gentle rotation for one minute. The solution was diluted to 200 ml with deionized water, and 10 ml of phosphoric acid, 0.2g ammonium fluoride, and 10 drops diphenylamine indicator were then added and titrated with 0.5N ferrous ammonium sulphate solution until the colour changed from dull green to a turbid blue.

Carbon density (t/ha) = % Organic carbon X Bulk density X Soil depth

3.3.6 Determination of soil Phosphorus

The standard Mehlich-1 (M1) extraction method (1953) was used to determine P content. Air-dried, ground and sieved soil samples were soaked in 50 ml of Mehlich extracting solution (double acid, containing 0.025N H_2S0_4 and 0.05N HCl). The mixtures were placed on reciprocating shaker and shaken for 30 minutes at room temperature. The mixtures were then filtered. The filtrates were thereafter analyzed for P using blank and standards prepared in the Mehlich extracting solution and the absorbance read on a spectrophotometer at 882 nm wavelength.

3.3.7 Determination of total Nitrogen

The Kjeldahl method described by Kjeldahl, (1883) was used. One (1) g soil sample of approximately 0.5mm average particle size was weighed into a clean digestion tube to which was added 8ml 36N sulphuric acid. Samples were digested and titrated against 0.01N HCl

3.3.8 Determination of Cation Exchange Capacity

The Cation exchange capacity (CEC) was determined using Metson (1961) method. A10 grams of air-dried soil was weighed and ground to less than 2 mm and placed into a 250 ml beaker. About 25 ml of Ammonium acetate was added to the soil and the beaker covered and for 6 hours. A 7 cm Buchner funnel was prepared for each sample by fitting it with a 7 cm Whatman filter paper. 75 ml Ammonium acetate for each sample was measured into a plastic squirt bottle with one bottle for each sample. 10 ml of the Ammonium acetate in the bottle was used to transfer all of the soil to the Buchner funnel. The soil was leached 5 to 7 times with 10 to 15 ml increments of Ammonium acetate. The leachate was transferred to a 250 ml volumetric flask and the solution for Ca, Mg, K, and Na analyzed using atomic absorption spectrophotometry.

3.3.9 Determination of soil aggregate stability

The aggregate stability assessment was based on the principle that unstable soil particles disintegrate more readily than stable aggregates when immersed into water. This parameter was determined using the wet sieving method described by the Natural Resource Conservation Service (NRCS) (USDA, 1996). Eight sieves were filled with 5g of soil which had been passed through a 5.00 mm sieve and a 2.00 mm sieve consecutively

The samples were soaked and allowed to stand for 10 minutes and the shaker switched on for 10 minutes. Unstable aggregates fell apart when soaked in water, passed through the top sieve and collected in the sieve below. The amount of soil retained on each sieve was oven dried at 105^{o}C for 24 hours and weighed. The stability of the aggregates (% SA) was then calculated using the following formula.

$$Aggregate\,Stability\,\%\,\frac{Mass\ after\ dispersion}{Mass\,before\,dispersion + Mass\ after\ dispersion}\times 100$$

3.3.10 Determination of soil bulk density

Bulk density was determined using the core method as described by Okalebo *et al*., (2002). Steel cylinders were used to obtain undisturbed soil samples for bulk density estimation. The samples were then oven-dried and weighed (Okalebo *et al*., 2002).

3.3.11 Determination of penetration resistance

Penetration resistance was determined using a penetrometer. The penetrometer was pushed through the soil profile to two depths (0 to 6" and 6 to 18") to assess surface and subsurface compaction. An even pressure was applied to the penetrometer aimed at exerting penetration pressure of 1.5"/s. The highest pressure reading measured for each of the two depths was recorded.

3.3.12 Determination of soil moisture content

Soil moisture content was estimated using the gravimetric method (Okalebo *et al.,* (2002). It entailed weighing a moist soil sample in the core rings, oven-drying it to a constant weight at 105^{o}C for 48 hours (g water/g oven-dry soil).

$$Gravimetric\ field\ moiture\,content = \frac{Wet\ weight - Oven\,dry\ weight}{Oven\,dry\ weight}$$

3.3.13 Determination of hydraulic conductivity

Hydraulic conductivity was determined using the Constant head method described by (Wessolek *et al.,* 1994). Determination of hydraulic conductivity of saturated soils was based on the direct application of Darcy equation to a column of uniform cross sectional area. A hydraulic head difference was imposed on the soil column and the resulting flux of water measured.

$$Conductivity = \frac{V.L}{A.T.H}$$

V=Volume of water (Q) that flows through the sample of cross sectional area (A) in time T and H is the hydraulic head difference imposed across a sample length

3.3.14 Assessment of water- holding capacity

Water holding capacity was determined by the method described by Batey (1988). Samples of undisturbed soils were obtained from the core rings and soaked in water with a nylon cloth placed at the bottom of the ring, saturated samples were weighed and placed in the pressure cooker with ceramic plates saturated earlier, Pressure units were sealed and pressure adjusted to different pressure levels i.e 0.1, 3.0bar, 5.0, 10.0 and 15.0 bar after 48 hours when equilibrium conditions were attained for each level.

Soil Water Retention (Cm/Cm^3) is thus:

$$\theta = \frac{W_{t(i)} - W_{t(OD)}}{V_t P_w}$$

Where θ = Soil water retention (cm/cm^3)

$W_{t\,(i)}$ = Weight of soil sample at given tension (g)

$W_{t\,(OD)}$ = Oven dry weight of the sample (g)

V_t = Field volume of the soil sample (cm^3)

Pw = Density of water (taken as g/cm^3)

3.5. Statistical analysis

A two-way analysis of variance (ANOVA) was performed to determine if the measured soil and vegetation attributes were significantly different among the grazing regimes. A one-way ANOVA was performed on the herbage biomass yield and utilization data to test whether there was significant difference among the grazing systems. Significant differences for the analysis of variance were accepted at $P < 0.05$. Tukey's HSD post hoc was used to separate means of the measured soil and vegetation attributes under the various grazing treatments.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Aboveground standing biomass

Figure 4.1 represents aboveground standing biomass in holistic and non-holistic grazing sites. Grasses generally had more aboveground biomass (197.4-1193 kg/ha than forbs (66.1-249.5 kg/ha) (Figures 4.1b and 4.1c). Overall, herbaceous standing biomass differed significantly (P = 0.0012, F = 77.376) among the grazing treatments, being highest in the grazing sites under complete holistic grazing (CHG) followed by areas under partial holistic grazing (PHG) and lowest in areas under non-holistic grazing (Control) during both seasons (Figure 4.1a). These patterns were similar to standing grasses (Figure 4.1b), but not for forbs (Figure 4.1c). Total aboveground standing forbs significantly differed between the grazing treatments, being highest (P < 0.05) in CHG followed by PHG (P = 0.01) and lowest in control (P = 0.049) (Figure 4.1c). The interactions between treatment and season were not significant for grass (P = 0.058, F = 1.836) and forbs (P = 0.89 F = 0.20) but was significant for overall aboveground standing biomass (P = 0.02, F = 3.56), with more stubble biomass during the wet than dry season across all treatments.

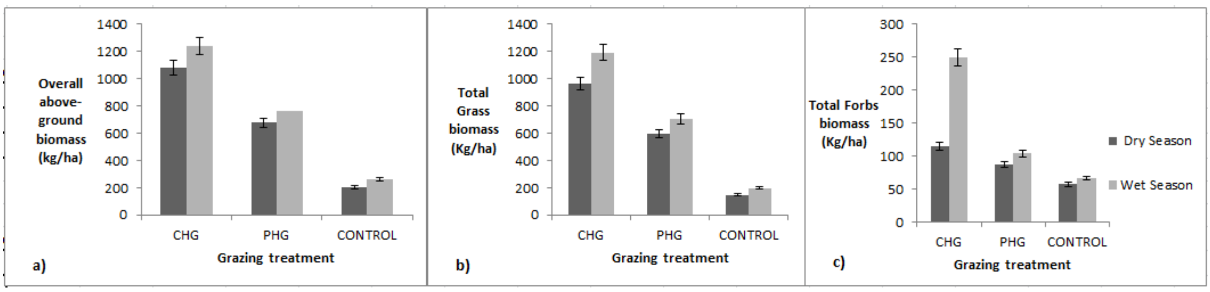


Figure 4. 1: Average aboveground standing biomass (Kg/ha) across grazing treatments

4.1.2 Herbage yield

Amount of biomass produced during the sampling period differed significantly among treatments (P = 0.001, F =15.116), being significantly higher (P < 0.05) in CHG than in the PHG and the Control (Figure 4.2a). Forbs production was higher in CHG than PHG (P = 0.02.) and Control (P = 0.02), but did not differ (P = 0.165) between the control and PHG (Figure 4.2c)

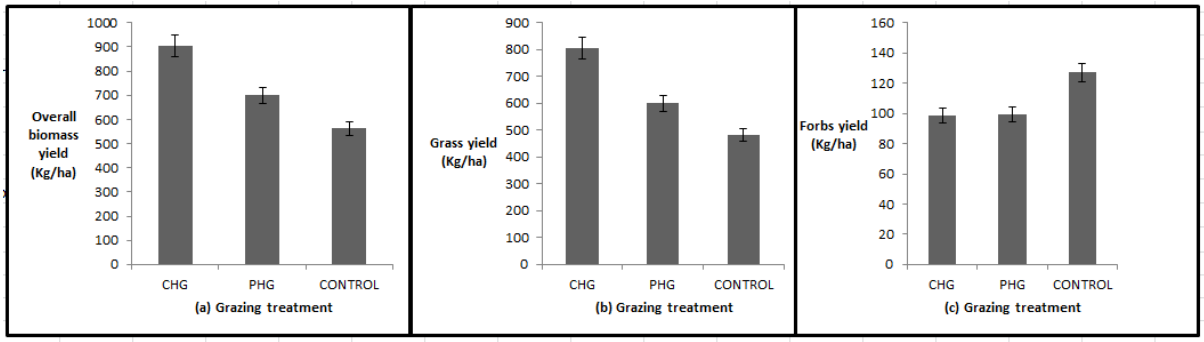


Figure 4. 2: Mean biomass yield (Kg/ha) across grazing treatments

4.1.3 Herbage utilization

Figure 4.3 presents herbage utilization between holistic and non-holistic grazing sites. Herbage utilization differed across grazing management systems being higher (P < 0.05) in non-holistic grazing sites (control) than in each of the treatments CHG and PHG (Figure 4.3a). Overall herbage utilization was higher in PHG than in CHG (P = 0.016). Utilization of grass was lower in CHG than the control (P = 0.013) and PHG (P = 0.045) (Figure 4.3b). Similarly, utilization of forbs was lower in CHG than Control (P = 0.015) and PHG (P = 0.039) (Figure 4.3c)

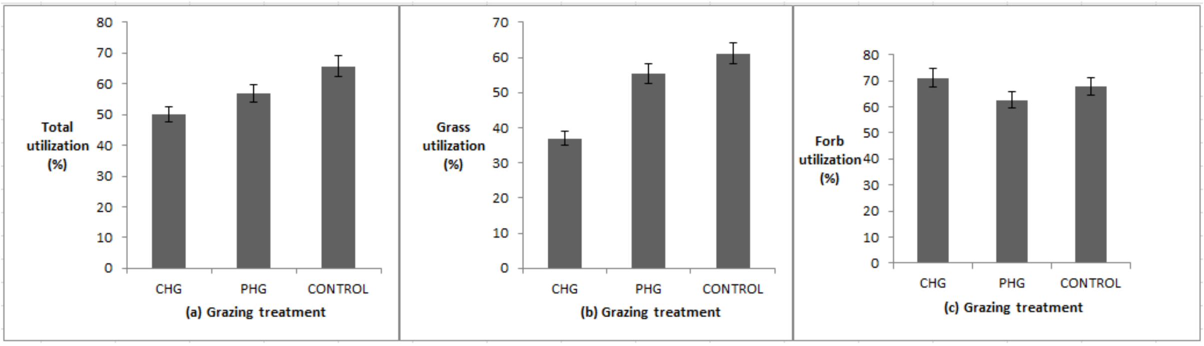


Figure 4. 3: Mean herbage utilization (%) under different grazing treatments

4.1.4 Soil organic carbon and total Nitrogen

Overall, soil organic carbon (SOC) differed (P = 0.006, F = 466.55) across the grazing treatments. Specifically, SOC was higher in holistic grazing sites (CHG) than in non-holistic grazing sites (Control) (Figure 4.5a). However, there was no significant difference in SOC between the wet and dry seasons (P = 0.248, F = 1.397). Also, the interaction effects between the season and treatment were not significant for SOC (P = 0.465). Total soil nitrogen content significantly differed (P = 0.001, F = 218.07) across the treatments, being higher in CHG than control (P = 0.003) and PHG (P = 0.006) (Figure 4.5 b). The interactions between seasons and treatments were not significant (P = 0.610, F = 0.618).

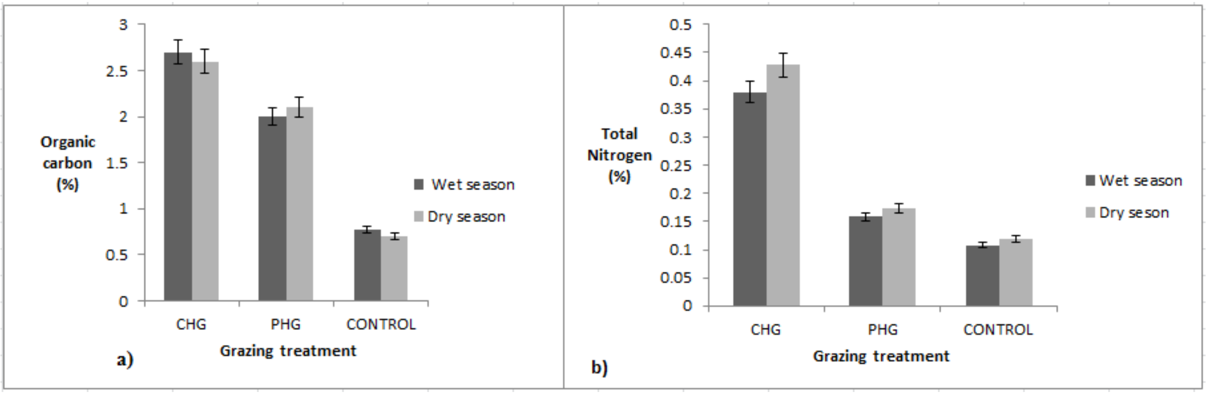


Figure 4. 4: Average soil organic carbon (%) and total nitrogen (%) across grazing treatments

4.1.5 Carbon density

Carbon density was significantly higher in CHG than control (P = 0.004) and PHG (P = 0.002) (Figure 4.6a). However, it was neither significantly different (P = 0.299 F = 1.129) across the seasons, nor across the interactions between the treatments and season (P = 0.563, F = 0.696). It was significantly higher (P = 0.041) in the top soil than the subsoil in CHG (Figure 4.6b).

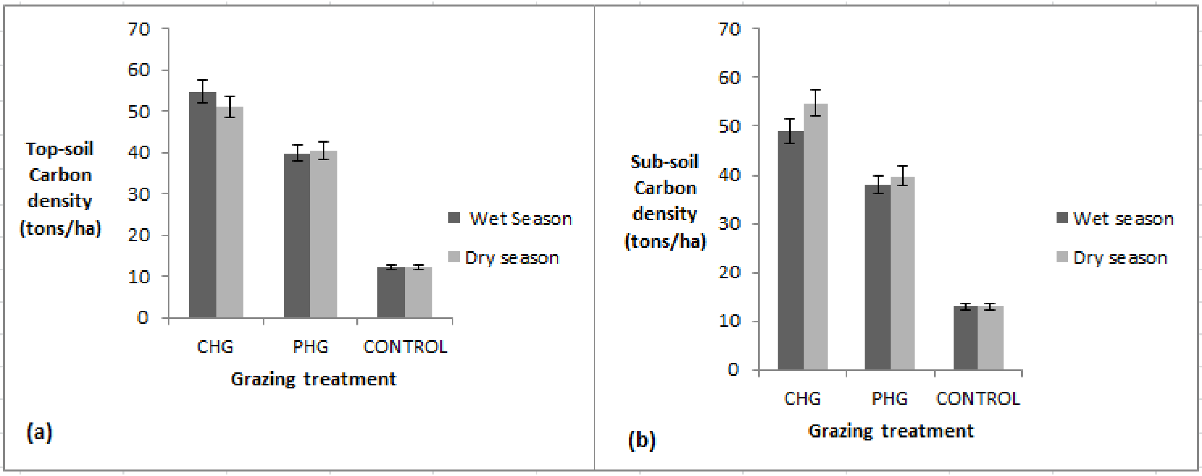


Figure 4. 5: Mean soil carbon density (tons/ha) in various grazing treatments

4.1.6 Soil Phosphorous and Potassium

Table 4.1 presents the means of soil pH and CEC across the grazing treatments while Table 4.2 presents the differences in the means of phosphorous and potassium across the treatments and seasons. Potassium content differed significantly (P = 0.001, F = 57.95) across the treatments (Table 4.2) and was higher in CHG than PHG and control. However, there was no significant difference between the seasons (P = 0.575, F = 0.323) and soil depths (P = 0.065).

Table 4. 1: Average soil pH, and CEC (Cmol/kg) under different grazing treatments

	Wet season				Dry season			
	PH		CEC		PH		CEC	
Depth	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
Complete holistic grazing	6.8^{b}	6.9^{b}	20.1^{c}	18.2^{c}	6.9^{b}	6.9^{b}	20.4^{c}	10.2^{b}
Partial holistic grazing	6.4^{a}	6.3^{a}	15.8^{b}	14.4^{b}	6.4^{a}	6.4^{a}	15.9^{b}	14.7^{a}
Control	5.9^{a}	6.0^{a}	12.7^{a}	11.6^{a}	6.0^{a}	6.03^{a}	13.1^{a}	13.2^{a}
LSD	0.4	0.4	1.3	1.6	0.3	0.4	1.4	1.9
CV%	4.0	4.0	5.1	6.8	3.6	4.0	5.1	7.8

Means with the same letters within the row are not significantly different (P <0.05)

Soil phosphorous content differed significantly across grazing systems (P = 0.001 F = 28.205), being higher in holistic grazing sites (CHG) than in non-holistic grazing sites (Table 4.2) CEC significantly differed between treatments (P = 0.0002, F = 117.72), being highest (20.23 Cmol/kg) in CHG than in Control (12.88 Cmol/kg) (Table 4.1) The effect of seasons were non-significant (P = 0.631, F = 0.237); neither were the interactions between main treatments (P = 0.984, F = 0.053) (Table 4.1).

Table 4.2: Average Soil potassium (Cmol/kg) and phosphorous (mg/kg) under different grazing systems

	Wet Season				Dry Season			
	K		P		K		P	
Depth	0-10	10-20	0-10	10-20	0-10	10-20	0-10	10-20
Complete holistic grazing	1.27^{b}	1.25^{b}	80.25^{b}	78.12^{b}	1.27^{b}	1.28^{b}	85.80^{b}	77.82^{b}
Partial holistic grazing	0.52^{a}	0.46^{a}	58.18^{a}	57.40^{a}	0.55^{a}	0.50^{b}	61.63^{a}	58.42^{a}
Control	0.44^{a}	0.42^{a}	36.63^{a}	36.30^{a}	0.48^{a}	0.41^{ba}	36.78^{a}	34.97^{a}
LSD	0.25	0.25	44.57	40.77	0.25	0.48	44.57	45.65
CV	18.4	19.90	32.00	30.50	18.4	38.00	32.0	33.70

Means with the same letters within the row are not significantly different (P <0.05).

4.1.7 Aggregate stability and hydraulic conductivity

Figure 4.7a presents mean soil aggregate stability between holistic and non-holistic grazing sites. Aggregate stability differed significantly (P = 0.036, F = 17.14) between holistic and non-holistic grazing sites. Whereas percent aggregate stability was found to be significantly higher (P < 0.05) in CHG than in PHG and control, there was no significant difference between PHG and control (P = 0.245). Similarly, interaction between treatment and season was not significant (P = 0.991, F = 0.036). Hydraulic conductivity differed (P = 0.002, F = 166.17) among the treatments with that of CHG being higher than PHG and the control (Figure 4.7b). While there was no significant difference in hydraulic conductivity between the control and PHG (P = 0.810), it was significantly higher (P = 0.02) in CHG than PHG (Figure 4.7b)

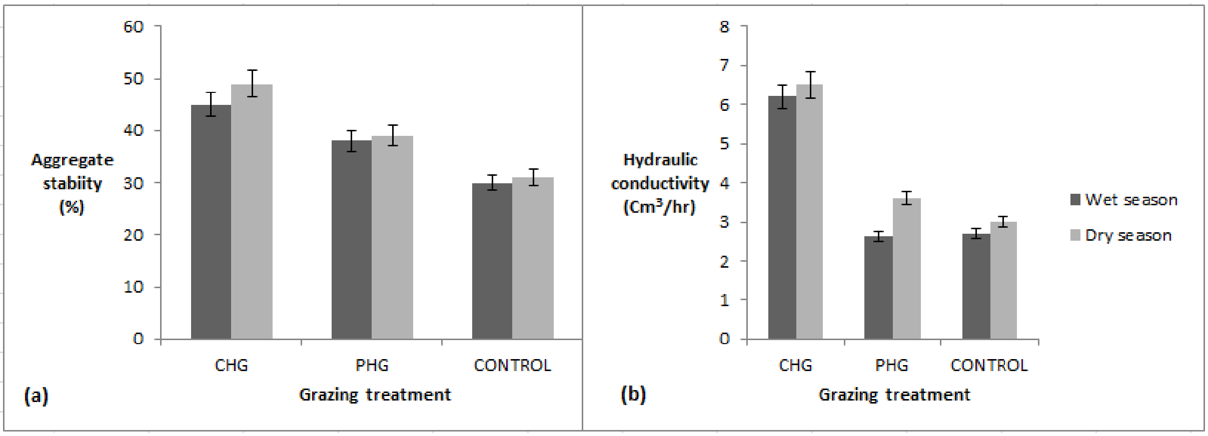


Figure 4. 6: Average aggregate stability (%) and hydraulic conductivity (Cm^3/hr.) during wet and dry seasons

4.1.8 Soil moisture and available water capacity for plant use

The average soil moisture content differed significantly (P = 0.01, F = 19.72) between the grazing systems, being higher (P < 0.05) in CHG than in the control (P = 0.03) and PHG (P = 0.01), but not significantly different between the control and PHG (P = 0.121). The available water content differed across grazing sites (P = 0.03, F = 76.07), being higher (P < 0.05) in

CHG than in control and PHG (Figure 4.8b). There was no significant difference in the amount of available water content ($P = 0.158$, $F = 2.12$) between wet and dry seasons neither was the interaction of treatment and season significant ($P = 0.838$, $F = 0.282$).

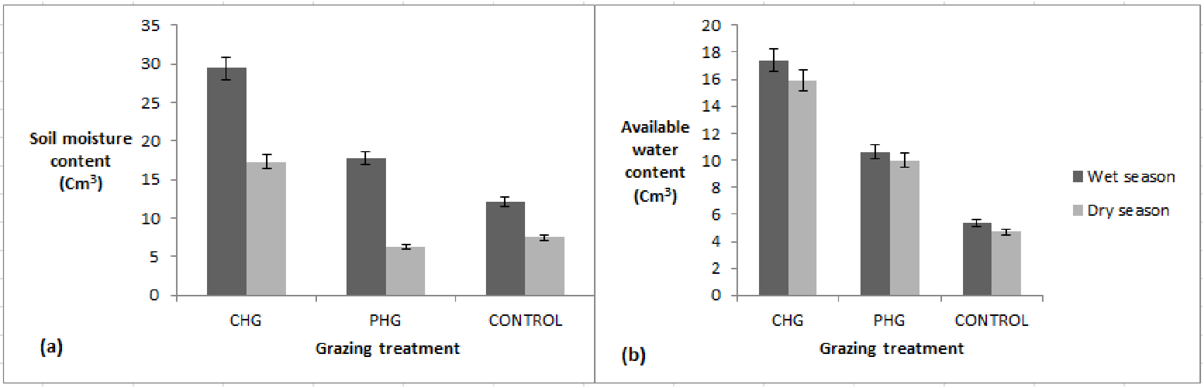


Figure 4. 7: Mean soil moisture (cm^3) and available water content (cm^3) across grazing treatments

4.1.9 Soil bulk density and penetration resistance

Bulk density differed significantly ($P = 0.012$, $F = 79.69$) across the treatments (Figure 4.8a). It was higher ($P < 0.05$) in the control (non-holistic grazing sites) than in CHG and PHG (Figure 4.9a). There was however no significant difference between the season ($P = 0.864$, $F = 0.03$) as well as the interaction between the season and treatment ($P = 0.965$, $F = 0.09$). Penetration resistance differed significantly ($P = 0.023$, $F = 71.9$) across grazing treatments, being lower in CHG than in PHG and the control (Figure 4.8b).

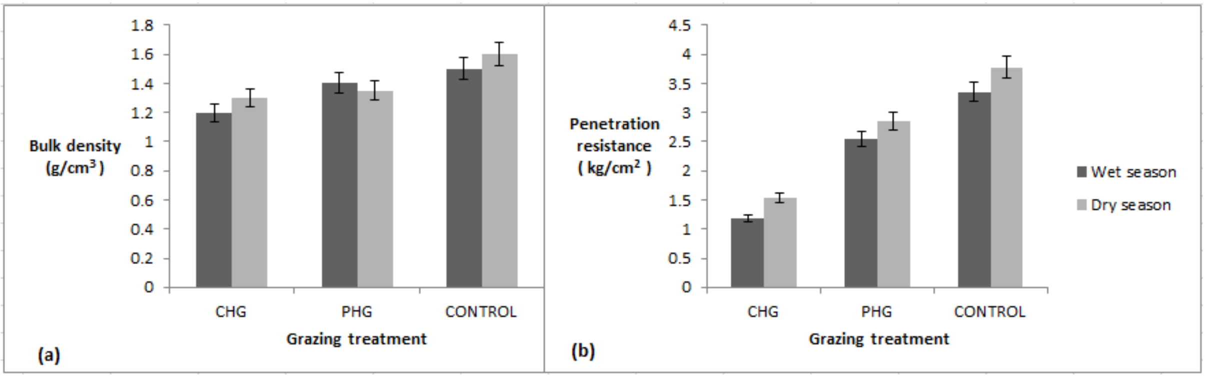


Figure 4. 8: Average Bulk density (g/cm^3) and penetration resistance (kg/cm^2) under different grazing treatments

4.2 Discussions

4.2.1. Effects of holistic grazing on herbaceous production and utilization

The enhanced biomass production in HGM sites could be attributed to higher forage recovery time under holistic grazing management. Under non-holistic grazing management, livestock has unrestricted access to the entire range until forage becomes inadequate to sustain them. This exposes plants to more frequent defoliation, which can be deleterious to plant productivity, especially during the growing season (Kamau, 2004, Kioko, 2012, Lemus, 2011, Matera, 2010).

In addition, by combining both the frequency and intensity of use of forage in the growing season with adequate recovery upon utilization in the holistic grazing sites, forage utilization is likely to be more uniform, leading to increased productivity of palatable forage species (Oba *et al*., 2001). This is in contrast to non-holistic grazing where the range was grazed on continuous basis, thereby resulting in more intense utilization of palatable species. The deterioration of the overgrazed areas is evident in the low production of grasses and forbs and low aboveground standing biomass in non-holistic grazing sites.

Low biomass was produced in non-holistic grazing sites partly because individual plants were subjected to multiple, severe defoliations without sufficient physiological recovery time. High frequency of livestock grazing invariably leads to a decline in the plant's productivity, root biomass and vigour (Kamau, 2004), particularly in species that are less tolerant of high grazing intensities (Metera *et al*., 2010). This in turn results in less recruitment and survival of preferred plants due to competition from non-selected plants (Kioko *et al*., 2012). As a result of low recruitment, percent utilization of the available forage increase (Peco *et al*. 2006) as evident from the results of this study

The observed low aboveground standing crop and biomass yield in non-holistic grazing sites could have negative implications on soil chemical and physical properties, leading to further reduction in herbage productivity. Specifically, low soil organic matter content and low soil fertility is expected which would support less biomass production (Casasus *et al.,* 2007). Ordinarily, the soils are less developed in these areas and shallow, permitting only limited water storage (Thurow, 2005). This then in turn affects the production of more biomass in such areas (Li *et al.,* 2011 and Gao *et al*., 2009), accounting for the observed low aboveground biomass in non-holistic grazing sites. The little amount of biomass produced would be overused due to high grazing pressure as observed in the non-holistic grazing areas in this study.

In a study on the effects of grazing animals on the savannah grasslands in Kenya, Kioko *et al*. (2012) reported that more biomass were produced in areas under high intensity, short duration grazing areas than areas where continuous grazing was practiced. Similarly, Kamau, (2004) while studying the effects of livestock grazing on the composition of vegetation, productivity in rangelands of Mbeere district, Kenya, reported that livestock grazing can influence the composition and structure of the community primarily by modifying the competitive interactions via selective feeding of livestock between plants

These results corroborate those of Gebremeskel (2006) who reported more biomass production under moderate grazing regimes that are well utilized by the grazing animals than areas that had been severely and continuously grazed in the semi-arid lands of Ethiopia. Jacobo *et al.,* (2006) in the study of rotational grazing effects on rangeland vegetation reported that in time-controlled grazing systems, the frequency and duration of grazing and the non-grazing periods allow beneficial plant species to recover from defoliation and gain vigor again for their survival resulting in more biomass produced for use by the grazing animals.

Other studies (Ilan *et al*., 2008; Radford *et al.,* 2008; Steffens *et al*., 2008; Kamau, 2004) have also found that more biomass in well planned grazing systems is as a result of more recovery time allowed for grazed plants after defoliation than in the continuous grazing that is subject to high grazing pressure over a long period of time.

In this study, more aboveground standing biomass in holistic grazing sites promotes soil and water conservation thereby controlling erosion. Soil that has more aboveground standing biomass allows water to penetrate into the cracks of the soil, which are formed by the plant roots, hence permitting more water infiltration and aeration for the soil that are prerequisite conditions for the growth and development of plants (Bilotta *et al.*, 2007).

While studying savanna dynamics in relation to rangeland management systems and environmental conditions in semi-arid rangelands of Botswana, Kgosikoma (2011) observed that the effect of grazing on the ecosystem depends on its intensity, and continuous grazing leads to overutilization of forage resources, which affects the ability of plants to regrow after defoliation hence low aboveground biomass and biomass yield. In their study of the linkages between land use change, land degradation and biodiversity across East Africa, Maitima *et al.* (2009) found that both the type of grazing animals and the grazing intensity of an area have a lot of impact on biodiversity and that the two should be balanced to achieve better results in the production and utilization of available grazing resources. High percent utilization of pasture in the non-holistic grazed areas is an indication of high grazing pressure, which, according to Thurow, (2005) affects vegetation production by removing bunch grasses hence exposing the soil to higher erosion, low water infiltration resulting in minimal moisture and soil fertility. When the plant leaf area is reduced by the grazing animals and given little or no time to recover the absorption of active radiation for photosynthesis is highly affected. This reduces the ability of the plant to convert light energy into chemical energy for production of biomass. Limited conversion of energy affects the functioning, growth and development of the plant (Li *et al.*, 2011). The root system is also greatly affected by high grazing pressure because the energy to support the root biomass and new root production is reduced hence affecting the longevity of the roots as well. When plants are subjected to high grazing pressure, their ability to access the required water and nutrients for their survival is undermined (Holechek *et al*., 2001) leading to low plant biomass as was observed in the non-holistic grazing sites.

The results of a study conducted by Oba *et al*. (2001) on the relationship between biomass and plant species richness in Moyale District, northern Kenya, demonstrated that when a range is properly utilized it economically provides quality forage to meet some if not all of the animal's nutritional requirements during the grazing season, while maintaining the forage in a healthy vegetative state. Both Adler *et al*. (2001) and Fuhlendorf and Engle, (2001) reported that when an area is severely utilized to an extent that it does not allow regrowth after defoliation, the undesirable forage species increase at the expense of more palatable ones. This leads to the decline of carrying capacity of the land, as well as poor animal performance due to lack of nutritious forage for grazing. Studies have shown that herbivores affect the productivity, composition, and stability of plants through mediation of plant natality, recruitment, and mortality (Adler *et al*., 2005, Bergman *et al*., 2001) This may cause directional changes in community structure and function (Fortin *et al*., 2003). A community may be relatively stable and resistant to changes produced by grazing up to a certain threshold beyond which changes become rapid as they are accentuated by stochastic abiotic factors such as rainfall.

The ability of plants to replace tissue lost to herbivores and to tolerate continued defoliation is a function of the rate at which stored reserves are utilized and subsequently replenished during regrowth. Root growth declines when a plant has been severely defoliated because most of the root reserves are mobilized and carbon preferentially allocated because the leaf surface which has the photosynthetic capacity is limited after being grazed upon (Bergman *et al*., 2001, Fuhlendorf and Engle, 2001, Holechek *et al*., 2001, Adler, 2003). Adler (2001) found that a considerable amount of changes in the composition of plants occurs as a result of unsustainable grazing pressure which causes improper use of the range plants.

4.2.2 Effects of Holistic Grazing Management on soil chemical properties

The higher SOC and Nitrogen (N) content in the holistic grazing sites than in non-holistic grazing sites can be attributed to higher aboveground biomass in the former than the latter grazing system. The aboveground standing biomass under holistic grazing sites significantly reduced loss of organic matter and nutrients from the soil-plant system through soil erosion as more vegetation remained after grazing. Consequently, more stubble biomass is expected under holistic grazing sites than non-holistic grazing sites, which means a conversion of the atmospheric carbon through the process of photosynthesis into carbon and nitrogen compounds that are returned to the soil through litter fall and dead plant materials. The observed increases in soil C and N could therefore be attributed to increased belowground biomass under holistic grazing management. Plant root residues are the primary source of soil organic matter (Reeder *et al.* 2004) and therefore increase of below ground biomass may enhance soil organic matter.

Increased carbon concentration can also be attributed to better microclimates in holistic grazing sites that resulted from adequate herbaceous cover which reduced the soil temperatures and subsequent rate of evapotranspiration. The low plant cover as a result of low aboveground standing biomass results in exposed soils, which suffer from increased soil temperatures and evapotranspiration rates that increase the decomposition of organic matter resulting in higher losses of carbon from the soil (Southorn, 2002). High grazing intensities in the non-holistic grazing sites may have stimulated soil mineralization, ammonification and nitrification, which resulted in higher respiration rates and nitrogen oxide emissions. This may have reduced the concentration of Carbon and Nitrogen in the soil (Polley *et al*., 2008)

Continuous grazing in non-holistic grazing site could have exposed the soil to high soil temperatures and low below and aboveground biomass, which may have reduced soil C and N accumulation in the soil (Johnson and Matchett, 2001). Ritchie *et al.* (2012), in a study on soil carbon dynamics, reported that prolonged, heavy continuous grazing in the Northern Rangeland Trust Conservancies depleted most of the soil organic pools, resulting in bare ground and increased soil erosion that reduces productivity of the range. As observed by Jobba´gy and Jackson (2000) and Derner *et al.*(2006) continuous heavy grazing decreases both the aboveground litter deposition and belowground carbon allocation which may be attributed to the low C and N observed in the non-holistic grazing sites. In a six year study conducted by Sanjari *et al.,* (2008) in semi-arid rangelands of South Africa, a relative increase in soil organic matter under time controlled grazing as opposed to under continuous grazing was reported. This was attributed to higher rates of grass growth and rest periods that increased the accumulation of litter. The results also showed that an average of 1.37 ton/ha extra carbon was stored in the top 10 centimeters of the soil under time controlled grazing compared with the continuous grazing. This confirms that adequate rest periods in holistic grazing sites were vital in the recovery of the grazed plants which increased the above ground organic matter and its incorporation to enhance the soil pool.

A study by Reeder and Schuman (2004) showed similar results with areas that were slightly grazed having more soil organic carbon (SOC) than areas that were under heavy grazing. They attributed the increase in SOC to increased rates of nutrient cycling, annual shoot turnover and altered plant species composition. The increased organic matter decomposition may partly explain the low SOC observed under non-holistic grazing in the current study.

Franzluebbers *et al.* (2010) reported increased soil organic carbon in grazing systems that conserved soil and water and controlled soil erosion. This can be said of the HGM which was found to enhance soil aggregate stability and vegetation cover after grazing. In the study of the effects of grazing intensity on soil carbon in Mongolia, Han *et al*. (2008) reported less organic carbon in areas with high grazing intensity than those under low and medium grazing intensities. The results were attributed to high net primary production, which increases below ground biomass allocation of carbon that is more efficient under low and medium intensity grazing than under high intensity grazing.

In contrast to the findings of this study, Ingram *et al*. (2008) reported that areas under continuous heavy grazing had more organic carbon than areas that were lightly stocked. They attributed this result to higher root mass that was found under high grazing areas. A review of different studies on the effect of grazing on soil organic carbon by Pineiro *et al.* (2010) revealed divergent results where grazing increased SOC while in some instances, it was found to reduce or have no influence on SOC. The results of this study show that grazing animals may affect soil organic carbon by altering soil organic matter that affects the nitrogen cycling, net primary production and decomposition which in turn affects the amount of nitrogen and carbon available in the soil.

Different studies have reported divergent results on the effect of clay content on carbon storage in the soil. Conant *et al.* (2001) found that the rates of carbon sequestration were not strongly related to soil texture. Similarly, Silver *et al.* (2010) found clay content to be only weakly positively correlated with C content, while Burke *et al.* (1989) found that silt and clay content increased C content in rangeland soils. There was no relative difference in sand, silt and clay content between areas under holistic grazing and those under non-holistic grazing in this study. Therefore, the difference in the amount of soil organic carbon could not be attributed to texture.

Various studies have shown that grazing increase soil nitrogen content (Frank *et al.* 2004, Han *et al.* 2008) input through faecal matter droppings and changes in plant species composition of grazed communities of plants. In the current study areas under holistic grazing had more soil nitrogen content than the non-holistic grazing sites. As reported by Frank *et al*. (2004) and Han *et al.* (2008) nitrogen losses from the soil occur through processes such as NH_3 volatilization, denitrification and leaching. However, in this study leaching may not have been a problem since water was limiting in all the study sites, and the soil aggregates in holistic grazing sites were found to be stable to permit the loss of N through leaching. NH_3 volatilization which is the loss of nitrogen as free ammonia (NH_3) could have contributed more to loss of N from the study sites.

The high temperatures enhance NH_4^+ dissociation and reduce the solubility of NH_3 in soil water (McGarry *et al.*, 1987) and therefore promotes the conversion of N to NH_3 which is easily lost through volatilization (Frank *et al.*, 2004). Reduced soil cover and aboveground biomass observed under non-holistic grazing may have resulted in increased soil temperature due to direct exposure to solar radiation thereby leading to N losses through volatilization

Whereas grazing is known to increase N loss through NH_3 volatilization, grazing animals can also increase deposition of more urine and dung in grazed fields resulting in increased soil N abundance. The latter is, however, contrary to the findings in non-holistic grazing areas, partly because the rate at which nitrogen was lost from the soil through volatilization could have been higher than the rate of deposition through dung and urine.

Areas under non-holistic grazing had continuous grazing intensity which decreases soil carbon through the loss of photosynthetic tissue that reduces carbon (IV) oxide fixation. This also reduces the production of the below ground biomass and high root litter turnover (Gao *et al.*, 2008). However, proper grazing management may increase carbon and nitrogen storage in the soil through changes induced by grazing in the allocation of belowground carbon and the alteration of root C: N ratio.

In their study on the potential of rangelands in sequestrating carbon, Derner and Schuman (2007) noted that grazing usually increases carbon storage on C_4 dominated grasslands. A high rate of soil organic matter decomposition is partly the reason why areas that are under intense grazing involving excessive trampling have a low SOC and N. These results contradict that of Liebig *et al.*, (2006) who found that the total N in the surface soil of heavily grazed pasture was greater than that of moderately grazed pasture in the great plains of Northern America. The highest concentration of nitrogen in the heavily grazed pastures was attributed to the re-deposition of dung and urine, which increased the concentration of nitrogen. However, this would only apply when the rate at which nitrogen compounds are deposited into the soil exceeds the rate at which it is volatilized from the soil.

The lower K^+ in the areas under continuous grazing in non-holistic grazing sites could be due to soil degradation and losses through erosion as these areas were stripped of vegetation cover due to high grazing pressure. There was also low organic matter in these areas, which could also reduce the amount of soil potassium concentrations in the soil. Organic matter is known to be rich in negatively charged ions that would adsorb more potassium cations in the soil (Evans *et al.,* 2012). The presence of more herbaceous biomass in holistic grazing sites could also be responsible for the pumping of more K^+ from the subsoil to the topsoil hence accounting for the decreasing K^+ with increasing depth.

The low Phosphorous (P) levels in the non-holistic grazing sites can be attributed to high erosive processes that occur in these areas due to lack of vegetation cover. As indicated by Quinton *et al.* (2001) phosphorous is normally lost through erosion as is the case when soil lacks cover. As grass cover decreases due to animal grazing and trampling, erosion of P forms increases.

The concentration of CEC was found to be low in non-holistic grazing treatments, indicating low levels of soil fertility in these areas. Grazing animals usually deposit more organic manure through dung and urine, which are normally a large source of $Ca^{2+,}$ K^+, P, and Mg^{2+} that increase cation exchange capacity of the soil. However, bare soil promotes erosion and exposure of micro-aggregate organic carbon and organic matter to microbial decomposition by changing the moisture and temperature regimes. This reduces the organic matter concentrations in the soil therefore reducing the CEC of the soil (Johnson, 2002). According to Mureithi *et al.,* (2014), soils with high organic matter content have high cation exchange capacity. The high organic matter in holistic grazing sites explains in part the higher cation exchange capacity than was observed in non-holistic grazing sites. Organic matter usually increases the available negative charges in the soil, hence increasing the CEC.

4.2.3 Effects of Holistic Grazing Management on soil physical properties

High aggregate stability in holistic grazing sites could be attributed to high standing biomass in these areas which kept the soil protected against erosion agents. Enhanced soil aggregation could also be as a result of built up organic matter due to high biomass production associated with holistic grazing management (Curran, 2010). Grasses have dense fibrous root systems that increase the organic matter content in the soil and also encourage more microbial activity which binds the soil particles together increasing aggregation (Wasonga, 2009). The increased organic matter in the soil enhances biological activity that, in turn, accelerates the accumulation of cations such as calcium and magnesium (USDA, 2001). These processes are known to enhance the aggregate stability of the soil thereby reducing disintegration into individual particles that may close down the soil pores to cause crusts that impede water infiltration and aeration (USDA, 1996).

The low aggregate stability in non-holistic grazing sites could be associated with low organic matter content as a result of high grazing pressure that may have led to decreased microbial activity, thereby undermining the soil aggregate stability. In addition, low aboveground standing biomass may have also exposed the soils to the direct impact of raindrops and wind that disperse soil particles and reduce the aggregate stability of the soil.

In a study to determine the impacts of livestock grazing on soil physical properties in semi-arid pastoral areas of Otago, Curran (2010) observed that areas which were intensely grazed for a long period of time exhibited lower aggregate stability than moderately grazed areas. In a similar study, Azarnivand (2010) observed that soil aggregate stability decreased as grazing intensity increased in the rangelands of Hosainabad. Wasonga (2009), studying the impacts of land-use on soil physical properties in the Njemps flats, observed that soil aggregate stability may also be affected by the predominant type and amount of clay and the adsorbed cations. The expansion and contraction of clay particles may break the soil aggregates (USDA, 2001). However, both the type and soil texture in the sites of the current study were not significantly different and therefore this could have not contributed to the differences in soil aggregate stability between the treatments.

The low bulk density in holistic grazing sites can be attributed to the minimum livestock impact (Tufour, 2014) and loafing (Wang, 2014) due to short duration grazing that gives maximum rest to the grazed plants. The high soil bulk density in non-holistic grazing sites, on the other hand, is probably a result of soil compaction due to continuous grazing (Wolf, 2011; Curran, 2010).

According to the USDA (2008), long-term solutions to bulk density and soil compaction problems revolve around the reduction of soil disturbances and increasing organic matter content. Igwe (2005) found that areas grazed continuously exhibited higher bulk density than the areas under moderate grazing in southeastern Nigeria. This finding was attributed to consistent animal trampling that increases soil compaction.

In areas under holistic grazing, soil bulk density was below the threshold that limits the growth of roots which permits easy penetration of roots and therefore increased access to nutrients and water by herbaceous plants. As bulk density increases, pore space decreases and the amount of air and water held in the soil also decreases thereby compromising soil fertility and therefore productivity. Soils with low bulk density exhibit higher water infiltration rates than those with high BD. High BD minimizes runoff, improves water quality, and reduces storm-water flow, which reduces water infiltration capacity of the soil and subsequent available water for plant use.

The higher soil penetration resistance values of non-holistic grazing sites than on the holistic grazing sites could be as a result of soil compaction associated with continuous grazing. According to Arevalo (1998) an adult cattle have a static pressure of approximately 1.7 kg/cm^2 in the hoof area, such pressure is significant enough to cause soil compaction. Crush (2011) also found that pressures of 490 kPa can be exerted by a front foot of a 500-kg cow and that this is enough to compact wet soil to a point where the growth of grass root is restricted. This could partly explain why penetration resistance under non-holistic grazing was high due to high soil compaction, which, according to Lemus (2011) reduces soil pore spaces as a result of disintegrated soil particles that cause soil crusts. A highly compacted soil is likely to have high soil bulk densities as well as low gas exchange and air capacity (Da Silva *et al*., 2003). This reduces the infiltration capacity of the soil, leading to poor drainage, increased surface runoff and reduced microbial activity (Crush, 2011; USDA, 2008; Ampe, 2002). Such alteration of soil physical properties leads to poor forage establishment, uneven plant stands, shallow root system and consequently lower biomass production (Kate *et al*., 2004).

Studies have shown similar results with penetration resistance increasing in areas where grazing is continuous and unplanned. In their study on impacts of grazing on penetration resistance of soil on a year-long used pasture by the cattle in a semi-arid rangeland, Stankovicova *et al*., (2008) found that areas with moderate grazing had lower penetration resistance than those under year-long grazing. This was attributed to increased soil compaction caused by more animals trampling following continuous grazing.

While investigating time-dependent changes in the distribution patterns of soil bulk density and penetration resistance in semi-arid rangelands of Palandoken mountain grazing areas, Aksakal (2011) found that all areas under continuous grazing showed significant increase in the penetration resistance. Penetration resistance increases with increase in bulk density; this however, reduces with the increase in soil moisture as noted by Gomez *et al*., (2005). Increase in moisture content is accompanied by a decrease in the solid fraction in the soil, decreasing interlocking and long-range forces between small particles, and the true strength parameters also decrease, especially the cohesion hence reducing the penetration resistance (Aksakal 2011).

Highly compacted soil has low soil moisture content (Azarnivand, 2010; Tufour, 2014; Igwe, 2005) and high penetration resistance, both which result in the low vegetation productivity.

The low soil bulk density observed in the holistic grazing sites ensured adequate water infiltration which is expected to have contributed to more water available for use by the plants than under non-holistic grazing.

The unstable, disintegrated soil particles that break up due to excessive cattle trampling are partly responsible for the reduced soil hydraulic conductivity in the non-holistic grazing sites. Important properties that affect hydraulic conductivity include pore size distribution, pore shape, specific surface, and porosity. When the pore spaces reduce, the amount of water in the soil reduces too, and this means that the little water available in the soil becomes more bound on the soil particle with a high suction force. This makes water unavailable for plant use because of the high suction force required to access the water bound on the compacted soil particles. In the current study, areas under holistic grazing had higher vegetation cover that resulted in high aggregate stability through increased organic matter leading to enhanced hydraulic conductivity. The adjacent areas under non-holistic grazing had a lower vegetation cover and less stable soil aggregates which could have contributed to low soil hydraulic conductivity.

The results of this study are consistent with those of Amiri (2008) who in the study of the effects of livestock grazing on vegetation composition and soil moisture properties in grazed range sites of Isfahan found that soil moisture content declined with increase in grazing pressure. This finding was attributed to high water infiltration rates in the areas with high vegetation cover and more stable soil aggregates.

Previous studies by Igwe (2005) and Zhang *et al*., (2001) have attributed the relatively higher soil moisture to soil organic matter and a little contribution from the clay content. Azarnivand (2010) found that areas under continuous grazing had very low soil moisture content which was attributed to decreased soil porosity as a result of compaction caused by livestock trampling. Livestock grazing intensity decreases vegetation cover of the soil, which consequently lowers water infiltration, hydraulic conductivity as well as water holding capacity of the soil. Various studies on the effect of livestock grazing on soil moisture properties in semi-arid areas by Drewry *et al*. (1999), Mc Dowell *et al*. (2004) and Teague *et al*. (2010) have reported that soil compaction and loss of vegetation through uncontrolled grazing adversely affect soil physical properties by reducing soil porosity, water infiltration as well as hydraulic conductivity.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Despite of both sites having similar ecological conditions, areas under holistic grazing showed better physical and chemical soil properties, and more biomass production than those under non-holistic grazing management. These results show that the success of all grazing systems is constrained by similar ecological variables, and therefore the difference in their performance is as a result of the effectiveness and the efficiency with which the grazing management practices are used rather than ecological variables. Non-holistic grazing sites had high levels of percentage utilization which hampered adequate recovery of grazed plants after defoliation. This resulted in a decreased herbage biomass, which exposed the bare ground to agents of soil erosion. This study has demonstrated that holistic grazing management has the potential to significantly increase above ground biomass, which in turn reduces the loss of both energy and nutrients from the soil-plant system through minimized soil erosion. Adequate stubble biomass under holistic grazing ensures the conversion of atmospheric carbon through the process of photosynthesis, leading to the accumulation of carbon and nitrogen compounds in the soil through litter fall and dead plant materials.

Soil properties and range productivity can be enhanced when grazing animals are bunched to assert maximum impact on soil and pasture for a short duration followed by adequate rest period to allow post-grazing pasture recovery. Improved soil physical and chemical properties in the holistic grazing sites are expected to translate to enhanced productivity and therefore good health of the range. Efforts aimed at restoration and sustainable utilization of rangelands should therefore consider livestock as an integral part of rangeland ecosystems, and therefore their exclusion as an ecological imbalance. This implies that flexibility to allow livestock movement or herd mobility is an indispensable component of sustainable range management in the drylands.

5.2 Recommendations

- Continuous monitoring of the study sites would be helpful in determining the long-term effects of holistic grazing management in communal pastoral rangelands.
- Whereas soil microorganisms play a vital role in determining the organic matter dynamics in the soil, this study did not investigate the effect of soil microorganism on soil properties. Therefore, further research on the effects of HGM on soil microorganisms would help to further reveal the mechanisms underlying the observed enhancement of the measured soil properties under holistic grazing management.

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APPENDICES

Appendix 1: Soil texture under different grazing treatments

	SAND	SILT	CLAY
Complete holistic grazing	71.85^{a}	3.010^{a}	25.17^{a}
Control	78.41^{ab}	4.273^{a}	17.32^{ab}
Partial holistic grazing	80.3^{b}	4.263^{a}	15.41^{b}
LSD	3.331	2.989	5.187
CV%	2.7	43.8	16.4

CHG=Holistic grazing . PHG= Partial holistic grazing. Control. Means with the same letters within the column are not significantly different ($P < 0.05$)

Appendix 2: Relationship between soil texture, bulk density and root growth

	Soil texture		
Bulk density g/cm^3	Clayey	Sandy	Silt
Ideal for plant growth	<1.10	<1.60	<1.40
Restrict root growth	>1.47	>1.80	>1.65

Source: USDA NRCS. 2008

Appendix 3: Analysis of variance of the soil physical attributes under different grazing treatments and seasons

Soil attributes	Source	d.f	V.r	P<0.05
Aggregate stability	Management	3	18.36	0.01*
	Season×Management	3	0.04	0.990
Bulk density	Management	3	131.17	0.01*
	Season×Management	3	0.15	0.930
Penetration resistance	Management	3	71.51	0.01*
	Season×Management	3	1.00	0.411
Hydraulic conductivity	Management	3	163.80	0.01*
	Season×Management	3	0.11	0.951
Soil moisture	Management	3	21.49	0.01*
	Season×Management	3	5.93	0.004*

*** = Significant at P≤0.05**

Appendix 4: Analysis of variance of the soil chemical attributes in different grazing systems and seasons

	SOV	d.f	v.r	P<0.005
%SOC	Management	3	800.02	<0.001*
	Season×Management	3	1.51	0.241
%OM	Management	3	800.02	<0.001*
	Season×Management	3	1.51	0.241
C Density t/ha	Management	3	533.08	<0.001*
	Season×Management	3	1.17	0.344
Ph	Management	3	40.55	<0.001*
	Season×Management	3	0.02	0.995
Cmol/kg K	Management	3	61.53	<0.001*
	Season×Management	3	0.02	0.995
Mg/kg P	Management	3	25.31	<0.001*
	Season×Management	3	0.001	0.999
Cmol/kg CEC	Management	3	111.97	<0.001*
	Season×Management	3	0.05	0.985
%N	Management	3	227.4	<0.001*
	Season×Management	3	0.64	0.595

*** = Significant at P≤0.05**