Effects of Grazing Exclusion on Field Layer Species Composition, Biomass and Selected Soil Properties in Gibe Valley National Park, South-western Ethiopia

Firew Bekele Abebe

Addis Ababa University

Addis Ababa, Ethiopia

June 2017

Effects of Grazing Exclusion on Field Layer Species Composition, Biomass and Selected Soil Properties in Gibe Valley National Park, South-western Ethiopia

Firew Bekele Abebe

A Thesis Submitted to

The Department of Plant Biology and Biodiversity Management

Presented in Partial Fulfillment of the Requirements for the Degree of

Master of Science (Plant Biology and Biodiversity Management)

Addis Ababa University

Addis Ababa, Ethiopia

June 2017

ADDIS ABABA UNIVERSITY
GRADUATE PROGRAMMES

This is to certify that the Thesis prepared by Firew Bekele Abebe, entitled*:* Effects of Grazing Exclusion on Field Layer Species Composition, Biomass and Selected Soil Properties in Gibe Valley National Park, South-western Ethiopia and Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science (Plant Biology and Biodiversity Management) complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Signed by Examining Board:

Name **Signature** **Date**

1. ______________________(Examiner) ____________________ ______________ ____
2. ______________________(Examiner) ____________________ _______________ ___
3. ______________________(Advisor) _____________________ __________________
4. ______________________(Advisor) _____________________ _____________ ____
5. ______________________(Advisor) ______________________ _____________ ____
6. ______________________(Chairman) ____________________ __________________

Abstract

Effects of Grazing Exclusion on Field Layer Species Composition, Biomass and Selected Properties in Gibe Valley National Park, South-western Ethiopia

Firew Bekele Abebe, MSc Thesis

Addis Ababa University, 2017

Grazing of domestic livestock is one of the most common land-uses in Sub-Saharan Africa. In this study, the effects of grazing exclusion on field layer biomass, litter moisture content, field layer species composition, soil bulk density and soil volumetric water content, soil organic matter and soil pH were investigated using six permanent grazing exclosures situated along an altitudinal gradient in Gibe river gorge, South-western Ethiopia. Species composition was tested by Adonis test and an indicator species analysis was done. Nested anovas were used to examine the effect of grazing on all other parameters. The results showed that after 1.5 years of livestock exclusion, there was a difference in field layer species composition ($p=0.022$). The significant indicator species for grazed plots was the common grazing weed Leucas deflexa, whilst the most valuable pasture grass Bothriochloa insculpta was the significant indicator species for plots inside exclosures. Field layer cover, grass cover, number of grass species, field layer maximum and average heights were significantly higher inside exclosures than in grazed plots ($p=0.020$, $p=0.004$, $p=0.008$, $p<0.001$and $p<0.001$ respectively). Area cover of bare soil was significantly higher in grazed plots ($p<0.001$). Exclosures had significantly higher grass biomass and soil volumetric water content ($p=0.025$ and $p=0.017$ respectively) than grazed plots. These large differences between exclosures and grazed plots showed the large effect of grazing exclosures in changing the vegetation, in an area with relatively high grazing pressure. Excluding an area here from grazing for 1.5 years did not significantly change the number of species, leaf and wood litter biomass, moisture content of four fine fuel biomass fractions, soil bulk density, organic matter content and pH of both 0-5 and 5-10 cm soil layers. However, results indicate a slightly higher soil organic matter and pH, and slightly lower soil bulk density in exclosure plots compared to grazed plots. This finding indicates that these are variables which could become significantly altered by the fences if the livestock exclusion was run over a longer time period.

Key words: Altitudinal gradient, Bulk density, Fine fuel biomass, Pasture biodiversity, Soil volumetric water content

Acknowledgments

First of all I would like to thank the almighty God for helping and guiding me. He made things possible to begin and finish this study successfully. And I would like to thank Haromaya University for giving opportunity to attend the Msc program and for financially supporting me. I would like also to thank Addis Ababa University for giving me a chance to study the Msc program and particularly to do this research. I also would like to thank Prof Sileshi Nemomissa, Dr. Tamrat Bekele and Dr. Maria Johansson for providing me the opportunity to carry out this research.

My deepest gratitude extends to my advisors Prof Sileshi Nemomissa, Dr. Maria Johansson and Dr.Tamrat Bekele for their expert guidance and important comments starting from proposal writing.

My special and warm thank goes to Dr. Maria Johansson for her financial support, unreserved guidance and tireless support. This work would have not been completed on time without her support.

My special thanks also goes to Mr. Anteneh Argaw, Mr. Awol Assefa and Mrs Feven Mulugeta for their technical and moral support.

I also would like to thank the Gibe Valley National Park staff and park manager Mr. Seud Ahmed for giving me support during data collection, especially Mr. Birhanu Mabratu (park scout) was helping me until the end of my data collection. I also like to thank Department of Natural Resources Management (Haromaya University) and Department of Plant Biology for allowing me to conduct laboratory works in their respective laboratories.

My gratitude goes to all my classmates for encouraging and helping me to do this research.

I am grateful for all my family members (Mrs. Feven Mulugeta, Mr. Bekele Abebe, Mrs Munete Kebede, Mis. Tsgereda Bekele, Mrs. Etagene Kebede, Mrs.Tsetita Tesefaye, Mrs .Belaynesh Tiruneh and Dagim Bekele), their encouragement was unforgettable. Finally I am sorry if I forgot to thank people, who helped me, please forgive me.

Table of Contents

List of figures

List of tables

List of appendices

List of Acronyms

IIED	International Institute for Environment and Development
CEC	Cation exchange capacity
SOM	Soil organic matter
BD	Soil bulk density
Ca^{2+}	Calcium ion
Mg2+	Magnesium ion
H+	Hydrogen ion
Alt**.**	Altitude
UTM.	Universal Transverse Mercator
pH	Potential of hydrogen
SE	South east
N	North
W	West
E	East
m.a.s.l.	Meters above sea level
CO_2	Carbon di oxide
cm	Centimeter
RH	Relative humidity
°C	Degree Celsius
Km	Kilometre

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

Grazing of domestic livestock is one of the most common land-uses in Sub-Saharan Africa supporting the livelihoods of at least 20 million people in East Africa (IIED, 2017). Grazing and pastoral fire management are the most essential factors affecting grassland ecology. Grazing has substantial effects on many ecosystem processes and functions, such as nutrient pools and nutrient cycling, soil moisture and structure, pasture productivity and species composition (Gao et al., 2007). According to Sternberg et al. (2000) a main mechanism by which grazing affects ecosystem function is through the modification of species composition. Grazers could affect species composition and diversity in different ways, depending on the type of grazing animals, their plant species selectivity, the intensity of grazing and forage plant species (Obeso, 1993; Bardgett and Wardle, 2010). In addition to grazing animals, intensity of grazing and the plant species, the timing of grazing is also important (Humphrey and Patterson, 2000).

Overgrazing by domestic livestock has been cited as an important cause of land degradation in different ecosystems (Perveen et al., 2008; Huang et al., 2007). It is considered as one of the main causes of rangeland degradation through lowering the productivity and resilience of forage species, reduction of vegetation cover, and increase of unpalatable grazing weed species, alteration of soil structure and compactness and decrease of species diversity (Kairis et al., 2015; Belsky and Blumenthal, 1997). The loss of species diversity as a result of excessive grazing occurs through processes such as selective grazing that facilitates the dominance of grazing-tolerant and unpalatable species (Sternberg et al., 2000; Owen-Smith, 1999). The last decade a new view of pasture land ecology has emerged, that savanna rangeland systems cannot be managed by static stocking rates and carrying capacity ideas, because they are non-equilibrium systems due to long-term high variation in precipitation, and feedback loops between vegetation, grazers and soil fauna (Briske et al., 2003; Vetter, 2005). Also there is an increasing new understanding that controlled fire management can prevent bush encroachment and restore pasture productivity in savanna systems (Archibald et al., 2009; Parr et al., 2014; Knowles et al., 2016).

Based on studies of grasslands, an apparent effect of grazing is the removal of above-ground biomass by livestock and subsequently, a significant impact on the rotation of the nutrients and their absorption (Shariff et al., 1994). More than two-thirds of the carbon stored in grasslands is located below ground in soil organic matter pools (Parton et al., 1987; Burke et al., 1989).

Grassland carbon stocks are primarily determined by climatic factors; total carbon increases with precipitation as a result of increased primary production, and decreases with increasing temperature due to increased decomposition rates (Burke et al., 1989). But carbon stocks are also very much influenced by consumers, large grazers remove 20 to 75% of the aboveground net primary production (Hairston, et. al., 1960; Milchunas and Lauenroth, 1993; Oesterheld et al., 1999). By diverting carbon away from the plant detrital pathway, grazing animals may reduce the energy supply to soil decomposers (Cebrian, 1999; Wardle and Bardgett, 2004). Thus, grazing exerts a major influence on grassland carbon cycling, affecting not only transfers between vegetation and soil compartments, but also ecosystem input and output flows.

The mechanical impact of animal hooves on the soil surface can be a disturbance on topsoil structure through the external forces applied by trampling and this mechanical impact changes the form and stability of soil aggregates, which results in changes in bulk density pore size distribution, and soil aggregation, among other properties (Greenwood and McKenzie, 2001; Drewry, 2006).

Grazing can facilitate the establishment of invasive plants by trampling and defoliating established species, thereby reducing their competitive ability and creating bare patches, and by disrupting nutrient cycles (Kimball & Schiffman, 2003; Dorrough, et al., 2004). Due to the selective behavior of the grazers, palatable species can be disfavored and unpalatable species can increase in cover, reducing the quality of the pasture land. Invasions of two types are often causing concern in grassland management; these are the invasion of grasslands by woody species with the consequent loss of the pasture productivity and the invasion of grasslands by alien and typically relatively unpalatable species (Watkinson and Ormerod, 2001).

To reduce woody species, increase production of valuable pasture plants, mainly grass species, and discourage predators and vermin, in savannas all over the world pastoralists have used fire as a management tool for thousands of years. In African savannas it is often impossible to discern between natural and anthropogenic fire regimes and fire is an integrated component of the system with strong interactions with the grazing regime (Archibald et al., 2009). Due to misunderstanding of the role of fire, in many parts of Africa national fire bans starting from the 1970´s have been partially responsible for the bush-encroachment which has reduced productivity of many savannas (O'Connor et al., 2014; Knowles et al., 2016).

1.2 Statement of the problem

The heterogeneous savannah landscape with a dominance of grassland vegetation and a patchy distribution of woody plants is essential for conservation of biodiversity and pasture productivity in such ecosystems (Bond and Midgley, 2000). However the current trend of increase of bush cover is suppressing the productivity of herbaceous plant species and is negatively affecting productivity and biodiversity (O'Connor et al., 2014). Causes suggested for the long-term increase in bush cover in savannas all over Africa has been overgrazing, general bans on traditional fire-management and possibly an increase in atmospheric CO_2 concentrations which can give competitive advantage to the C_3 woody species over the C_4 grass species (O'Connor et al., 2014). Extensive and prolonged overgrazing by cattle, especially in savannas in Ethiopia, can affect the field layer biomass, species composition, soil bulk density, soil volumetric water content, soil organic matter and pH. In addition to the mentioned effects, overgrazing and subsequent reduction or removal of surface fuel is attributing to the reduction in fire intensity which can have an impact on tree survival and the conservation and management of savannah systems.

Although different researchers have studied the effects of grazing in other savannah ecosystems, notably in South Africa and Tanzania, there are very few studies from Ethiopia. The few studies that have been published have mainly studied effects of community exclosures (without fences) on forest regeneration and soils in Tigray (Tefera Mengistu et al., 2005; Wolde Mekuria et al., 2007 and 2013; Tesfay Yayneshet, 2011). There is no published work regarding the effects of grazing exclosure by replicated permanent fences on filed layer biomass, species composition, soil organic matter, soil bulk density and volumetric water content in a savannah system in southern Ethiopia. Therefore, this study was focused on generating clear scientific information on the effects of total livestock exclusion on field layer biomass and species composition, soil organic matter, soil bulk density, soil pH and volumetric water content in Gibe Valley National Park, Ethiopia.

1.3. Objectives

1.3.1 General objective

- ➢ The general objective of this study was to quantify the effect of complete grazing exclusion (using permanent fences) on field layer species composition, biomass, surface fuel moisture content and selected soil properties in Gibe Valley National Park, South- western Ethiopia.

1.3.2 Specific objectives

The specific objectives of this study were:

- ✓ To quantity the effect of grazing exclusion on field layer species composition
- ✓ To quantify the effect of grazing exclusion on surface fuel biomass and surface fuel moisture content.
- ✓ To quantify the effects of grazing exclusion on soil organic matter, pH, Volumetric water content and bulk density.

1.4. Research hypotheses

- ➢ 1.5 years of grazing exclusion affects field layer species composition.
- ➢ 1.5 years of grazing exclusion affects surface fuel biomass and surface litter moisture content.

- 1.5 years of grazing exclusion affects organic matter, pH, bulk density and volumetric water content.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Grassland importance, ecology and management

Rangelands or semi-natural grasslands cover ca 40% of the terrestrial area and support the livelihoods of several hundred million people (Kemp and Michalk, 2007; Neely et al., 2009). Semi-natural grasslands are composed of mainly native grass and herb species and have been managed by non-intensive traditional methods using grazing and fire to maintain their productivity for game and livestock. Fire management has been practiced for thousands of year to prevent bush encroachment and reduce predators and vermin (Butz, 2009). The trees are adapted to the fire regime and large trees normally survive the rather low-intensity anthropogenic fires (Butz, 2009). Commercial fertilizers have traditionally not been used, instead the nitrogen that is lost in exported products has been replaced by leguminous trees and herbs (Belsky, 1994). With increasing population density, settlement and loss of land to agriculture, the traditional nomadic or transhumant pastoralist systems have been disrupted and problems of overgrazing have emerged locally (Kemp and Michalk, 2007). This has been further aggravated by misplaced agricultural policies, such as loss of essential dry season pastures along rivers (Gil-Romera et al., 2011) and the ban on savanna fire management from the 1970´s, which has, in combination with overgrazing, and also possibly the increased atmospheric CO_2 levels, led to bush encroachment and a decrease in pasture productivity (Angassa and Oba, 2008). The last ten years there has been a new understanding of grassland systems as non-equilibrium systems (Vetter, 2005). Because rainfall is highly variable over decades it is not possible to determine pasture carrying capacity and legislate about stocking rates in a static fashion, but a more dynamic management is required to sustain productivity (Briske et al., 2003). Savanna tree cover can range from 10-90% but still functionally belonging to the tropical grassy biome (i.e. savanna) as long as the field layer is dominated by C_4 grasses (Parr et al., 2014). The current political focus on increasing carbon storage can threaten savanna productivity and biodiversity if grazed savannas are interpreted as degraded forests and converted into exclosures for forest restoration excluding fire and grazing (Parr et al., 2014). Grazing exclusion could also initially increase fuel loads and the risk of more high-intensity wildfires.

Savanna systems are highly spatially heterogeneous with scattered trees and patches of tree stands (Bond and Midgley, 2000). The tree canopy height, size and species composition is the major factor influencing everything below it, the microclimate (Belsky, 1994; Holdo & Mack, 2014), shrub- and field layer biomass and species composition, litter quantity and quality (Holdo and Mack, 2014), soil pore size (Ilstedt et al., 2016), soil organic matter and pH (Holdo and Mack, 2014). This tree canopy effect on vegetation and soil is typically larger than the effect of grazing exclusion, so in experiments analyzing grazing exclusion, the tree canopy cover has to be adjusted for or standardized.

2.2. Effects of grazing exclusion on species composition and biodiversity

Herbivory is one of the most important factors influencing the above-ground community composition (Hairston et al.,1960). In many parts of the world, especially in Africa livestock range freely and hence largely influence vegetation composition and forest regeneration (Wei Li et al., 2011). Grazing affects the botanical composition and often the species diversity by depressing the vigour of dominant species, which then enables colonization by less competitive, but grazing tolerant plant species (Tilman, 1994; Sternberg et al., 2000). The trampling and disturbance by livestock creates open patches where new species can germinate and occupy a space in a dense grass lawn according to the theory of the importance of the regeneration niche (Van der Maarel and Sykes , 1993).

Selective grazing of palatable herbaceous plants by livestock enhances the growth of annuals and unpalatable herbaceous plants as well as woody plants (Skarpe, 1992; Rutherford et al., 2012) resulting in the decline of palatable species (Fensham et al., 2010; Owen-Smith, 1999).The decline of palatable species following the increase of woody vegetation can be due to encroaching woody species supressing palatable grasses and herbs (Scholes and Archer, 1997) through competition for light, soil moisture and nutrients.

Several studies have been carried out in several parts of the world to observe the effect of livestock grazing on herbaceous species composition and woody plants. In a study which was carried out in the semi-arid grazing systems in Tigray region of northern Ethiopia, Tesfay Yayneshet (2011) reported that the species composition and diversity of herbaceous and woody plants was higher in the exclosures (16 years) than in the grazed areas. Similarly Stephen M. et al. (2016) found that excluding livestock grazing in the conservation zones for 10 years in a Kenyan Semi-Arid Savannah resulted in higher species diversity as compared with the continuously grazed zones. Findings from studies of Beeskow et al. (1995) in Argentina, and Verdoodt et al. (2009) in Kenya also indicated that plant species diversity was higher in enclosure sites, compared with adjacent grazed rangeland. However, in a four-year range exclosure experiment in semi-arid rangelands in Texas, McGinty et al. (1979) reported that the species diversity of exclosures was similar with adjacent freely grazed lands. I suggest that the contrasting results above may reflect differences in grazing pressures and the fact that in early succession the field layer species may increase in numbers in exclosures compared to hard-grazed controls, but after several years, if the tree canopy closes the shade-intolerant C_4 grass species disappear and is replaced by another forest floor flora with less grass species in the field layer.

According to Skarpe (1991) and Bilotta et al. (2007) severe overgrazing can reduce vegetation cover and increase bare soil patches. Following the exclusion of livestock grazing Mureithi et al. (2016) reported a higher cover of grasses and forbs, total herbage and lower bare ground than continuously grazed plots.

2.3. Effects of grazing exclusion on surface biomass

Grazing is a form of herbivory in which herbaceous plants (grasses and forbs) are consumed by vertebrate herbivores. It is an important process in nearly all biomes and is considered a key factor affecting biomass production and biodiversity in grassland ecosystems (Hairston et al., 1960; Blair et al., 2014).

Many studies have been conducted to observe the effect of grazing on plant biomass using grazing exclosures in many parts of the world. In one study which was carried out in the semi-arid grazing systems in the Tigray region of northern Ethiopia, Tesfay Yayneshet (2011) reported that exclosures yielded more than twice standing herbaceous biomass than that of the adjacent grazed areas. In New Zealand, excluding grazing by sheep and rabbits for 15 years resulted in a two- to three-fold increase in the total biomass (Peter et al., 1996). Also, McIntosh and Allen. (1998) reported that exclusion of grazing (for sixteen years) in the seasonally-dry steep-lands of New Zealand resulted in an approximate doubling of standing above-ground biomass and increased litter biomass.

Another study conducted by Chen et al. (2012) in a semiarid ecosystem in northern China, reported that excluding grazing (by fences) yielded significantly greater standing biomass relative to the grazed land. In agreement with the above findings, studies in Rocky Mountain National Park, Colorado (Singer and Schoenecker, 2003) and in central Argentina (Pucheta et al.,1998) reported decreases (33%) in standing biomass under grazing compared with an area that had been excluded from grazing (for two years).

The increased biomass yield in exclosures as compared with freely grazed areas, is due to the fact that grazing leads to excessive defoliation of herbaceous vegetation, reducing standing biomass (Bilotta et al., 2007) and the trampling pressure (static load) exerted by the animals (Savadogo et al., 2007). Some plants, especially grasses, can overcompensate and produce more biomass if they are grazed a little (Belsky et al., 1993), but if they are continually defoliated the total standing biomass is reduced. Grasses can also as a response to defoliation excrete sugars to soil microbes to increase nutrient mineralization rates to be able to grow faster and compensate for lost leaf biomass (McNaughton et al., 1988).

In addition to the reduced defoliation of herbaceous vegetation and reduced trampling pressure, the improvement in soil properties and nutrients can be a key factor for the enhancement of biomass production in exclosures (Wolde Mekuria et al., 2007). Pandey and Singh (1992) also highlighted that after a period of herbivore exclusion, the quality of the grass and the intensity of grazing determines the change in quantity of the standing aboveground biomass. This beneficial effect of resting the pasture is the reason why in traditional pastoral systems the grazing land was allowed to rest and recover between periods of grazing, and there was cultural practices regulating seasonal timing of burning and grazing (Gil-Romera et al., 2011).

2.4. Effect of grazing exclusion on soil organic matter

Soil is a vital natural resource that is not capable of being renewed on the human time scale (Liu et al., 2006). It plays many key roles in terrestrial ecosystems, for example, as sources of available nutrients to plants. Soil organic matter (SOM) is a major source of nutrients and microbial energy because it contains, and can store, large quantities of plant nutrients which act as a major reservoir of nutrients for plants (Magdoff and Weil, 2004), SOM holds water and nutrients in plant-available form, it usually promotes soil aggregation and root development, and improves water infiltration and water-use efficiency (Allison, 1973). It also influences the pH buffering of surface soils, because it contributes a significant fraction of soil cation exchange capacity (CEC) and causes the dissociation of weak acid functional groups on SOM molecules (Brady and Weil, 1996). Furthermore, SOM is both a source of energy for the soil biota and a product of biologically mediated processes of the soil. It is positively related to the size of the microbial community, which affects food web changes and nutrient cycling (Mulongoy and Merckx, 1993). The organic matter content of soils is therefore a key attribute to both soil health and soil quality. Soil health is defined as the continued capacity of soil to function as a vital living system, within ecosystem and land use boundaries, to sustain biological productivity, promote the quality of air and water environments, and maintain plant, animal and human health (Doran and Safley, 1997). Plant species which have a high content of chemical defense against herbivores, e.g. tannins and phenolic, form a more recalcitrant type of litter and soil carbon when they die, since also the microbes have difficulties in decomposing these substances (Wardle & Bardgett, 2004). Grass species do not have these chemical compounds and grass litter is therefore a very easily decomposed type of litter. In savanna systems the dominance of high-quality grass litter, together with high temperatures make decomposition rates high. Therefore the SOM content of savanna soils is typically rather low compared to other systems.

Grazing exclusion is one of several management practices used to increase the organic matter of the soil by increasing the quantity and quality of the biomass that is returned to the soil (Oesterheld et al., 1999; Su et al., 2005). The findings of Raiesi and Riahi, 2014; Wolde Mekuria and Ermias Aynekulu, 2013 demonstrate that exclosures yield more soil organic carbon content than grazed land. This lowering of soil organic carbon in grazed land as compared with exclosure should be the consequence of the reduced amount of organic materials (litter fall) input and the exposure of micro-aggregate organic matter to microbial decomposition through weaker physical protection of organic matter in the soil (Fantaw Yimer et al., 2015). However, studies conducted by Hafner et al. (2012) and by Young-Zhong et al. (2005) demonstrated a decrease in soil carbon content in exclosures as compared with grazed controls. Another study reported that, grazing exclusion had no effect on soil carbon (Medina-Roldán et al., 2012). The differences in reported results concerning the effect of grazing exclosure on soil organic carbon content may result from the difference in grazing pressure of the controls, the contributions of different grassland ecosystem types (Luan et al., 2014), time lengths of grazing exclusion (Gao et al., 2011), soil heterogeneity (Wolde Mekuria and Ermias Aynekulu, 2013), and different environmental conditions (Raiesi and Riahi, 2014). Also the presence of alternative herbivores like termites or grasshoppers should be important.

Soil organic carbon also shows difference with soil depth. Studies conducted by Fantaw Yimer et al. (2015) and others showed that, soil organic carbon content decreases with soil depth. Similarly, Hiederer (2009) explained the relationship between soil organic carbons with soil depth as depth increases, soil organic carbon decreases in the soil profile. The difference in soil organic matter or the decrease in soil organic carbon with increased soil depth can be explained by the presence of lower accumulation rates of organic matter resulting from lower below-ground root biomass in the sub-surface layer and the distance to the litter addition site at the soil surface.

In heterogeneous savannas with scattered trees, the major source of SOM comes from the litter of tree species with highly recalcitrant litter, therefore there is large variation in SOM, and all other soil properties as well, between under the trees and outside tree canopies (Holdo and Mack, 2014). This effect is probably often larger than the effect of grazing exclusion, so in experiments analyzing grazing exclusion, the tree canopy cover has to be adjusted for, or standardized.

2.5. Effects of grazing exclusion on soil bulk density

Soils are composed of solids (minerals and organic matter), and pores which hold air and water. The bulk density of a soil sample of known volume is the mass (or weight) of that sample divided by the bulk volume. The "ideal" soil would hold sufficient air and water to meet the needs of plants with enough pore space for easy root penetration, while the mineral soil particles would provide physical support and store plant essential nutrients.

Different studies have been carried out on the effects of livestock grazing on soil bulk density (Steffens et al., 2008; Wood et al., 2008) and among those studies many have shown grazing exclusion to be associated with variations in soil compaction or soil bulk density (Greenwood and McKenzie, 2001; Hoshino et al., 2009; Mofidi et al., 2013). According to Blake and Hartage (1986) the most commonly reported measure of soil compaction is soil dry bulk density. In general as the soil surface is compacted, the volume of pore space in the soil's O and A horizon is reduced and its dry bulk density increases. Soil properties such as texture, organic matter, water content and other environmental conditions govern the degree to which compaction occurs (Mapfumo et al., 1999). Livestock grazing has a large effect on soil compaction particularly under high grazing pressure (Fleischer, 1994; Robertson, 1996).

In one study conducted by Gao et al.(2011) soil bulk density (BD) was reported to be lower in grazing exclusion as compared to freely grazed grassland. The studies of Warren et al. (1986); Steffens et al. (2008); Woldeamlak Bewket and Stroosnijder (2003) also demonstrated increases in bulk density in grazing land. The lower bulk density in grazing exclosures compared to grazed is likely due to the elimination of soil trampling by livestock causing compaction (Gao et al., 2011), as well as the increase of root biomass accumulation due to the reduced compaction (Yuan et al., 2012). The higher bulk density in grazed land may also be caused by reduction in soil organic carbon due to the reduced litter input (Fantaw Yimer et al., 2015).

However, as opposed to the above findings, Tate et al. (2004) in a study of Californian sandy loam soils, where grazing was excluded for six and twenty-six years, reported that exclosure had no effect on soil bulk density. Similarly, in their study, Solomon Tefera et al. (2007) and Lu et al. (2015) concluded that grazing found no significant effect on soil bulk density. These dissimilarities in results on the effect of grazing exclosure on soil bulk density is probably due to difference in soil types, because clayey soils are more sensitive to compaction than sandy soils (Tate et al., 2004).

2.6. Effect of grazing exclusion on soil water content

Soil water content is an important environmental indicator for the energy-water balance (Snyman, 1998; Sheppard et al., 2009), soil water balance, and of a soil's ability to regulate the hydrologic cycle. Several studies were conducted to observe the effect of grazing exclosure on soil water content of soil in different parts of the world. Among those studies many have shown the positive effects of grazing exclusion on soil water content, but the changes showed different responses to exclosure duration. After two years of grazing exclusion in a desert steppe in the Alxa region of Inner Mongolia, Pei et al. (2008) reported that topsoil volumetric soil water content increased. In an arid steppe, Qin et al. (2015) similarly reported that fenced desert rangeland had higher soil water content than the grazed controls, which showed that grazing exclusion increased soil water content.

In agreement with the above findings, the finding of Yuqiang et al. (2012) indicate that the exclusion of livestock grazing from severely degraded sandy grassland had a positive effect on soil moisture content compared with continuous grazing.

Less infiltration has been attributed to soil compaction and sealing by animal trampling and reduced litter cover (Naeth et al., 1991). Thus, reductions in soil water in grazed controls compared with grazing exclosures can be caused by increased runoff and decreased infiltration. Livestock reduces grass biomass and often creates patchy vegetation alternating with bare soil. Thus, vegetated patches positively affected soil moisture through less runoff and higher infiltration of rainwater compared to patches of bare soil (Rietkerk et al., 2000).

2.7. Effect of grazing exclusion on soil pH

Livestock grazing can cause disturbances on soils and influence savanna ecosystem productivity and fertility by altering the soil chemical properties such as soil pH (Neff et al., 2005; Liebig et al., 2006). Soil pH is an important soil property that affects the solubility of most elements necessary for plant growth (Al-Seekh et al., 2009) and different studies have been conducted to observe the effect of grazing exclusions on soil pH.

In a study conducted in the southern Maasai land of Kenya, Kioko et al. (2012) reported that soil pH was high in the area excluded from grazing for eight years. The increase in soil pH in exclosures as compared to grazed plots can be due to the effects of organic matter that trap base cations. It can also be due to organic matter accumulation which might reduce soil erosion resulting in higher concentration of soluble base cations (Ca^{2+} and Mg^{2+}) that reduce H^+ responsible for acidity, which in turn increases soil pH in the soil (Fantaw Yimer et al., 2015).

In contrast to the above reports there are other studies which report that grazed lands had higher pH values compared to grazing exclosures (Raiesi and Riahi, 2014; Lu et al., 2015).The increased soil pH in grazed land as compared with exclosures may be because of the addition of livestock urine, which increased soil pH largely due to the hydrolysis of urea (Raiesi and Riahi, 2014). Somda et al. (1997) reported that urine pH of ruminants is about 8.4 to 8.6 in grazed grassland. Therefore, animal urine accumulation may have contributed to increased pH in the grazed compared with the exclosures.

As opposed to increase and decrease in soil pH in exclosures, there are also other studies which concluded that exclosures do not have any effect on soil pH (Moussa et al., 2008; Shan et al., 2011).

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the study area

Gibe Sheleko National Park is the closest national park to Addis Ababa (located ca 174 km southwest of Addis Ababa). It is located in Gurage zone (Figure 1), ca 17 km West of Welkite, where the Jimma road drops down into Gibe River Gorge, and where Wabe River meets Gibe River. It is one of the most recent national parks of Ethiopia, established in 2009 to protect the high biodiversity of the upper Gibe River Gorge. The park is managed by the Southern Nations and Nationalities' Regional State (SNNPR) and is unique due to its high bird species diversity and mosaic of grasslands and woodland ecosystems (Alemneh Amare, 2015).

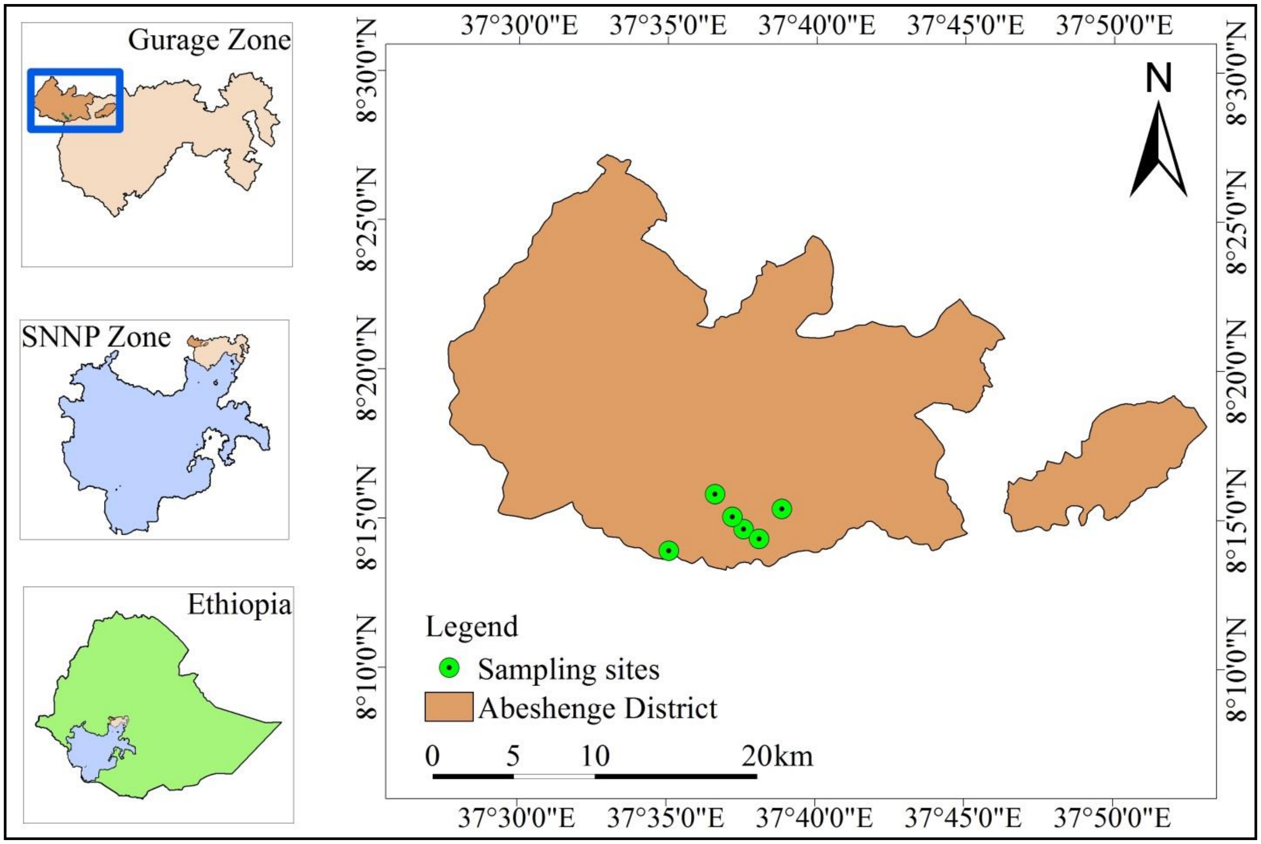


Figure 1 Map of the study area and study sites

The altitude at the park head-quarter, at the edge of the Welkite plateau, is ca 1600m and the bridge across Gibe River (the border to Oromia) is located at ca 1100m.The park covers an area of 360 km^2 (Alemneh Amare, 2015).

3.1.1. Climate

The climate data were acquired from the National Meteorological Agency collected at a former State Farm located at the river at 1110m.a.s.l. between 1976-1992. Gibe Valley National Park has unimodal rain fall pattern (having one rainy season from March to October, even though it is controlled by two different weather systems; the short *"Belg"* rains created by a south-eastern monsoon from the Indian Ocean during March, and the long *"Kiremt"* rains created by the ITCZ during June-October. Its total rain fall and mean annual temperature are 921 mm and 25 °C, respectively.

The mean maximum temperature and mean minimum temperature of Gibe Valley National Park are 36.5 °C and 12.4 °C, respectively (Figure 2). The dry season hot months are December, January and February and the cooler months are June, July and August.

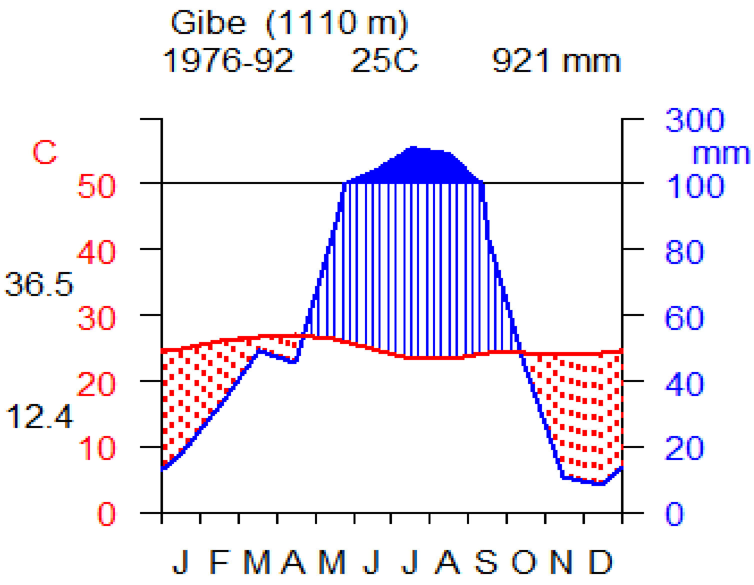


Figure 2 Climate diagram of the study area

3.1.2. Vegetation

The vegetation is dominated by deciduous fire-managed savannah woodlands, but with denser evergreen forests along gully streams and the tall riverine forests along the rivers .In the savannah woodlands, flatter ground with deeper soil is dominated mainly by trees like *Acacia polyacantha*, *Acacia seyal*, *Acacia etbaica* and *Cussonia holstii*. Steeper stony slopes are dominated by *Combretum molle*, *Combretum collinum* and different *Acacia* species (Appendix. 3). Typical grass species are *Hyparrhenia dregeana*, *Hyparrhenia filipendula* and *Bothriochloa insculpta*.

3.1.3. Peoples and livelihoods

The principal Ethnic groups around the park are the Gurage, Oromo, Kebeana and Mareko . There are also Yem people to the southern side of the National park. Amhara people have been resettled along the road and near the bridge in the 1970´s and 1980´s.

These people are economically depends on agriculture and animal husbandry (Figure 3) that combines the cultivation of Enset, different root crops and cereals cultivation. Agriculture has been practised mainly on the plateau and livestock grazing mainly in the river gorge. Traditional fire management has been practised in the river gorge to imrove pasture and reduce the infestation of Tse-Tse flies which cause sleeping sickness (Trypanosomiasis) in the livestock. The first time Tse-Tse arrived to this part of Gibe river gorge was sometime between 1979 and 1983 causing mass-mortality of the livestock (Reid et al., 2000). After the epidemic there were large-scale fires in the river gorge according to interviews done in the study area (Maria Johansson, personal communication). Both Oromo and Gurage used to have many more cows per family before the Tse-Tse arrived. Today the Gurage have adapted to a more horticultural lifestyle with only few cows, while the Oromo still aim to have many cows. Despite Tse-Tse eradication programmes, farmers have to buy medicine to treat the livestock and both groups lost many cows and oxen last year due to Trypanosomiasis.

Figure 3 Economically important crops, berbere and sorghum, and animal husbandry.
Photo by Firew Bekele, November 2016.

3.1.4. Wildlife

Wild life in the park includes greater kudu, Menelik’s bushbuck, Bohor reedbuck, leopard, spotted hyena, olive baboon, Colobus monkey, warthog, bush pig, hippo, Nile crocodile, 7m long python snakes and more than 250 species of birds (Alemneh Amare, 2015).

3.2. Experimental Design

The experiment was conducted using six existing permanent livestock grazing exclosures (table 1) in the river gorge (along the altitudinal gradient, from the river to just below the plateau edge) each with size of 30 m x 30m, constructed in August 2015, by using 180 cm tall mesh wire, in different types of savanna vegetation to measure the effects of grazing (Figure 4). Plots of the same size established next to each exclosures were used as control plots for this experiment on field layer plant species composition, surface fuel biomass and selected soil properties.

Table 1.Altitude, slope and UTM position of experimental and control sites

Site	Name	Treatment	Alt. (m)	Coordinate (UTM)	Coordinate (UTM)	Slope
1	Italian bridge	Fenced	1123	N 8° 13.936'	E 37° 35.070'	5%
		Control	1122	N8° 13.922'	E37° 35.062'	4%
2	Road	Fenced	1289	N 8° 15.352'	E 37° 34.866'	0.5%
		Control	1288	N 8° 15.349'	E 37° 34.848'	1%
3	Campsite	Fenced	1450	N 8° 15.833'	E 37° 36.622'	0%
		Control	1450	N 8° 15.835'	E 37° 36.640'	0%
4	Above farm	Fenced	1550	N 8° 14.667'	E 37° 37.585'	4%
		Control	1550	N 8° 14.671'	E 37° 37.603'	4%
5	Headquarter	Fenced	1520	N 8° 15.076'	E 37° 37.208'	2%
		Control	1520	N 8° 15.095'	E 37° 37.204'	3%
6.	Agemsa	Fenced	1558	N 8° 14.347'	E 37° 38.110'	3%
		Control	1559	N 8° 14.314'	E 37° 38.096'	4%

3.3. Data Collection Methods

3.3.1. Field layer species composition

Plant specimens were collected for all field layer species for identification at the National Herbarium of Ethiopia, Addis Ababa University. Species relative area covers were visually estimated, and heights were measured using a measure stick, inside/outside the exclosures using 1m x 1m vegetation quadrats (n=8) placed along four line transects (placed along the contour lines) (two quadrats per transect), one on each half of the plot (situated on 7 - 8 m and 22 -23 m respectively on a 30m long measure tape). A total of 96 vegetation quadrats were sampled. In order to maintain consistency, the visually estimation of plant area cover was done by the same person, as well as all other sampling of biomass and soil. To establish baseline data for this experiment tree and shrub canopy covers were recorded by the line transect method (Bauer, 1943) in the same line transects (Appendix 4).

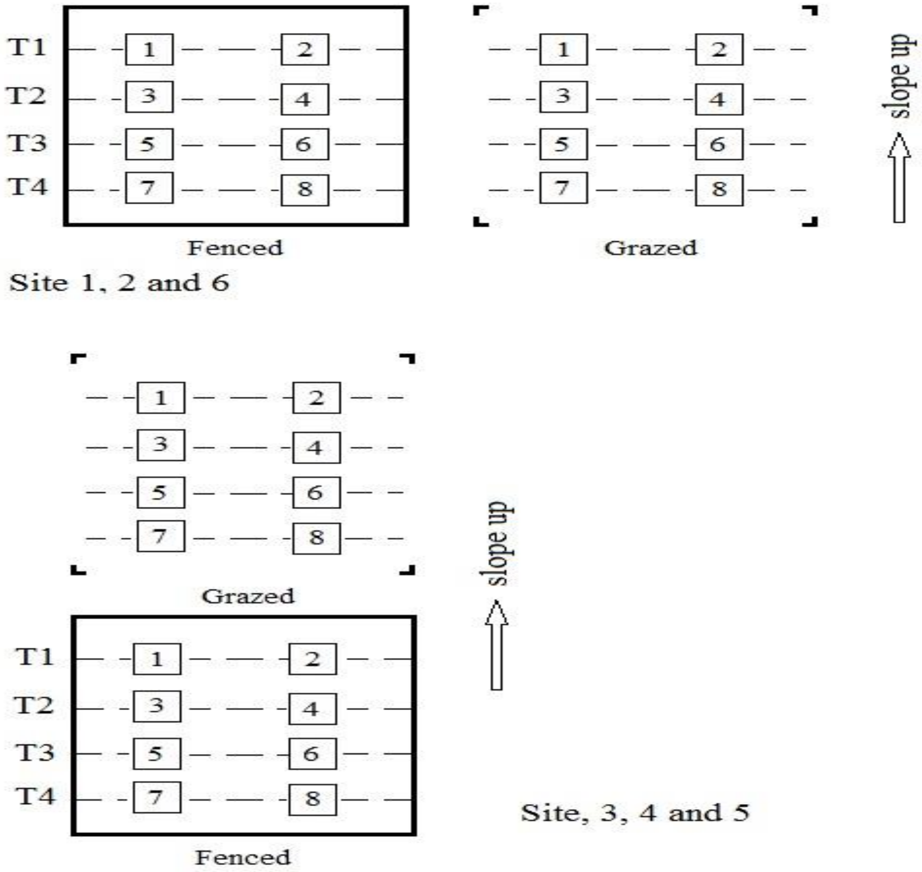


Figure 4 Spatial arrangement of exclosures in relation to control plots and vegetation transects and quadrat placements.

3.3.1.1. Voucher specimens identification

Identification of voucher specimens collected from the study areas was conducted at the National Herbarium of Ethiopia, Addis Ababa University using taxonomic keys in the Flora of Ethiopia and Eritrea and by comparison with herbarium specimens. Further confirmation of the accuracy of the identification was made with the assistance of taxonomic experts. Finally, the identified specimens were stored at National Herbarium of Ethiopia, Addis Ababa University for further educational and research purposes. The Nomenclature of species follows the Flora of Ethiopia and Eritrea.

3.3.2. Field Layer Biomass

Field layer and litter biomass (=surface fuel biomass) was measured by clipping and collecting the entire above-ground portions in a fixed area (1m x 1 m quadrats) of the: **1.** Field layer, **2.** Leaf litter, **3.** Wood litter and **4.** Fine litter, which were collected in different marked bags. Then all 4 different harvested biomass fractions were separately weighted on a field scale (accuracy 0.1 g, Figure 5) (total harvested fresh weights) per subplot (5 subplots per treatment and site). Then, to reduce transport volume, only small subsamples of all fractions were transported to the lab for weighing and calculating moisture content. In the lab all the four biomass fractions were dried in an oven in 48 degree Celsius until constant weight, and the dry weight was measured by using the same field scale. Finally moisture content (MC %). and total dry weight (DW) were calculated by the following equations. A total of 50 (5 quadrats per exclosure /control) quadrats were used to measure the effects of grazing on field layer biomass and litter moisture content.

Total dry weight in the field (TDW) was calculated afterwards, using the FW and MC. (using these 2 equations (Daly et al., 2000):

$$MC\ (\%) = (FW-DW)/DW * 100$$

$$TDW = FW / (1 + MC/100)$$

Where, MC=Moisture content

FW=Fresh weight of subsample transported to the lab

DW=dry weight of the sub sample

Figure 5 Sampling of field layer (or, surface fuel) biomass.
Photo by Berhanu Mabratu, December 2016.

3.3.3. Soil Organic Matter Determination

To quantify the effect of grazing exclusion on the organic matter content of the soil, soil samples were collected (soil samples collected after litter harvest) from the same plots in which the four fraction of biomass harvested (from 5 quadrats in fence and 5 in grazed). Soil auger was drilled from center of the quadrat (Figure 6) and 2 layers of soil were collected in each quadrat starting from the top of the soil surface (the 0-5 cm layer and the 5-10 cm layer from the same drill hole) and placed in separate plastic bags marked with quadrat ID and soil layer (0-5 or 5-10cm). In total 100 soil samples (5 x 2 soil layers x 2 treatments x 5 sites) were transported for soil organic matter analysis to Haromaya University soil laboratory. In the soil laboratory, the soil samples for chemical analyses were air dried and crushed before passing through a 2 mm mesh sieve. Then the Walkley and Black’s Titration method (Walkley and Black, 1933) was used to determine soil organic carbon. Then, the percentage of SOM was calculated by multiplying the soil organic carbon with 1.724, the Van Bemmelen factor (Tan, 2005).Soil organic carbon and organic matter were calculated using the following equations.

$$\%C = N \times \frac{V1 - V2}{S} \times 0.39 \times mcf$$

Where:-

N = Normality of ferrous sulfate solution (from blank titration)

$$\frac{(N\ K_2Cr_2O_7 \times V\ K_2Cr_2O_7)}{VFeSO_4}$$

V1 = ml ferrous sulfate solution used for blank

V2 = ml ferrous sulfate solution used for sample

S = weight of air-dry sample in gram

mcf = moisture correction factor.

% Organic matter = 1.724 x % Carbon

Figure 6 Soil sampling for organic matter and pH analysis.
Photo by Firew Bekele, December 2016.

3.3.4. Soil bulk density

Soil bulk density (gcm^{-3}) was determined via the core method (Blake and Hartage, 1986; Chen et al., 2010) using 2.5 cm x 5cm cylindrical metal core (Figure 7). Soil samples were collected from the same plots in which field layer biomass and soil organic matter were collected. All litter at each exclosures and control collection point had been clipped to the mineral soil surface and removed prior to collection of the soil core. A total of 50 cores (5 x 2 treatments x 5 sites) were collected for determination of soil bulk density and transported to Addis Ababa University Plant Biology and Biodiversity Management laboratory. In the laboratory soil samples were dried at 105 degree Celsius in an oven for 24 hours using aluminum foil and the mass of the soil after drying was determined by weighing on a balance with an accuracy of 0.1g. Finally soil bulk density (BD) was calculated as the mass of oven-dried soil (105 °C) divided by its volume (Chen et al., 2010) using the following formula.

$$\rho s = Ms/Vb$$

Where:

ρs = soil bulk density (g/cm^3)

Ms = mass of soil after oven dry (g)

Vb = bulk volume of the soil (cm^3)

3.3.5. Volumetric soil moisture content (SMC, %)

The volumetric soil moisture content (SMC, %) was determined following the method described by Cuenca (1989). Before the soil was oven dried, the initial weights were measured by using afield scale with an accuracy of 0.1 g, followed by oven drying for 24 h at 105 °C, and weighing the oven-dried soil. The volumetric soil moisture content was determined using the following formula.

$$MC (\%) = (Wwet - Wdry) / Wdry \times 100$$

Where:

MC = soil water content on mass basis (%)

Wwet = the weight of the wet soil sample (g)

Wdry = the weight of the dried soil sample (g).

Figure 7 Soil sampling using core sampler for soil bulk density and soil water content measurement.
Photo by Berhanu Mabratu and Firew Bekele, December 2016.

3.3.6. Soil pH

The soil pH was measured potentiometrically with a digital pH meter (for two separate soil layers; 0-5cm and 5-10 cm) in the supernatant suspension of 1: 2.5, soil: water suspension (Carter, 1993) from the same quadrats in which soil samples for organic matter measurement were taken. A total of 100 soil samples (2 treatments x 5 quadrats x 2 soil layers x 5 sites) were measured using soil pH meter.

3.4. Data analysis

A nested analysis of variance, using the *nlme* package in R (Jose et al., 2011). were treatment was nested within site, was used to examine the effect of grazing on field layer species composition, field layer biomass and plant moisture content, soil organic matter and soil pH, soil bulk density and soil volumetric water content. One- way analysis of variance was used to examine the variation in soil organic matter and soil pH in relation to soil depth. Species composition was tested by Adonis in the vegan package in R (Oksanen, 2013). An indicator species analysis was done using the *indval* function in the *labdsv* package (Roberts, 2015). All analyses were made in R (R Core Team, 2014).

CHAPTER FOUR

4. RESULTS

4.1. Effect of grazing exclusion on field layer plant species composition and plant height

Significant difference in plant field layer cover (Figure 9A), grass cover (Figure 9B), proportion of bare soil/m² (Figure 9C), number of grass species (Figure 10B) and species composition was observed (p=0.020, p=0.004, p<0.001, p=0.0082 and p=0.022, respectively) between fenced plots and grazed plots. However, number of species/m² between fenced plots and grazed plots was not significantly different (Figure 10A, table 3).

The large difference in field layer maximum (Figure.10C; Figure 8) and average heights (Figure 10D; Figure 8) between fenced plots and grazed plots was significant (p<0.001, and p<0.001, respectively, table 2).

Table 2. Nested anova results for differences in field layer cover and height between grazed and fenced plots.

		log bare soil cover		log field layer cover		grass cover		log field layer max height		log field layer av. height	
	DF	*t*	P	*t*	P	*t*	p	*t*	p	*t*	p
Treatment	1	**7.02**	**<0.001**	**-3.37**	**0.020**	**-5.13**	**0.004**	**-8.63**	**<0.001**	**-8.72**	**<0.001**
Site	5										

Significant results in bold text (significant at p<0.05). Number of observations = 96, DF = degrees of freedom, some values were logged to ensure equal variance.

Figure 8 The effect of livestock exclusion on field layer height, which was in average 91 cm inside the fence and 35 cm outside the fence in the 1550 m plots.
Photo by Firew Bekele November 2016.

The indicator species for fenced plots were *Bothriochloa insculpta* (significant), *Heteropogon contortus*, *Sorghum arundinaceum* and *Justicia heterocarpa* and the indicator species for grazed plots were *Leucas deflexa* (significant) and *Ageratum conyzoides* (Appendix 2). A total of 42 field layer species were identified during the study. The number of herb, grass, tree, shrub and climber were 18, 13, 5, 4 and 2, respectively. Out of 10 plant families identified during filed layer species study, Poaceae had the highest number of species (13), the second was Fabaceae with nine species and the third was Acanthaceae with 6 species (Appendix 1).

Table 3. Nested anova results for differences in species richness between grazed and fenced plots.

		no. of species		no. of grass species	
	DF	*t*	p	*t*	p
Treatment	1	0.00	1.000	**-4.24**	**0.008**
Site	5				

Significant results in bold text (significant at p< 0.05). Number of observations = 96, DF = degrees of freedom.

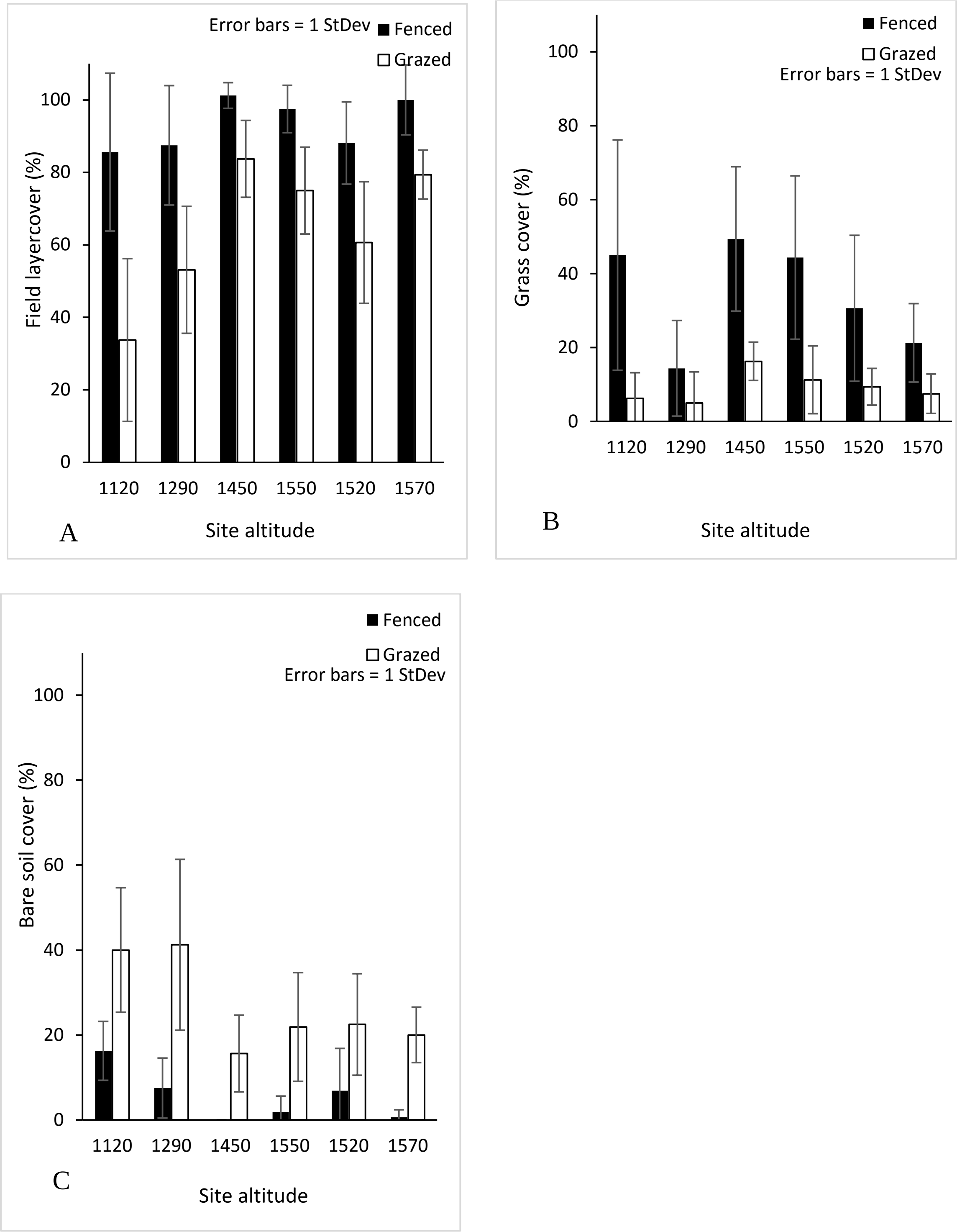


Figure 9 Area cover of A) field layer, B) grass and C) bare soil in fenced and grazed plots (n=8).

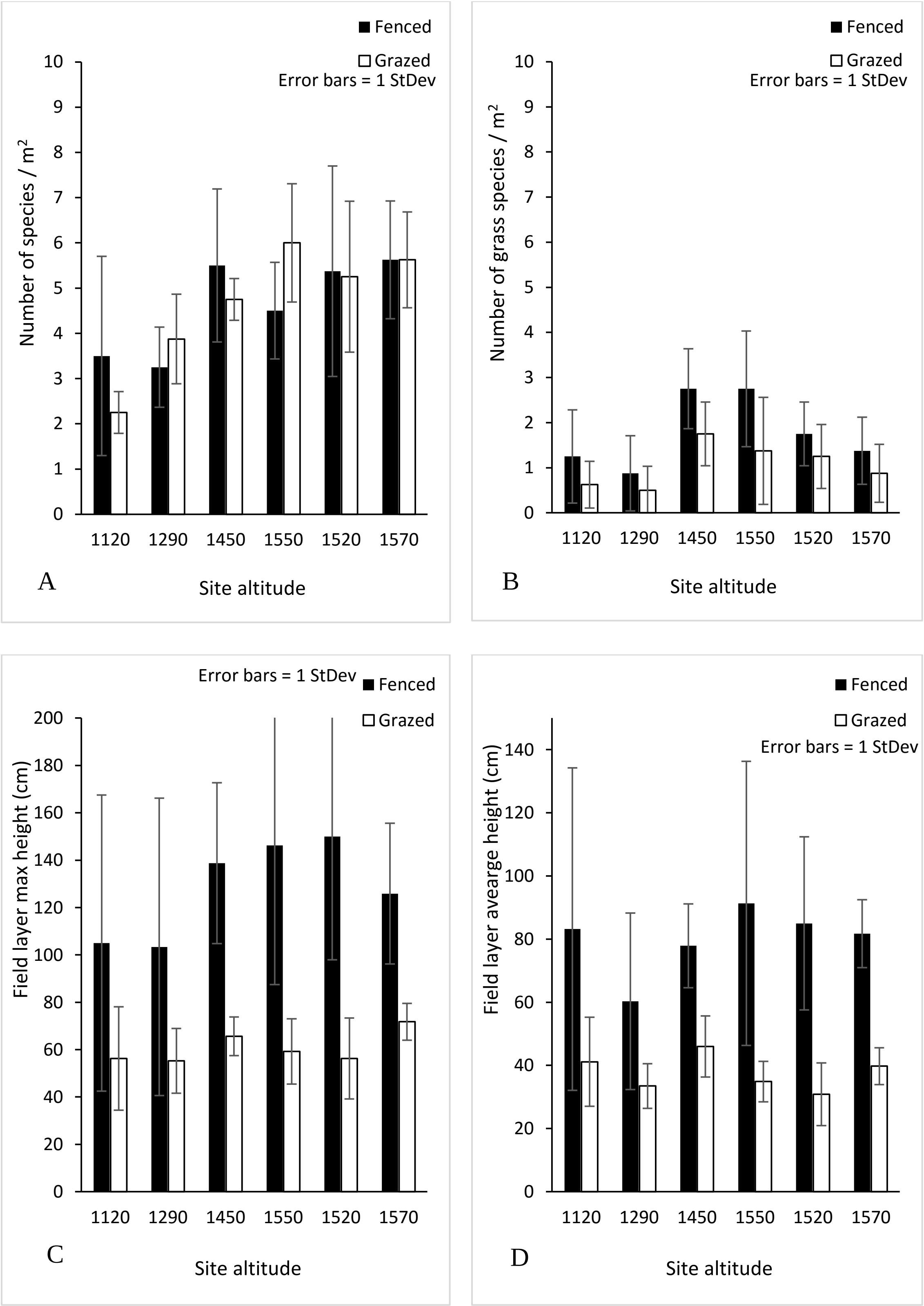


Figure 10 A) number of species/m^2, B) number of grass species/m^2, C) field layer max height and D) field layer average heights in fenced and grazed plots (n=8).

4.2 Effects of livestock exclusion on Surface fuel biomass and moisture content

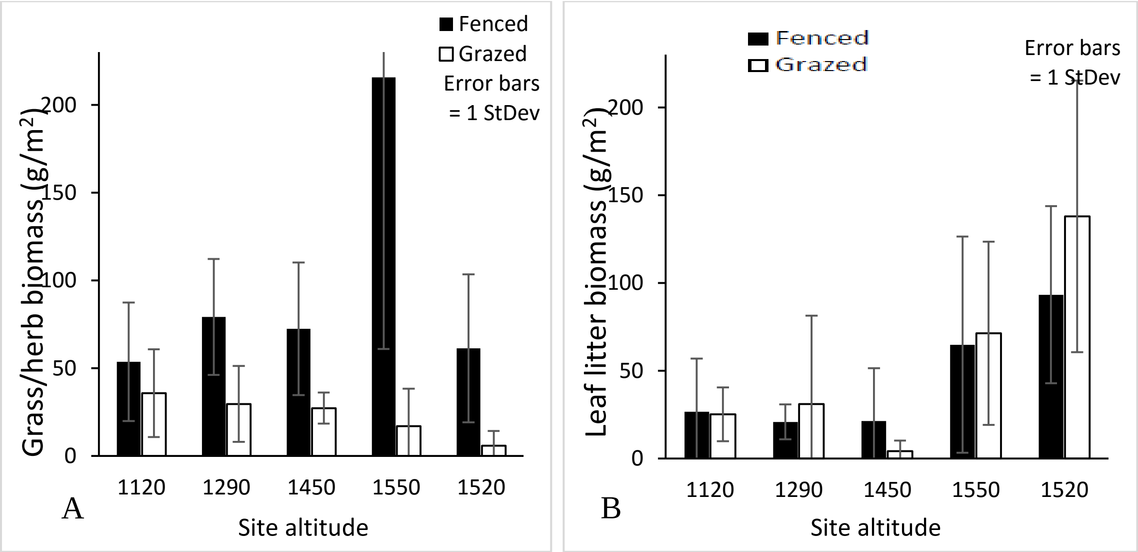
4.2.1 Effects of livestock exclusion on Surface fuel biomass

Significant differences in dead grass biomass was observed between fenced plots and grazed plots (p=0.025, Figure. 11A). The difference in leaf litter, fine litter and wood litter biomass between fenced plots and freely grazed plot was not significant (Figure 11B, 11C and11D, respectively, table 4). However, average wood litter and fine litter biomass inside fences was slightly higher than in grazed plots. The average difference in total surface fuel biomass (Figure 11E) between fenced plots and grazed plots was 83.3 g/m^2 and significant (p= 0.047, table 4). The average standing biomass in field layer and litter after 1.5 years of total exclusion of all domestic livestock was 235 g/m^2.

Table 4. Nested anova results for differences in surface fuel biomass between grazed and fenced plots.

		log DW grass/herb litter		DW leaf litter		DW wood litter		log DW fine litter		DW total biomass	
	DF	*t*	p	*t*	P	*t*	p	*t*	p	*t*	p
Treatment	1	**-3.49**	**0.025**	0.69	0.530	-0.03	0.978	-2.17	0.096	**-2.84**	**0.047**
Site	4										

Significant results in bold text (significant at p< 0.05). Number of observations = 50, DF = degrees of freedom, DW = dry weight. Some values were logged to ensure equal variance.



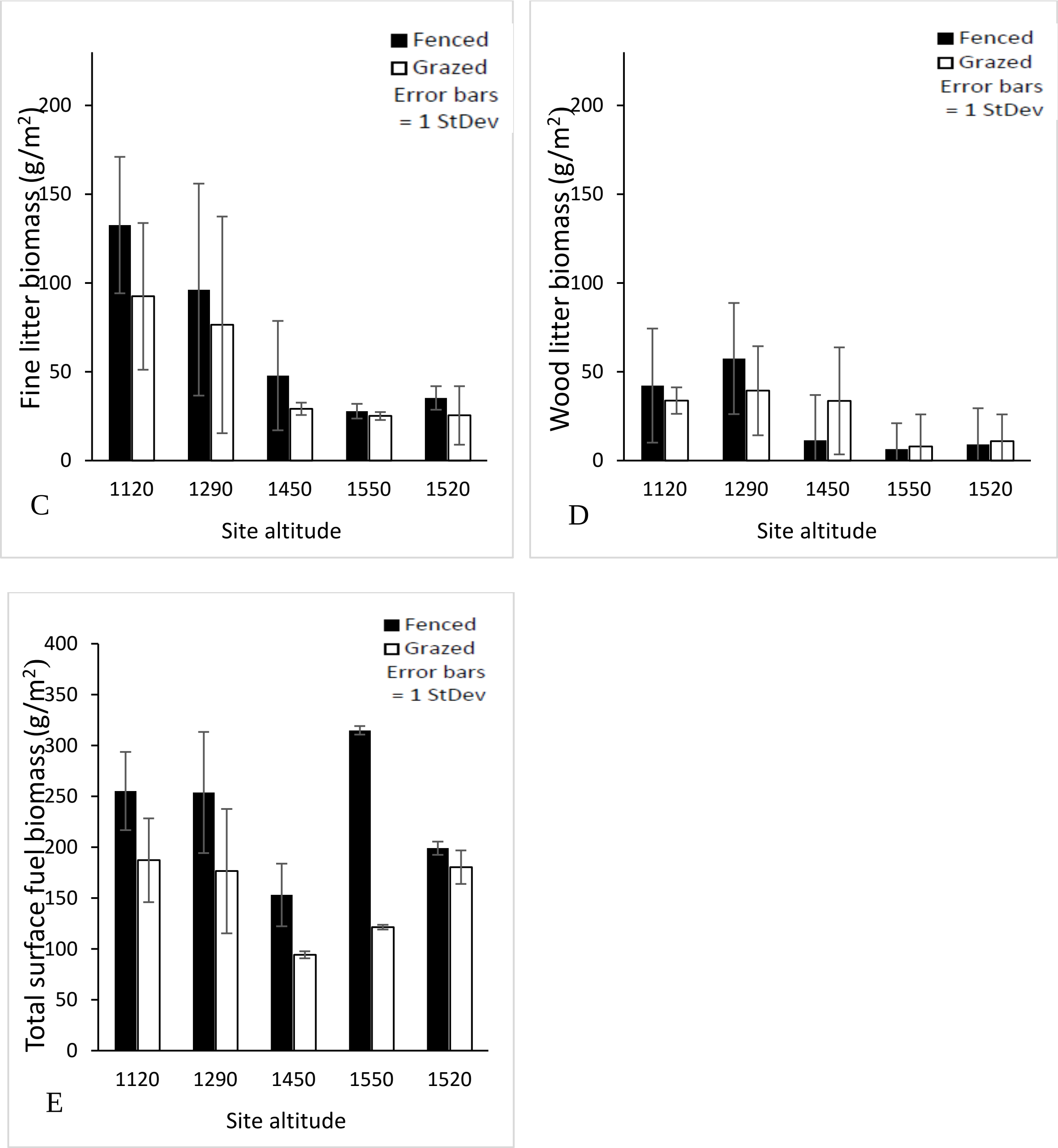


Figure 11 Surface fuel biomass of the A-D) different fuel fractions and E) total biomass in fenced and grazed control plots (n=5).

4.2.2. Gibe Valley National Park litter moisture content in dry season, December

The difference in litter moisture content for all biomass fractions was not significant (table 5). However, average litter moisture content of the four biomass fractions inside fenced plots was slightly higher than in grazed plots (Fig. 12A, B, C, D).

Table 5. Nested anova results for differences in surface fuel moisture content between grazed and fenced plots.

		MC grass/herb litter		MC leaf litter		MC wood litter		Log MC fine litter	
	DF	*t*	p	*t*	P	*t*	p	*t*	p
Treatment	1	-2.28	0.085	-0.10	0.928	-0.51	0.635	-2.68	0.055
Site	4								

Significant results in bold text (significant at $p < 0.05$). Number of observations = 50, DF = degrees of freedom, MC = moisture content. Some values were logged to ensure equal variance.

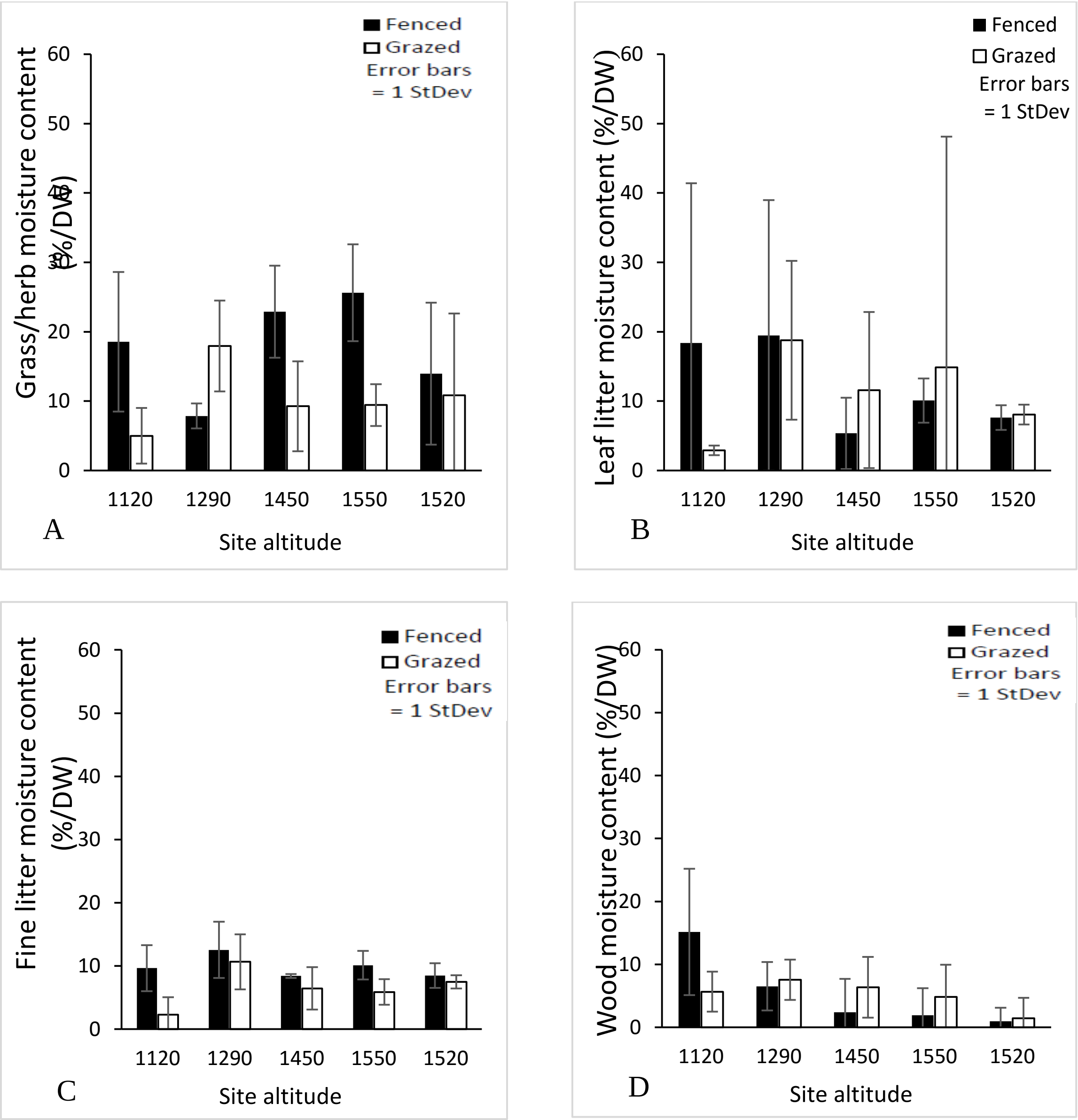


Figure 12 Fine fuel moisture content (A-D) in the different fuel fractions in fenced and grazed control plots (n=5).

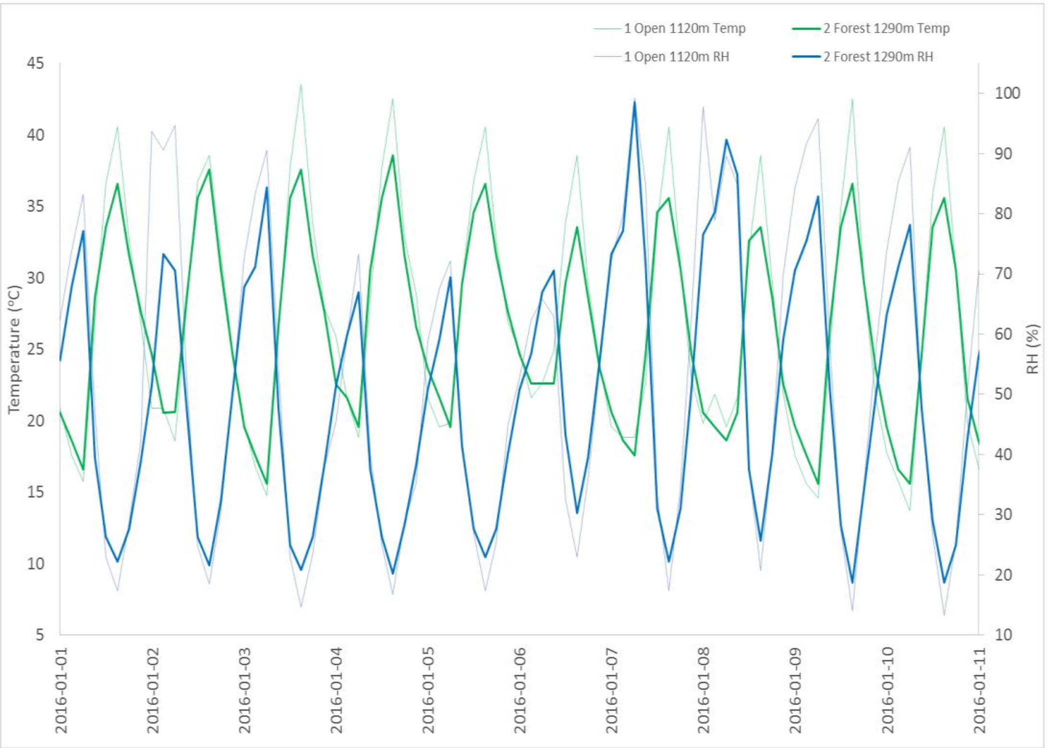


Figure 13 Daily fluctuations in RH and temperature 50 cm above ground in a closed-canopy Forest plot (at 1290m) and one Open canopy plot (at 1120m)

4.3. Effects of grazing exclusion on soil properties

4.3.1. Effect of grazing exclusion on soil organic matter

The difference in soil organic matter content between fenced plots and grazed plots was not significant for any of the soil depths 0-5 cm or for 5-10 cm (table 6). However, average soil organic matter content of fenced plots for both soil depths was slightly higher than grazed plots (Figure 14).

Table 6.Nested anova results for differences in soil parameters between grazed and fenced plots.

		soil bulk density		soil moisture content		SOM 0-5 cm		SOM 5-10 cm		soil pH 0-5 cm		soil pH 5-10 cm	
	DF	*t*	p	*t*	P	*t*	p	*t*	p	*t*	p	*t*	P
Treatment	1	2.60	0.060	**-3.93**	**0.017**	-1.02	0.367	-1.98	0.119	-0.37	0.733	-0.68	0.533
Site	4												

Significant results in bold text (significant at $p< 0.05$). Number of observations = 50, DF = degrees of freedom, SOM = soil organic matter.

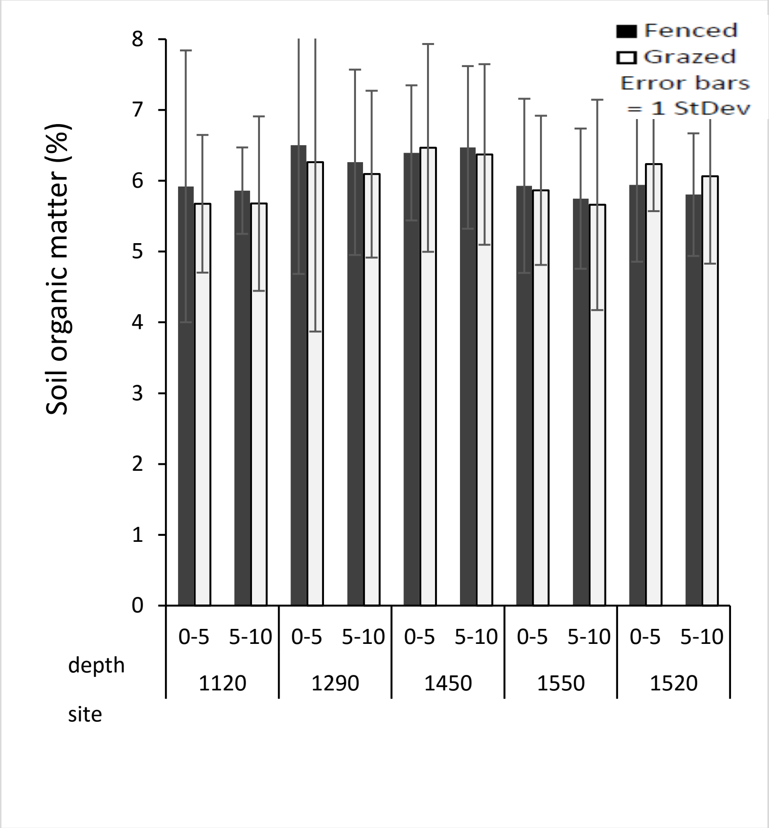


Figure 14 Soil organic matter content of fenced and grazed plots within 0-5 and 5-10cm soil depths (n=5).

The variation in soil organic matter within fenced plots was not significant when depth of soil increased (table 7). However, average soil organic matter content of 0-5 cm depth soil layer was slightly higher than 5-10 depth soil layer (Figure 15A). Effect of soil depth on organic matter content within grazed plot for soil depths between 0-5 and 5-10 cm was significant (p=0.035, Figure 15B).

Table 7 One way anova results for effects of soil depth on organic matter and soil pH within fenced and within grazed plots

		Soil OM Within fenced	Soil OM Within grazed	Soil pH Within fenced	Soil pH Within grazed
	DF	p	p	p	p
Depth	1	0.063	**0.035**	0.247	0.225
Site	4				

Significant results in bold text (significant at p< 0.05). Number of observations = 50, DF = degrees of freedom, SOM = soil organic matter.

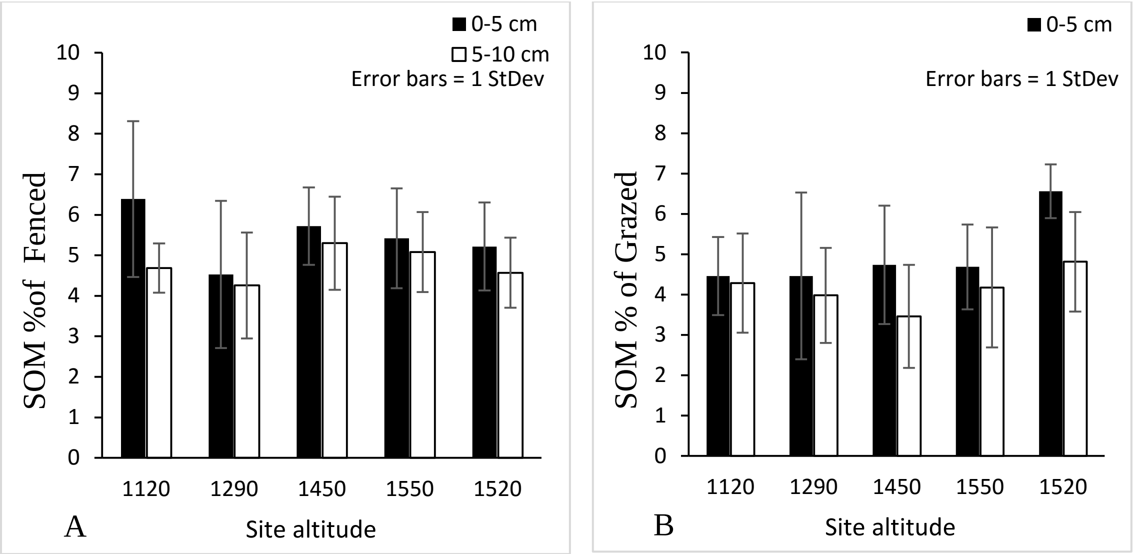


Figure 15 Soil organic matter content within fenced (Figure A) and within grazed plots (Figure B) when depth increases.

4.3.2. Effect of grazing exclusion on soil pH

The difference in soil pH between fenced plots and grazed plots was not significant for neither 0-5 nor 5-10 cm soil depths (table 6). However, the pH of fenced plots´ soil for both depths was slightly higher than grazed plots (Figure 16).

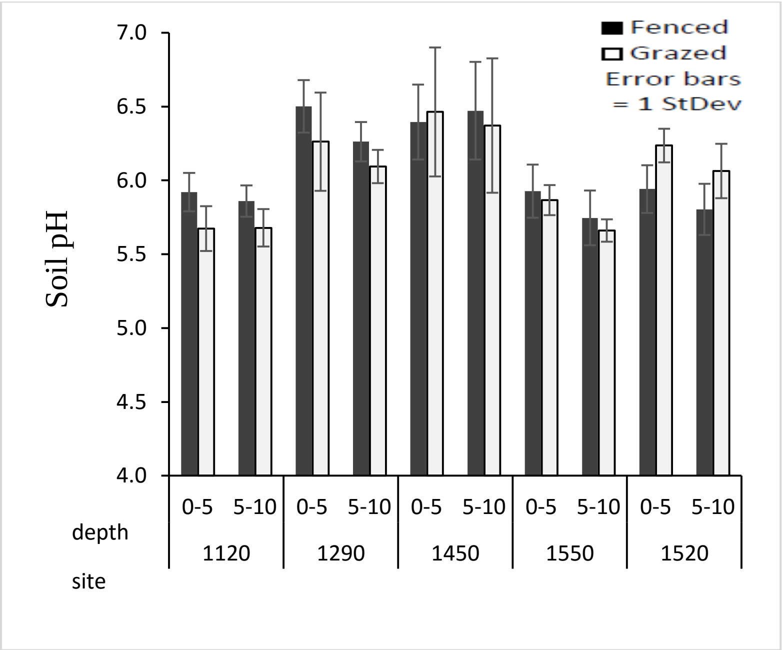


Figure 16 Soil pH between fenced and grazed plots for the two soil depths.

The variation in pH within fenced and within grazed plots was not significant when depth of soil increased (table 7). However, soil pH of 0-5 cm depth soil layer was slightly higher than 5-10 depth soil layer both within fenced (Figure 17A) and within grazed plots (Figure 17B).

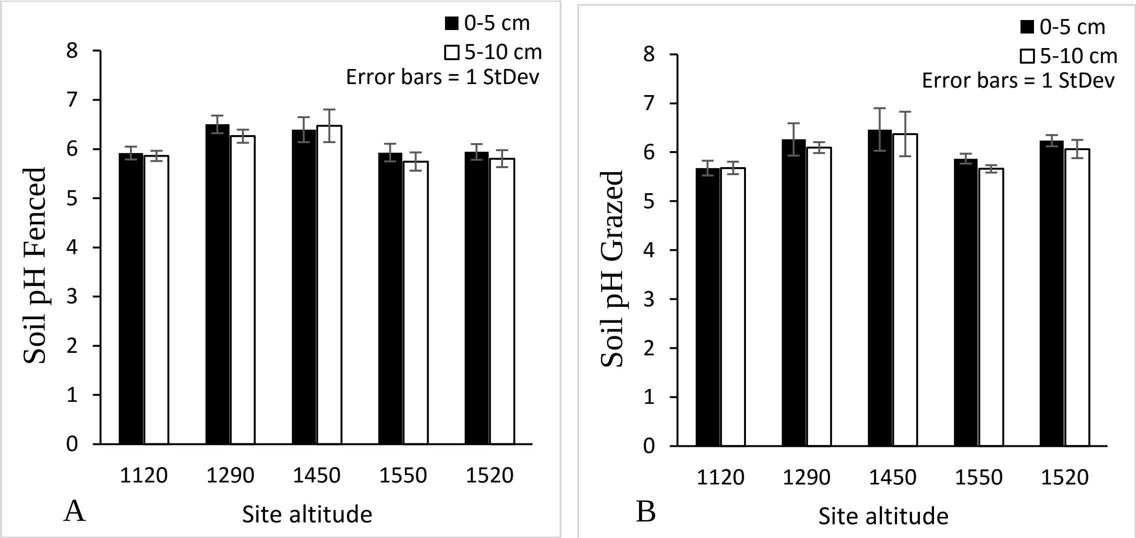


Figure 17 . Soil pH within fenced (A) and within grazed plots (B) at the two different depths.

4.3.3. Effects of grazing exclusion on soil bulk density and soil volumetric water content

The difference in soil bulk density between fenced plots and grazed plots was not significant (table 6). However, soil bulk density of fenced plots was slightly lower than in grazed plots (Figure.18A). The difference in soil volumetric water content between fenced plots and grazed plots was significant (p=0.017, Figure.18B and 19).

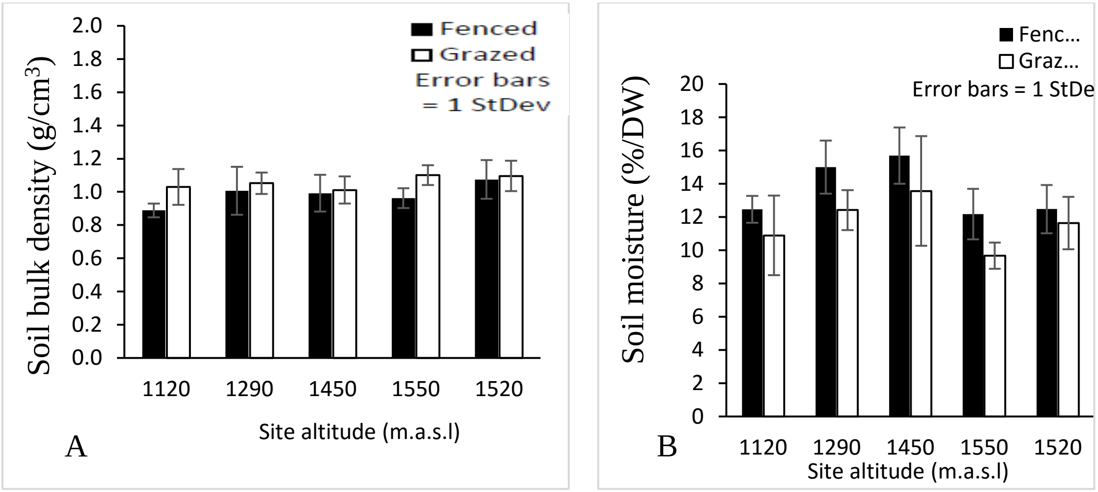


Figure 18 Soil bulk density (A) and volumetric water content (B) in fenced and grazed plots.

Soil moisture measured by hand-held tensiometer, varied depending on the season, being higher in fenced in Oct. – May (dry-season, plus short rainy season), but lower during big rain (Fig 20).

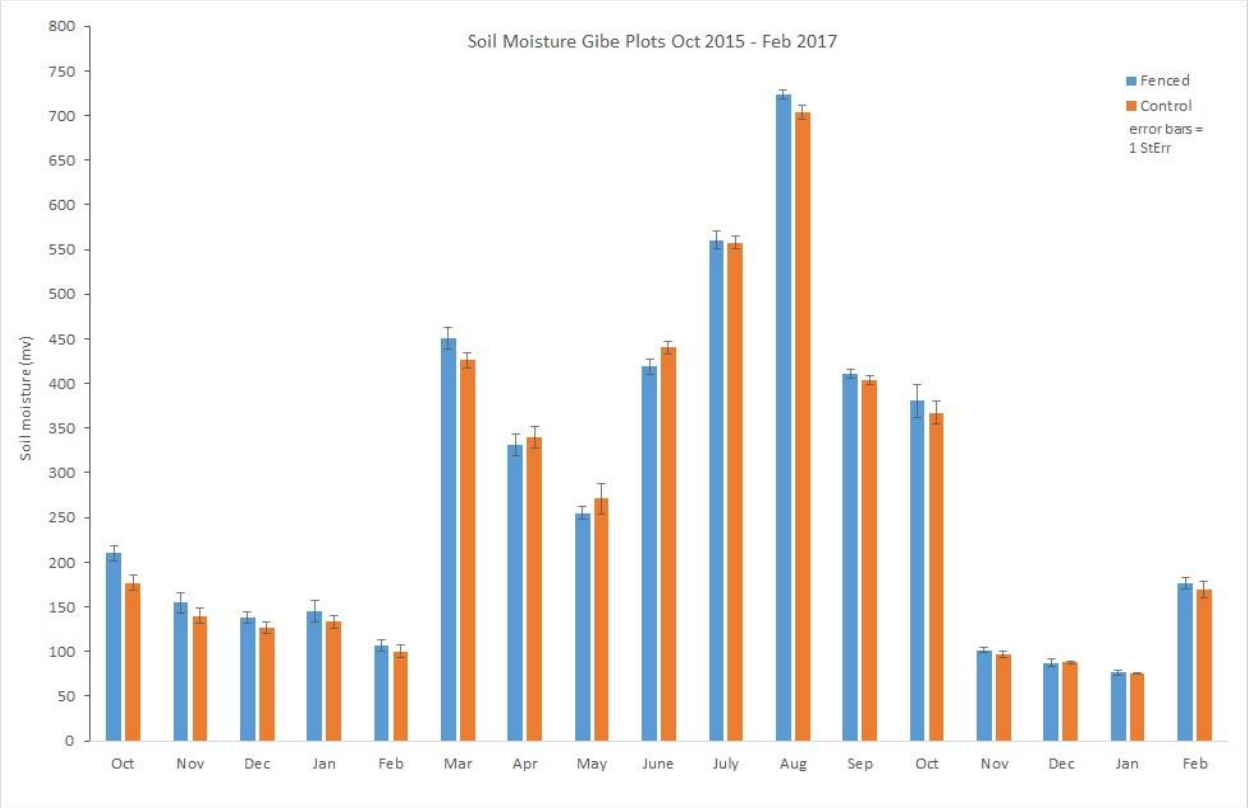


Figure 19 Soil moisture content measured monthly by a conductivity meter of fenced and grazed plots from 0ctober 2015 up to February 2017.

CHAPTER FIVE

5. DISCUSSION

5.1. Effects of grazing exclusion on field layer plant species composition, height, biomass and litter moisture content

5.1.1. Effects of grazing exclusion on field layer plant species composition, cover and height

Significant differences in field layer species composition (even though differences between sites were larger than differences between treatments), field layer cover, grass cover, and bare soil cover were observed between fenced plots and grazed plots. Fenced plots had a different species composition, higher field layer cover and grass cover than grazed plots. Bare soil cover was higher in grazed plots. The lower field layer and grass cover, and the higher bare soil cover in grazed plots should be due to the removal of grass/herbs by grazing animals (Milton et al., 1994; Robertson, 1996). The findings of this study was in agreement with the study of Mureithi et al. (2016) in conservation zones in a Kenyan Semi-Arid Savannah in which excluding livestock grazing resulted in a higher grass and forbs cover and biomass, and lower bare ground cover than continuously hard-grazed plots.

Field layer species composition differed between fenced and grazed plots, since the communities diverged in the ordination plot, but the differences between the six different sites were larger. This is natural since the field layer flora differs depending on altitude, soil type and tree canopy species.

The difference in number of species between fenced plots and freely grazed control plots was not significant. This can be due to short duration of exclosure. Number of grass species was significantly higher in fenced plots. The effect of grazing on species richness can differ, depending on ecosystem and grazing pressure. In European semi-natural grasslands heavy grazing increases species numbers due to the suppression of dominant species, which allows weaker competitors to remain in the grass lawn (Tilman, 1994). A moderate grazing pressure should have the same effect in African savannas (Parr et al., 2014), but very heavy grazing pressure, which is common in Ethiopia, where livestock continue to consume almost all accessible dead grass throughout the dry season will have a negative effect on the species diversity of palatable species which is observed in the dry season. Since the livestock feed selectively and prefer the grass species, the cover and height of grass species in grazed control plots was lower than in fenced plots, this was most obvious for the most valuable forage grass species *Bothriochloa insculpta*, which was the one significant indicator species for fenced plots. *Leucas deflexa* was the one significant indicator species for grazed plots. It is a hard, spiny and chemically defended Lamiaceae herb which is avoided by the livestock and often becomes a grazing weed (Kikoti and Mligo, 2015).

Field layer maximum and average heights were significantly higher in fenced plots compared to grazed plots. The findings of this study was in agreement with the reported results of Kioko et al. (2012) under a study on savanna grassland in Kenya, in which average field layer height was higher in fenced plots as compared with grazed area. The lower field layer maximum and average heights in grazed plots is of course due to the grazing herbivores that constantly remove leaf tissue in grazed plots (Mbatha and Ward, 2010).

The plant inventories for this study were made in November, which was a bit too late to easily identify all species. Therefore species numbers are likely to be rather underestimated. Some savanna species, like *Cycnium tubulosum*, which is common in Give Valley, flower and reproduce early in the rainy season and the rest of the year they are invisible in the vegetation, whilst other field layer species, like *Crotalaria plowdenii* cannot be identified until they have set fruit, which for some species can be late in the rainy season. Therefore, it is not possible to identify all species present in only one inventory occasion.

Nevertheless, this study demonstrates a strong effect of livestock exclosure on field layer species composition, height and biomass which will have implications for conservation and fire ecology of the recently established national park.

5.1.2. Effect of grazing exclusion on field layer plant biomass and litter moisture content

Field layer standing biomass was significantly higher in fenced plots than grazed plots. This observation of increase in field layer standing biomass in fenced plots is consistent with similar observation in South African semi-arid savanna (Mbatha and Ward, 2010) and in Rocky Mountain National Park, Colorado (Singer and Schoenecker, 2003). The decrease in field layer standing biomass in grazed plots as compared with fenced plots, is of course due to the fact that both livestock and wildlife grazing leads to excessive defoliation of herbaceous vegetation, reducing standing biomass (Bilotta et al., 2007) and the trampling pressure exerted by the animals (Savadogo et al.,2007). However, one study finding with the opposite results is that of Frank and McNaughton (1993), who reported more herbaceous biomass production in lightly wildlife-grazed plots in

Yellowstone National Park, USA which they suggested was caused by plant overcompensation. However, Yellowstone National Park is a temperate area and the grazing occurred in only the summer season, unlike Gibe Valley National Park (savannah) where grazing occurs throughout the year, including grazing of dead grass in the dry season. The significant difference in total biomass between fenced plots and grazed plots is due to the absence of livestock grazing in exclosures. The slightly higher fine litter biomass accumulation is may be due to absence of grazing during the 1.5 years and its accumulation since the exclosures were constructed. The average standing biomass of field layer and litter at the end of the dry season in this study was 235 g /m^2. This is very low compared to literature findings of annual field layer production in low-productivity *Hyparrhenia* savannas of ca 1,5 – 1,9 kg grass DW / m^2 (FAO, 2017). The biomass in plot 3 Fenced treatment is much underestimated due to the difficulty of sampling the 2 m tall *Hyparrhenia* grass which was a bit unevenly distributed. Some grass biomass inside fences was lost to baboon trampling/breaking of tall grasses (especially in plot 1) and a substantial amount of grass biomass was probably consumed by grasshoppers, since we observed that they were extremely numerous inside the fences, and flew out in masses when plots were experimentally burnt in February, but not in the grazed controls. According to Porter et al. (1996), Grasshoppers in burnt Californian grasslands consumed 140g grass/ m^2 and in Africa, desert locusts at an average-high density (50 ind./m^2) can consume 100 g grass/m^2 per day, or equal to 30 dry sheep (NSW, 2017).

The difference in litter moisture content for all biomass fractions was not significant. However, average moisture content of the four biomass fractions inside exclosures was slightly higher than in grazed plots .This could be due to larger biomass reducing daily evaporation rates in fenced plots. Also, dead fine fuel moisture content stands in equilibrium with the relative air humidity (RH) which is higher under tree canopies than in open plots (Figure 13).

5.2. Effects of grazing exclusion on soil organic matter

The difference in soil organic matter content between fenced plots and grazed plots for soil depths 0-5 cm and 5-10 cm was not significant. However, the soil under fenced plots has slightly higher soil organic matter content than freely grazed plots, which could be a result of liter input. The result is in agreement with Wolde Mekuria et al. (2007) who found that grazed plots and fenced plots in Tigray differed in their soil organic carbon content, after 10 years of grazing exclusion, demonstrating the higher amount of SOM in fenced plots than grazed plots. Similarly, in another studies (Wolde Mekuria and Ermias Aynekulu, 2013; Raiesi and Riahi, 2014) the soil organic matter content was lower in the grazed plots compared to the fenced plots, probably the consequence of reduced amount of litter input and exposure of micro-aggregate organic matter to microbial decomposition through weaker physical protection of organic matter in the soil (Fantaw Yimer et al., 2015). This is in line with Mikola et al. (2001) who suggested that a reduction of soil organic matter was a result of lower biomass return in the grazed plot due to less grass cover resulting from the grazing.

Effect of soil depth on organic matter content of soil within fenced plots was not significant. However, soil organic matter content 0-5 cm depth soil layer was slightly higher than 5-10 depth soil layers. Effect of soil depth on organic matter content in grazed plot was significant. Soil organic carbon content decreases with soil depth (both in fenced and in grazed soil layers). In agreement with this, another study by Hiederer

(2009) explained the relationship between soil organic matter with soil depth—as depth increases, soil organic matter decreases because of lower addition rates of organic matter due to the lower below-ground root biomass in the sub-surface layer compared to the higher biomass of litter input from the top of the soil surface. Our Gibe Valley exclosures have only been in place for 1.5 growing seasons, so the larger field-layer biomass found inside fences might not yet have had time to accumulate into soil carbon. Over time there might be an increase in SOM inside fences, unless an increased decomposition rate, due to increased biomass consumption by insects or microbes would release the carbon at the same rate as it is produced.

Savanna soils typically have rather low SOM compared to other ecosystems, due to the quick decomposition the high-quality grass litter (Wardle and Bardgett, 2004). If the litter is not quickly decomposed by fire or large herbivores like livestock, it will be decomposed by grasshoppers, termites or soil microbes, leaving only a small fraction of recalcitrant carbon left in the SOM. Some tree species, like *Combretum sp.* have leaves with higher tannin and phenolics content which is more difficult for herbivores and microbes to consume; hence SOM is higher under such trees. This has not yet been tested on this data, but it will be in the future.

5.3. Effects of grazing exclusion on soil pH

The difference in soil pH between fenced plots and grazed plots was not significant neither for soil depth 0-5 cm nor 5-10 cm. However, pH of fenced plots soil was slightly higher than grazed plots, for both soil layers. Similar findings were also observed in the study of Wolde Mekuria et al. (2007) who reported that fenced plots and grazed plots showed no significant difference in soil pH. Probably soil pH depends more on tree cover than grazing exclusion, which will be tested on this data in the future. The slightly higher soil pH in fenced plots can be due to the effects of slightly increased soil organic matter that can trap base cations or can be due to that the organic matter accumulation might reduce soil erosion resulting in higher soluble base cations (Ca^{2+} and Mg^{2+}) that reduce H^+ ions responsible for acidity, which in turn could increase pH in the soil.

Effect of soil depths on pH for neither fenced nor grazed plot was not significant. However, pH of both fenced plots and grazed plots 0-5 cm depth soil layer was slightly higher than 5-10 depth soil layer. The decrease in soil pH with increase in soil depth can be due to the percolation of water to the deeper zones which leads to the formation of acids (Mitiku Habte, 1999).

5.4. Effects of grazing exclusion on soil bulk density

The difference in soil bulk density between fenced and grazed plots was not significant. However, soil bulk density of fenced plots soil was slightly lower than in grazed plots. The slightly lower soil bulk density in fenced plots compared with grazed plots can be due to the elimination of heavy trampling by livestock which is known to compact soil (Gao et al., 2011), as well as the likely increase of root biomass due to reduced trampling (Yuan et al., 2012). The slightly higher soil bulk density in grazed plots also can be due to the slightly lower organic matter with in grazed plots compared with fenced plots (Fantaw Yimer et al., 2015).

5.5. Effect of grazing exclusion on soil volumetric water content

Soil moisture is one of the primary limiting factors for plant growth. Therefore; available soil moisture is the principal determinant of productivity (Thomas and Squires, 1990). Our grazed plots had significantly lower soil moisture content compared to fenced plots.

This is in agreement with Pei et al. (2008) and Qin et al. (2015) in that grazed plots and fenced plots differ in their soil volumetric water content reflecting the higher moisture content in fenced plots than in grazed plots. According to Naeth et al. (1991) this could be explained by less infiltration caused due to soil compaction and soil pore sealing by animal trampling and reduced litter cover. Thus, reduction in soil volumetric water content in freely grazed land compared with fenced plots can be due to increased runoff and decreased infiltration. Also, the increased in soil volumetric water content in fenced plots could be due to increased vegetation cover, less bare patches of soil (Rietkerk et al., 2000), slightly lower soil bulk density and slightly higher soil organic matter causing a reduced evaporation of moisture from the soil surface in the dry season.

A long-term measurement of soil moisture in this study system showed that fenced plots had higher soil moisture all months of the year, except April-June, which is the time of the year when the grasses grow fastest. We suggest that the grasses consume more water than the daily precipitation during this time causing the lower soil moisture inside fences. Whilst during other times of the year the dead or less quickly growing grasses actually shade the soil surface and prevent direct evaporation from the soil, causing the higher soil moisture inside fences.

CHAPTER SIX

6. CONCLUSIONS, RECOMMENDATIONS AND MANAGEMENT IMPLICATIONS

6.1. Conclusions

Excluding an area from grazing for 1.5 years significantly changes field layer species composition and significantly increases field layer cover, grass cover, number of grass species and decreases the cover of bare soil. It also significantly and substantially increases field layer maximum and average height, biomass of grass and soil volumetric water content. This large difference between exclosures compared with grazed plots shows the large effects of grazing exclosures on vegetation and soil, in an area with relatively high grazing pressure.

Excluding an area from grazing for 1.5 years did not significantly change number of species, leaf, wood and fine litter biomass, plant moisture content of four biomass fractions, soil bulk density, organic matter content and pH of both 0-5 and 5-10 cm soil layers. However, it resulted in slightly higher litter moisture content of the four biomass fractions, fine litter biomass, soil organic matter and pH for both soil layer depths and slightly lower soil bulk density in fenced compared to grazed plots. These findings indicate that these are variables which could become significantly altered by the fences if the livestock exclusion was run over a longer time period.

6.2. Recommendations and management implications

Gibe Valley National Park is one of the newest National Parks of the country, which will be a destination for tourists in the future and is a source of feed for livestock on which local people´s livelihoods depend. The current observed changes in plant species composition and all other variables which are dependent on each other, will influence the sustainability of livestock production and biodiversity in near future, unless it get proper care from local people, park management and responsible government officials. Therefore, in order to conserve biodiversity in the park, as well as pasture quality for the local people, the following recommendations are provided:-

- Proper understanding and implementation of a joint grazing management system including controlled prescribed fire and a pasture resting time in the beginning of the rainy season when grazing is totally prohibited to ensure a better regrowth of grasses
- Further new settlement of people around the park and within park should be avoided.
- Serious consequences should be taken on people who produce charcoal within park, since this affects the structure and the value of the tree stands
- Further studies on effects of grazing exclusion on plant moisture content, fine litter biomass, soil organic matter and pH is needed.

The park management's main goals are to stop tree cutting and wildlife hunting. To reduce grazing pressure is also a park objective, but this needs to be done with caution, since the local people depend on their livestock and since the river gorge area has been managed by fire and grazing for a long time and the ecosystem is adapted to this management regime. A sudden large-scale removal of both grazing and annual fires might in a few years' time lead to surface fuel accumulation and an increased risk of large-scale, high-intensity wildfires which can kill even the large trees and reduce both the biodiversity and carbon storage of the park area.

References

Alemneh, Amare (2015). Conservation Challenges of Gibe Sheleko National Park, Southwestern Ethiopia. *Natural Resources*. **6**:286-289.

Allison, F.E. (1973). *Soil organic matter and its role in crop production*. Amsterdam: Elsevier.

Al-Seekh, S.A, Ayed, G.M and Yousef, A.A. (2009). Effect of Grazing on Soil Properties at Southern Part of West Bank Rangeland. *Hebron University Research Journal*. **4**(1):35-53.

Angassa, A., and Oba, G. (2008). Herder perceptions on impacts of range enclosures, crop farming, fire ban and bush encroachment on the rangelands of Borana, Southern Ethiopia. *Human Ecology*. **36**:201-215.

Archibald, S., Roy, D. P., Van Wilgen, B. W. and Scholes, R. J. (2009). What limits fire? An examination of drivers of burnt area in Southern Africa. *Global Change Biology*. **15**:613-630.

Bardgett, R.D. and Wardle, D.A. (2010). *Aboveground-belowground linkages: biotic interactions, ecosystem processes and global change*. Oxford University Press, Oxford.

Bauer, H.L. (1943) .The statistical analysis of chaparral and other plant communities by means of transect samples. *Ecology*. **24**:45-60.

Beeskow, A.M, Elissalde, N.O. and Rostagno, C.M. (1995). Ecosystem changes associated with grazing intensity on the Punta Ninfas rangelands of Patagonia, Argentina. *Journal of Range Management*. **48**:517–522.

Belsky, A. J. (1994). Influences of Trees on Savanna Productivity - Tests of Shade, Nutrients, and Tree-Grass competition. *Ecology*. **75**:922-932.

Belsky, A. J., Carson, W. P., Jensen, C. L. and Fox. G. A. (1993). Overcompensation by plants - herbivore optimization or red herring?. *Evolutionary Ecology*.**7**:109-121.

Belsky, A.J. and Blumenthal. D.M. (1997). Effects of livestock grazing on stand dynamics and soils in upland forests of the interior west. *Conservation Biology*. **11**(2):315–327.

Bilotta, G.S., Brazier, R.E. and Haygarth, P.M. (2007). The impacts of grazing animals on the quality of soils, vegetation, and surface waters in intensively managed grasslands. *Advances in Agronomy*. **94**:237–250.

Blair, J, Nippert, J, and Briggs, J. (2014). *Grassland Ecology*. Springer Science+ Business Media, New York.

Blake, G.R. and Hartage, K.H. (1986). Bulk density. In: A. Klute (ed.) Methods of soil analysis. Part1. Physical and mineralogical Methods-Agronomy monograph #9(second edition). pp363-367.

Bond, W. J., and Midgley, G. F. (2000). A proposed CO2-controlled mechanism of woody plant invasion in grasslands and savannas. *Global Change Biology*. **6**(8):865-869.

Brady, N., and Weil, R. (1996). *Soils and chemical pollution*. The Nature and Properties of Soils: Prentice Hall International.

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

Burke, I.C., Yonker, C.M., Parton,W.J., Cole ,C.V., Flach ,K. and Schimel ,D.S.(1989). Texture, climate and, cultivation effects on soil organic matter content in U.S. grassland soils. *Soil science society of American Journal*. **53**:800–805.

Butz, R. J. (2009). Traditional fire management: historical fire regimes and land use change in pastoral East Africa. *International Journal of Wildland Fire*. **18**:442-450.

Carter, M.R. (1993). *Soil sampling and methods of analysis*. Lewis Publishers. Boca Raton.

Cebrian, J. (1999). Patterns in the fate of production in plant communities. *American Naturalist*. **154**:449-465.

Chen, D.D., Zhang,S.H., Dong ,S.K., Wang, X.T., Du ,G.Z. (2010). Effect of land-use on soil nutrients and microbial biomass of an alpine region on the north eastern Tibetan plateau, China. *Land Degradation and Development*. **21**:446–452.

Chen, Y., Li, Y., and Zhao, X. (2012). Effects of Grazing Exclusion on Soil Properties and on Ecosystem Carbon and Nitrogen Storage in a Sandy Rangeland of Inner Mongolia, Northern China. *Environmental Management*. **50**:622–632

Cuenca, H.R. (1989). *Irrigation system designs an engineering approach*. Prentice-Hall Inc. Englewood Cliffs. p 552.

Daly, C., Bachelet , D., Lenihan, J.M., Neilson, R.P., Parton, W., Ojima, D .(2000). Dynamic simulation of tree-grass interactions for global change studies. *Ecological Applications*. **10**:449-469.

Doran, J.W. and Safely, M. (1997). *Defining and assessing soil health and sustainable productivity*. In: Pankhurst CE, Double BM, Gupta VVSR, editors. Biological indicators of soil health. New York: CAB International.

Dorrough, J., Ash, J., and McIntyre, S. (2004). Plant responses to livestock grazing frequency in anAustralian temperate grassland. *Ecography*. **27**: 798-810.

Drewry, J.J. (2006). Natural recovery of soil physical properties from treading damage of pastoral soils in New Zealand and Australia: *A review. Agriculture, Ecosystems and Environment*. **114**:159-169.

Fantaw Yimer, Getachew Alemu and Abdu Abdelkadir (2015). Soil property variations in relation to exclosure and open grazing land use types in the Central Rift Valley area of Ethiopia. *Environmental System Research*. 4:17.

FAO, (2017). Fodder resources and management, webpage: Available at http://www.fao.org/wairdocs/ilri/x5539e/x5539e05.htm .Accessed on 15th February 2017, 11:20 am.

Fensham, R.J., Fairfax, R.J, Dwyer, J.M. (2010).Vegetation responses to the first 20 years of cattle grazing in an Australian desert. *Ecology*. **91**:681-692.

Fleischer, TL. (1994). Ecological costs of livestock grazing in western North America. *Conservation Biology*. **8**(3):629-644.

Frank, D.A. and McNaughton, S.J. (1993). Evidence for the promotion of aboveground grassland production by native large herbivores in Yellowstone National Park. *Oecologia*. **96**: 157–161.

Gao, Y., Wang, D.L., Ba, L., Bai, Y.G., Liu, B. (2007). Interactions between herbivory and resource availability on grazing tolerance of *Leymus chinensis*. *Environmental and Experimental Botany*. **63**:113–122.

Gao, Y., Zeng, X., Schumann, M., and Chen, H. (2011). Effectiveness of exclosures on restoration of degraded alpine meadow in the eastern Tibetan Plateau. *Arid Land Research and Management*. **25**: 164–175.

Gil-Romera, G., Turton, D. and Sevilla-Callejo, M. (2011). Landscape change in the lower Omo valley, southwestern Ethiopia: burning patterns and woody encroachment in the savanna. *Journal of Eastern African Studies*. **5**:108-128.

Golodets, C., Kigel, J., and Sternberg, M. (2010). Recovery of plant species composition and ecosystem function after cessation of grazing in a Mediterranean grassland. *Plant and Soil*. **329**:365–378.

Greenwood, K. L. and McKenzie, B. M. (2001).Grazing effects on soil physical properties and the consequences for pastures: a review, *Australian Journal of Experimental Agriculture.* **41**:1231–1250.

Hafner, S., Unteregelsbacher, S., Seeber, E., Lena, B., Xu, X., Li, X., Guggenberger, G., Miehe. G., and Kuzyakov, Y. (2012). Effect of grazing on carbon stocks and assimilate partitioning in a Ti betan montane pasture revealed by CO_2 pulse labeling. *Global Change Biology*. **18**:528–538.

Hairston, N. G., Smith, F. E. and Slobodkin, L. B. (1960). Community structure, population control and competition. *American Naturalist*. **94**:421-425.

Haynes, A. G., Schütz, M., Buchmann, N., Page-Dumroese, D. S., Busse, M. D., and Risch, A.C. (2014).Linkages between grazing history and herbivore exclusion on decomposition rates in mineral soils of subalpine grasslands. *Plant and Soil.* **374**: 579–591.

Hiederer, R. (2009). *Distribution of organic carbon in soil profile data*. Office for Official Publications of the European Communities, Luxembourg. p 126.

Holdo, R. M., and Mack, M. C. (2014). Functional attributes of savanna soils: contrasting effects of tree canopies and herbivores on bulk density, nutrients and moisture dynamics. *Journal of Ecology*. **102**:1171-1182.

Hongqin, Li., Fawei, Zhang, Shaojuan, Mao, Jingbin, Zhu, Yongsheng, Yang, Huidan He, and Yingnian Li. (2016). Effects of Grazing Exclusion on Soil Properties in Maqin Alpine Meadow, Tibetan Plateau, China. *Polish Journal of Environmental Studies.* **25**(4):1583-1587.

Hoshino, A., Tamura, K., Fujimaki, H., Asano, M., Ose, K., and Higashi, T. (2009). Effects of crop abandonment and grazing exclusion on available soil water and other soil properties in a semi-arid Mongolian grassland. *Soil and Tillage Research*. **105**: 228–235.

Huang, D., Wang, K. and Wu, W.L. (2007). Dynamics of soil physical and chemical properties and vegetation succession characteristics during grassland desertification under sheep grazing in an agro-pastoral transition zone in Northern China. *Journal of Arid Environments.* **70**: 120-136.

Humphrey, J.W. and Patterson, G.S. (2000). Effects of late summer cattle grazing on the diversity of riparian pasture vegetation in an upland conifer forest. *Journal of Applied Ecology*. **37**: 986–996.

IIED. (2017). *Misconceptions on drylands and pastoralism.in I. I. f. E*. a. Development, editor., London.

Ilstedt, U., Tobella, A. B., Bazie, H. R., Bayala, J. E., Verbeeten, G., Nyberg, J., Sanou, L., Benegas, D., Murdiyarso, H., Laudon, D., Sheil, and Malmer, A. (2016). Intermediate tree cover can maximize groundwater recharge in the seasonally dry tropics. Scientific Reports 6.

Jose, P., Douglas, B., Saikat, D.R., Deepayan, S.and the **R** Development Core Team (2011). Available at https://cran.r-project.org/web/packages/nlme/citation.html .Accessed on 10th April 2017, 10:00 am.

Kairis, O., Karavitis, C., Salvati, L., Kounalaki, A. and Kosmas, K. (2015). Exploring the impact of overgrazing on soil erosion and land degradation in a dry Mediterranean Agro-Forest Landscape (Crete, Greece). *Arid Land Research and Management*. **29** (3):360–374.

Keesstra, S. D., Geissen, V., Mosse, K., Piiranen, S., Scudiero, E., Leistra, M. and Van Schaik, L. (2012). Soil as a filter for groundwater quality.*Curr. Opin. Environ. Su*. **4**: 507–516.

Kemp, D. R., and Michalk, D. L. (2007). Towards sustainable grassland and livestock management. *Journal of Agricultural Science*. **145**:543-564.

Kikoti, I. A., and Mligo, C. (2015). Impacts of livestock grazing on plant species composition in montane forests on the northern slope of Mount Kilimanjaro, Tanzania. *International Journal of Biodiversity Science, Ecosystem Services & Management*. **11**:114-127.

Kimball, S. and Schiffman, P.M. (2003). Differing effects of cattle grazing on native and alien plants. *Conservation Biology*. **17**: 1681-1693.

Kioko, J., Warui Kiringe ,J and Ole Seno, S. (2012). Impacts of livestock grazing on a savanna grassland in Kenya. *Journal of Arid Land*. **4**(1): 29−35.

Knowles, T., Assede, E., Daitz, D., Geldenhuys, C., Scholes, R. J., Trollope, W. S. W., and Zietsman, J. (2016). "Africa – the Fire Continent: Fire in Contemporary African Landscapes." TerrAfrica partnership and the World Bank Group.

Liebig, M.A., Gross, J.R., Kronberg, S.L., Hanson, J.D., Frank, A.B. and Phillips, R.L. (2006). Soil response to long-term grazing in the northern Great Plains of North America. *Agriculture, Ecosystems and Environment.* **115**:270-276.

Liu, X., Herbert, SJ., Hashemi ,A.M., Zhang, X. and Ding, G. (2006). Effects of agricultural management on soil organic matter and carbon transformation. *Soil and Environment.* **53**:531–543.

Lu, X., Yan, Y., Sun, J., Zhang, X., Chen, Y., Wang, X., and Cheng, G. (2015). Short-term grazing exclusion has no impact on soil properties and nutrients of degraded alpine grassland in Tibet, China. *Solid Earth*. **6**:1195–1205.

Mapfumo, E., Chanasyk, D. S., Naeth, M. A. and Baron, V. S. (1999). Soil compaction under grazing of annual and perennial forages. *Canadian Journal of Soil Science.* **79**: 191–199.

Mbatha, K.R. and Ward, D. (2010). The effects of grazing fire nitrogen and water availability on nutritional quality of grass in semi-arid savanna, South Africa. *Journal of Arid Environments.* **74**: 1294–1301.

McGinty, A.W., Smeins, F.E. and Merill, L.B. (1979). Influence of soil, vegetation and grazing management on infiltration rate and sediment production of Edward plateau rangeland. *Journal of Range Management.* **32**: 33-37.

McIntosh, P.D. and Allen , R.B. (1998) .Effect of Exclosure on Soils, Biomass,Plant nutrients, and Vegetation, on Unfertilised Steeplands, Upper Waitaki District,South island, New Zealand. *New Zealand Journal of Ecology*. **22**(2):209-217.

McNaughton, S. J., Ruess, R. W. and Seagle, S. W. (1988). Large mammals and process dynamics in African ecosystems. *Bioscience*. **38**:794-800.

Medina-Roldán, E., Paz-Ferreiro, J., and Bardgett, R. D. (2012). Grazing exclusion affects soil and plant communities, but has no impact on soil carbon storage in an upland grassland. *Agriculture, Ecosystems and Environment*. **149**: 118-123.

Mikola, J., Yeates, G.W., Barker, GM., Wardle, D.A. and Bonner, K.I (2001). Effects of defoliation intensity on soil food-web properties in an experimental grassland community. *Oikos*. **92**(2):333–343.

Milchunas, D.G., and Lauenroth, W.K.(1993). Quantitative effects of grazing on vegetation and soils over a global range of environments. *Ecological Monographs*. **63**:327–366.

Milton, S.J, Dean, W. R. J., Du Plessis , M. A, et al. (1994). A conceptual model of arid rangeland degradation. Bioscience. 44(2): 707–718. Morgan R P C. 1995. Soil Erosion and Conservation, 2nd ed. Essex: Longman Group.

Mitiku Habte, (1999).Soil acidity as a constraint to the application of arbuscular mycorrhizal technology, in: A. Varma, B. Hock (Eds.), Mycorrhiza 2nd ed. Springer-Verlag, Berlin, Germany, pp. 557-569.

Mofidi, M., Jafari, M., Tavili, A., Rashtbari, M., and Alijanpour, A. (2013): Grazing exclusion effect on soil and vegetation properties in Imam Kandi Rangelands, Iran. *Arid Land Research and Management*. **27**:32– 40.

Moussa A.S., Van Rensburg, L., Kellner K and Bationo, A. (2008). *Soil indicators of rangeland degradation in a semi-arid communal district in South Africa*. Future of Dry lands. pp. 383-393.

Mulongoy, K., and Merckx, R. (Eds.). (1993). *Soil Organic Matter Dynamics and Sustainability of Tropical Agriculture: Proceedings of an International Symposium.. Held in Leuven, Belgium, 4-6 November 1991*. Wiley.

Mureithi, S. M., Verdoodt, A., Njoka, J. T., Gachene, C K.K., Warinwa, F., Ranst, E. V. (2016). Impact of Community Conservation Management on Herbaceous Layer and Soil nutrients in A Kenyan Semi-arid Savannah. *Land Degradation and Development.* **27**: 1820–1830.

Naeth, M. A., Chanasyk, D. S., Rothwell, R. L. and Bailey, A. W. (1991). Grazing impacts on soil water in mixed prairie and fescue grassland ecosystems of Alberta. *Canadian Journal of Soil Science*. **71**: 313–325.

Neely, C., Bunning, S. and Wilkes, A. (2009). Review of evidence on drylands pastoral systems and climate change. FAO. CiteSeer. Available at http://www.fao.org/uploads/media/LWdisc_paper8_temp.pdf .Accessed on 3rd February 2017, 3:00 pm.

Neff, J.C., Reynolds, R.L., Belnap, J. and Lamothe ,P. (2005). Multi-decadal of grazing on soil physical and biochemical properties in southeast Utah. *Ecological Applications*. **15**(1):87-95.

NSW Prime fact (2017). Locust damage in crops and pastures. Prime Fact. NSW Department of Primaryindustries. Available at https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0005/336983/Locust-damage-in-crops-and-pastures.pdf. Accessed on January 20th March 2017.

Obeso, J.R. (1993). Does defoliation affect reproductive output in herbaceous perennials and woody plants in different ways? *Functional Ecology*. **7**:150–155.

O'Connor, T. G., Puttick, J. R .and. Hoffman. M. T. (2014). Bush encroachment in southern Africa: changes and causes. *African Journal of Range and Forage Science*. **31**:67-88.

Oesterheld, M., Loreti, J., Semmartin, M. and Paruelo, J.M. (1999). *Grazing, fire, and climate effects on primary productivity of grasslands and savannas*. In: Walker LR (ed) Ecosystems of disturbed ground. Elsevier, Amsterdam, pp 287–306.

Okansen, L., Blanchet, F., Kindt, R et al. (2013). Vegan: Community ecology package R package version 2.0-7. Available at https://cran.r-project.org/web/packages/vegan/index.html .Accessed on 20th April 2017.9:00 am.

Owen-Smith, N. (1999*). The animal factor in yield management: implications of selective patters of grazing*. In: Tainton N D. Veld Management in South Africa. Pietermaritzburg: University of Natal Press.pp. 129–130.

Pandey, C.B. and Singh, J.S. (1992). Rainfall and grazing effects on net primary productivity in a tropical savanna. *Indian Journal of Ecology*. **73**: 2007–2021.

Parr, C. L., Lehmann, C. E. R., Bond, W. J., Hoffmann, W. A. and Andersen, A. N. (2014). Tropical grassy biomes: misunderstood, neglected, and under threat. *Trends in Ecology and Evolution*. **29**:205-213.

Parton, W.J., Schimel, D.S., Cole, C.V. and Ojima, D.S. (1987). Analysis of factors controlling soil organic matter levels in Great Plains grasslands. *Soil Science Society of America Journal*. **51**:1173–1179.

Pei, S.F., Fu, H. and Wan, C. G. (2008). Changes in soil properties and vegetation following exclosure and grazing in degraded Alxa desert steppe of Inner Mongolia, China. *Agriculture, Ecosystems and Environment.* **124**:33 -39.

Perveen, A., Sarwar, G.R. and Hussain, I. (2008). Plant Biodiversity and phytosociological attributes of Dureji (Khirthar Range). *Pakistan Journal of Botany*. **40**:17-24.

Peter, D., Ralph, B. and Neal ,S.(1996). Effects of Exclosure and Management on Biomass and Soil Nutrient Pools in Seasonally Dry High Country, New Zealand. *Journal of Environmental Management*. **51**(2):170-173.

Porter, E.E., Redak, R.A., Braker, H.E. (1996). Density, biomass, and diversity of grasshoppers (Orthoptera: Acrididae) in a California native grassland. *Great Basin Naturalist*. **56**:172-176.

Pucheta, E., Cabido, M., Diaz, S. and Funes, G. (1998). Floristic composition biomass, and aboveground net plant production in grazed and protected sites in mountain grassland of central Argentina. *Acta Oecologica*. **19**:97–105.

Qin, Y., Decao Niu, Jian Kang, Yanfei Zhou, Xianglin Li (2015). Effects of Livestock Exclusion on Soil Physical and Biochemical Properties of a Desert Rangeland. *Polish Journal of Environmental Studies.* **24**(6):2587-2595

R Core Team (2014). R: A language and environment for statistical computing. In: R Foundation for Statistical Computing.(ed R Core Team).Vienna.

Available at on http://www.gbif.org/resource/81287.Accessed Accessed on 21th April 2017.10:00 am.

Raiesi, F. and Riahi, M. (2014).The influence of grazing exclosure on soil C stocks and dynamics, and ecological indicators in upland arid and semi-arid rangelands. *Ecological Indicators*. **41**:145–154.

Reid, R. S., Kruska, R. L., Muthui, N., Taye, A., Wotton, S., Wilson, C. J. and Mulatu, W. (2000). Land-use and land-cover dynamics in response to changes in climatic, biological and socio-political forces: the case of southwestern Ethiopia. *Landscape Ecology*. **15**:339-355.

Rietkerk, M., Ketner, P., Burger, J., Hoorens, B. and Olff, H. (2000). Multiscale soil and vegetation patchiness along a gradient of herbivore impact in a semi-arid grazing system in West Africa. *Plant Ecology*. **148**(2):207–224.

Roberts, D. (2015). Labdsv: Ordination and Multivariate Analysis for Ecology. R package version 1.7–0.
Available at https://cran.r-project.org/web/packages/labdsv/labdsv.pdf .Accessed on 21th april 2017.

Robertson, E. (1996). *Impacts of Livestock Grazing on Soils and Recommendations for Management*. California: California Native Plant Society.

Rutherford, M.C., Powrie ,L.W. and Husted, LB.(2012). Herbivore-driven land degradation: consequences for plant diversity and soil in arid subtropical thicket in southeastern Africa. Land Degradation & Development. DOI: 10.1002/ldr.2181

Sankaran, M., Hanan, N.P., Scholes, R.J., Ratnam, J., Augustine,D.J., Cade, B.S., Gignoux, J., Higgins, S.I., Le Roux, X., Ludwig, F., Ardo, J., Banyikwa, F., Bronn, A., Bucini, G., Caylor, K.K., Coughenour, M.B., Diouf, A., Ekaya, W., Feral, C.J., February, E.C., Frost, P.G.H., Hiernaux, P., Hrabar, H., Metzger, K.L., Prins, H.H.T., Ringrose, S., Sea, W., Tews, J., Worden,J., Zambatis, N. (2005). Determinants of woody cover in African savannas. *Nature*. **438**:846-849.

Savadogo, P, Sawadogo, L, Tiveau, D. (2007). Effects of grazing intensity and prescribed fire on soil physical and hydrological properties and pasture yield in the savanna woodlands of Burkina Faso. *Agriculture, Ecosystems and Environment*. **118**:80–92.

Scholes, R.J and Archer, S.R. (1997). Tree-grass interactions in savannas. *Annual Review of Ecology, Evolution and Systematics*. **28**:517-544.

Shan, Y., Chen, D., Guan, X., Zheng, S., Chen, H., Wang ,M. and Bai, Y.(2011). Seasonally dependent impacts of grazing on soil nitrogen mineralization and linkages to ecosystem functioning in Inner Mongolia grassland. *Soil Biology and Biochemistry*. **43**: 1943-1954.

Shariff, A.R., Biondini, M.E. and Grygiel, C.E. (1994). Grazing intensity effects on litter decomposition and soil nitrogen mineralization. *Journal of range Management*. **47**:444-449.

Sheppard, E., Porter, P.W., Faust, D.R., Nagar, R. (2009). *A World of Difference: Encountering and Contesting Development,* second ed. Guilford Press, New York. p.665.

Singer, F.J. and Schoenecker, K.A. (2003). Do ungulates accelerate or decelerate nitrogen cycling?. *Forest Ecology and Management*. **181**:189–204.

Skarpe, C. (1991). Impacts of grazing in savanna ecosystems. *Forestry and the Environment*. **20**:351–356.

Skarpe, C. (1992). Dynamics of savanna ecosystems. *Journal of Vegetation Science*. **3**(3):293-300.

Snyman, H.A. (1998). Dynamics and sustainable utilization of rangeland ecosystems in arid and semi-arid climates of southern Africa. *Journal of Arid Environments*. **39**:645-666.

Solomon Tefera, Snyman, H.A., Smit , G.N.(2007). Rangeland dynamics in southern Ethiopia: (1) Botanical composition of grasses and soil characteristics in relation to land-use and distance from water in semi-arid Borana rangelands. *Journal of Environmental Management.* **85**:429-442.

Somda, Z. C., Powell, J. M. and Bationo, A. (1997). Soil pH and nitrogen changes following cattle and sheep urine deposition. *Communications in Soil Science and Plant Analysis*. **28**:1253–1268.

Steffens, M., Kölbl, A., Totsche, K.U., Kögel-Knsbner, I. (2008). Grazing effects on soil chemical and physical properties in a semi-arid steppe of Inner Mongolia (P. R. China). *Geoderma*. **143**:63-72.

Sternberg, M., Gutman, M., Perevolotsky, A., Ungar , E.D and Kigel, J .(2000). Vegetation response to grazing management in a Mediterranean herbaceous community: a functional group approach. *Journal of Applied Ecology*. **37**:224–237

Su, Y.Z., Li, Y.L., Cu,i J.Y., Zhao, W.Z .(2005). Influences of continuous grazing and livestock exclusion on soil properties in degraded sandy grassland, Inner Mongolia, northern China. *Catena*. **59**:267–278.

Tan, K.H. (2005). *Soil sampling, preparation and analysis* (2nd ed) Boca Raton, Florida, USA. pp. 342-343.

Tate, K.W., Dudley, D.M., McDougald , N.K. and George, M.R. (2004). Effect of canopy and grazing on soil bulk density. *Rangeland Ecology and Management*. **57**(4): 411-417.

Tefera Mengistu, Demel Teketay, Håkan, H. and Yonas Yemshaw (2005). The role of exclosures in the recovery of woody vegetation in degraded dryland hillsides of central and northern Ethiopia. *Journal of Arid Environments*. **60**:259–281.

Tesfay Yayneshet (2011). Restoration of Degraded Semi-Arid Communal Grazing Land Vegetation Using the Exclosure Model. *International Journal of Water Resources and Arid Environments*. **1**(5):382-386.

Thomas, D. A and Squires ,V.R (1990). Available soil moisture as a basis for land capability assessment in semi-arid regions. *Plant Ecology*. **91**:183-189.

Tilman, D. (1994). Competition and Biodiversity in Spatially Structured Habitats. *Ecology* .**75**:2-16.

Van der Maarel, E., and Sykes, M. T. (1993). Small-scale plant species turnover in a limestone grassland: the carousel model and some comments on the niche concept. *Journal of Vegetation Science*. **4**:179-188.

Verdoodt, A., Mureithi ,S.M., Ye, L. and Van Ranst ,E. (2009). Chronosequence analysis of two enclosure management strategies in degraded rangeland of semi-arid Kenya. *Agriculture, Ecosystems and Environment*. **129**:332–339.

Vetter, S. (2005). Rangelands at equilibrium and non-equilibrium: recent developments in the debate. *Journal of Arid Environments*. **62**:321-341.

Walkley. A., Black, C.A. (1933). An examination of different methods for determining soil organic matter and the proposed modification of the chromic acid titration method. *Journal of Plant Nutrition and Soil Science.* **37**:29–38.

Wardle, D.A. and Bardgett, R. D. (2004). Human-induced changes in large herbivorous mammal density: The consequences for decomposers. *Frontiers in Ecology and the Environment*. **2**:145-153.

Warren, S.D., Nevill M.B., Blackburn, W.H. and Garza, N.E. (1986). Soil response to trampling under intensive rotation grazing. *Soil Science Society of America Journal*. **50**(5):1336-1341.

Watkinson, A.R and Ormerod, S.J. (2001).Grasslands, grazing and biodiversity. *Journal of Applied Ecology*. **38**:233–237.

Wei Li, Hai-Zhou Huang, Zhi-Nan Zhang and Gao-Lin Wu. (2011). Effects of grazing on the soil properties and C and N storage in relation to biomass allocation in an alpine meadow. *Journal of Soil Science and Plant Nutrition*. **11**(4):27-39.

Weil, R.R. and Magdoff, F. (2004). *Significance of soil organic matter to soil quality and health*. In: Magdoff F, Weil RR, editors. Soil organic matter in sustainable agriculture. London: CRC Press, p. 1–43.

Wolde Mekuria and Ermias Aynekulu (2013). Exclosure land management for restoration of the soils in degraded communal grazing lands in northern Ethiopia. *Land Degradation and Development.* **24**:528–538.

Wolde Mekuria, Veldkamp, E., Mitiku Haile, Nyssen, J., Muys, B. and Kindeya Gebrehiwot (2007).Effectiveness of exclosures to restore degraded soils as a result of overgrazing in Tigray, Ethiopia. *Journal of Arid Environments.* **69**:273–277.

Woldeamlak Bewket and Stroosnijder, L. (2003). Effects of agroecological land use succession on soil properties in Chemoga watershed, Blue Nile basin, Ethiopia. *Geoderma*. **111**(1):85-98.

Wood, K., Rubio, H., Wood, C. (2008). Rangeland management and hydrology. Proceedings XXI International Grassland Congress and VII International Rangeland Congress, Hohhot, China. 1:809–812.

Young-Zhong, S., Yu-Lin, L., Jian-Yaun, C. and Wen-Zhi, Z. (2005) Influences of continuous grazing and livestock exclusion on soil properties in degraded sandy grassland, Inner Mongolia, northern China. *Catena*. **59**:267–278.

Yuan, J., Ouyang, Z., Zheng, H., and Xu, W. (2012). Effects of different grassland restoration approaches on soil properties in the southeastern Horqin sandy land, northern China. *Applied Soil Ecology*. **61**:34–39.

Yuqiang, L., Xueyong, Z., Yinping, C., Yongqing, L., and Shaokun, W. (2012). Effects of grazing exclusion on carbon sequestration and the associated vegetation and soil characteristics at a semi-arid desertified sandy site in Inner Mongolia, northern China. *Canadian Journal of Soil Science*. **92**: 807-819.

Appendices

Appendix 1.List of field layer species

Species	Family	Habit
Bothriochloa insculpta (Hochst. ex A. Rich.) A. Camus	Poaceae	Grass
Leucas deflexa Hook .f.	Lamiaceae	Herb
Heteropogon contortus (L.) Roem. & Schult.	Poaceae	Grass
Ageratum conyzoides L.	Asteraceae	Herb
Sorghum arundinaceum (Desv.) Stapf	Poaceae	Grass
Justicia heterocarpa T. Anders.	Acanthaceae	Herb
Bidens pilosa L.	Asteraceae	Herb
Hyparrhenia dregeana (Nees) Stent	Poaceae	Grass
Pennisetum purpureum Schumach.	Poaceae	Grass
Vernonia congolensis De Wild & Muschl.	Asteraceae	Herb
Triumfetta rhomboidea Jacq.	Tiliaceae	Herb
Hyparrhenia filipendula (Hochst.) Stapf	Poaceae	Grass
Abutilon figarianum Webb.	Malvaceae	Herb
Hyparrhenia cymbaria (L.) Stapf	Poaceae	Grass
Hypoestes triflora (Forssk.) Roem & Schult.	Acanthaceae	Herb
Acacia polyacantha Willd.	Fabaceae	Tree
Hypoestes forskaolii (Vahl) R. Br.	Acanthaceae	Herb
Ocimum urticifolium Roth	Lamiaceae	Shrub
Glycine wightii (Wight & Arn.) Verdc.	Fabaceae	Climber
Melinis repens **(**Willd.) Zizka	Poaceae	Grass
Senna obtusifolia (L.) Irwin & Barneby	Fabaceae	Herb
Peristrophe paniculata (Forssk.) Brummitt	Acanthaceae	Herb
Achyranthes aspera L.	Amaranthaceae	Herb
Hygrophila schulli (Hamilt.) M.R. & S.M. Almeida	Acanthaceae	Herb
Acacia etbaica Schweinf.	Fabaceae	Tree
Acacia nilotica (L.) Willd. ex. Del.	Fabaceae	Tree
Dichrostachys cinrea (L.) Wight & Arn.	Fabaceae	Shrub
Dombeya torrida (J.F. Gmel.) P. Bamps	Sterculiaceae	Shrub
Grewia bicolor Juss.	Tiliaceae	Shrub
Panicum maximum Jacq.	Poaceae	Grass
Dregea schimperi (Decne.) Bullock	Asclepiadaceae	Climber
Oplismenus hirtellus (L.) P. Beauv.	Poaceae	Grass
Pennisetum trachyphyllum Pilg.	Poaceae	Grass
Sida rhombifolia L.	Malvaceae	Herb
Cynodon dactylon (L.) Pers.	Poaceae	Grass
Acacia abyssinica Hochst. ex Benth.	Fabaceae	Tree
Celosia argentea L.	Amaranthaceae	Herb

Sorghum purpureo sericeum (Hochst. ex A. Rich.) Aschers. & Schweinf.	Poaceae	Grass
Tagetes minuta L.	Asteraceae	Herb
Crotalaria plowdenii Bak.	Fabaceae	Herb
Parthenium hysterophorus L.	Asteraceae	Herb
Acacia seyal Del.	Fabaceae	Tree

Appendix 2.Indicator species for fenced and grazed plots, all species with p<0.25 listed). Significant results at the 0.05 level indicated in bold text.

Species	Family	Indicator species for	p-value
Bothriochloa insculpta	Poaceae	Fenced	**0.017**
Heteropogon contortus	Poaceae	Fenced	0.058
Sorghum arundinaceum	Poaceae	Fenced	0.124
Justicia heterocarpa	Acanthaceae	Fenced	0.235
Leucas deflexa	Lamiaceae	Grazed	**0.041**
Ageratum conyzoides	Asteraceae	Grazed	0.074

Appendix 3. List of tree and shrub species

Species	Family	Habit
Acacia etbaica Schweinf.	Fabaceae	Tree
Acacia nilotica (L.) Willd. ex. Del.	Fabaceae	Tree
Acacia polyacantha Willd.	Fabaceae	Tree
Acacia seyal Del.	Fabaceae	Tree
Combretum collinum Fresen.	Combretaceae	Tree
Combretum molle R. Br. ex G. Don.	Combretaceae	Tree
Cussonia holstii Harms ex. Engl.	Araliaceae	Tree
Dombeya torrida (J.F. Gmel.) P. Bamps	Sterculiaceae	Tree
Grewia bicolor Juss.	Tiliaceae	Tree
Maerua triphylla A. Rich.	Capparidaceae	Tree
Maytenus senegalensis (Lam.) Exell	Celastraceae	Tree
Rubus apetalus Poir.	Rosaceae	Tree
Terminalia schimperiana Hochst.	Combretaceae	Tree
Pavetta abyssinica Fresen.	Rubiaceae	Tree
Dichrostachys cinrea (L.) Wight & Arn.	Fabaceae	Shrub
Ehretia cymosa Thonn.	Boraginaceae	Shrub
Rhus natalensis Krauss	Anacardiaceae	Shrub
Ximenia americana L.	Olacaceae	Shrub
Ziziphus abyssinica Hochst. ex A. Rich.	Rhamnaceae	Shrub

Appendix 4.Tree and Shrub cover (%) (Averages from four 30 m transects)

Site	1	1	2	2	3	3	4	4	5	5	6	6
Treatment	F	G	F	G	F	G	F	G	F	G	F	G
Acacia etebaica			12	32	8	17					23	
Acacia nilotica				27						1	25	27
Acacia polyacantha	30	17				5						
Acacia seyal			19		7	5	3				24	20
Combretum collinum	22						7	23	19	21	5	13
Combretum molle			13		3			4	10	11	27	10
Cussonia holstii	5	2							17	7		1
Dombeya torrida								6	12			
Grewia bicolor				7	4	5				13		3
Maerua triphylla				4								
Maytenus senegalensis		5					9	10	7	7		
Rubus apetalus									24	11		
Terminalia schimperiana							13					
Pavetta abyssinica		17										
Tree cover %	**20**	**10**	**22**	**23**	**13**	**19**	**17**	**18**	**35**	**32**	**50**	**23**
# tree individuals/30 m trans.	**1**	**1**	**2**	**2**	**3**	**4**	**3**	**3**	**4**	**5**	**4**	**3**
# tree species / trans.	**1**	**1**	**2**	**2**	**2**	**2**	**3**	**2**	**3**	**4**	**2**	**2**
Shrub species												
Dichrostachys cinrea	11	12	9	9	18	12	12	12	10	14		12
Ehretia cymosa	2											
Rhus natalensis	16	19			5	10	5	10		3		12
Ximennia Americana					10							
Ziziphus abyssinica					3							
Shrub cover %*	**27**	**27**	**10**	**10**	**24**	**19**	**16**	**15**	**9**	**16**	**0**	**14**
# shrub individuals/30 m.trans.	**5**	**4**	**2**	**2**	**5**	**5**	**3**	**2**	**2**	**4**	**0**	**1**
# shrub species / trans.	**2**	**2**	**1**	**1**	**2**	**2**	**2**	**2**	**1**	**2**	**0**	**1**

*If tree species were < 250 cm tall (not common) they were recorded in the shrub layer

Appendix 5. Field layer species composition per site and plots

	1120 m		1290 m		1450 m		1550 m		1520 m		1570 m	
	Fenced	Grazed	Fenced	Grazed	Fenced	Grazed	Fenced	Grazed	Fenced	Grazed	Fenced	Grazed
Abutilon figarianum	5	5			5	5	5	5	10	6.7	10	5
Acacia abyssinica									10	5		
Acacia etbaica					5							
Acacia polyacantha			10	5	6.7	5						
Acacia seyal										5		
Achyranthes aspera	17.1	17.5	7.5	5	7.5	10	10	5	5	12	10	6.7
Ageratum conyzoides	10	20	35	10	12.9	37.5	7	16.3	14	14.2	13.1	19.4
Bidens pilosa	20	5	10	5	10	15	15	15	17.5	10	23.1	11.9
Celosia argentea									10	5		
Crotalaria plowdenii									10	10		
Dichrostachys cinrea	5											
Dombeya torrida							5					
Dregea schimperi	5						5	5				
Glycine wightii			35	5					5	10		
Grewia bicolor			5									
Hygrophila schulli					5	5	5	5	5	5	5	5
Hypoestes triflora								10	9	11.3	5	15
Hypoestes forskaolii			36.3	19.4	16.7	11	7.5	9.3	10	10	18.6	19.4
Justicia heterocarpa	7.5	5	19.2	7.1	6	6	8.3	7.5	5	5	11.4	6.3
Leucas deflexa	6.7	5	7.5	15.8	8.3	8.8	5	11.4	5	10	8.8	10
Ocimum urticifolium	10						10	5	5	10		
Parthenium hysterophorus	5						5	15				
Peristrophe paniculata	12.5	5	10	15	10	6.7					8.3	10
Senna obtusifolia	15	14									10	10
Sida rhombifolia					5	5			13.3	20		
Tagetes minuta					10	5						
Acacia nilotica									5			
Triumfetta rhomboidea	15						29.3	13	10	5	10	5
Vernonia congolensis	15						15	10				
Bothriochloa insculpta	10	5	10	5	15	5	10	5	5	5	10	5
Cynodon dactylon					12.5	10						
Heteropogon	25	15	15	25	25	11.3	21.4	10	16.7	9	15.8	10

contortus												
Hyparrhenia cymbaria					15.7	15	11.3	10	25	10		
Hyparrhenia dregeana					27.5	5	13.3	5	10	5	25	10
Hyparrhenia filipendula	30						15.8	5				
Melinis repens									20	5	5	5
Oplismenus hirtellus					20	5						
Panicum maximum											10	
Pennisetum purpureum	46.7	5	20	5	16.3	5						
Pennisetum trachyphyllum					20	5						
Sorghum arundinaceum	55		10	5	10	5	15	5	10	5		
Sorghum purpureo sericeum	20	10										

Declaration

I, the undersigned declare that this Thesis is my original work and it has not been presented in other universities, colleges or institutes for a degree or other purpose. All sources of the materials used have been duly acknowledged.

Name: __________________________ Signature: ______________ Date: ____________

This work has been done under my supervision.

Name: _____________________________Signature:_______________Date:__________

__________________________________Signature:_______________Date: __________

__________________________________Signature:_______________Date: __________