LONG-TERM ECOLOGICAL EFFECTS OF RANGELAND BURNING, GRAZING AND BROWSING ON VEGETATION AND ORGANIC MATTER DYNAMICS

A Thesis submitted for a the degree of

DOCTOR OF PHILOSOPHY IN PASTURE SCIENCE

at the Department of Livestock and Pasture Sciences, Faculty of Science and Agriculture, University of Fort Hare, South Africa

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February 2013

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Clement Ratsele Ratsele **February 2013**

ACKNOWLEDGEMENTS

This research work would not have been possible without the heart whelming support of many people. It bears on imprint of many individuals and institutions/organizations that I unreservedly acknowledge below:

Persons

Dr. S Dube (Supervisor), for his proficient guidance, constructive criticisms and support throughout my study

Dr. A Fatunbi, for his competent guidance during the preparation of research proposal for this study

Mr. T. Martins, for his editorial assistance and constructive comments

Mr. MS Lesoli, for his precise statistical analysis, data collection and general academic matters

Dr. B Moyo, for support and statistical analysis.

Mr. T Tshabalala, for his readiness to help, and data collection.

Mr. E Ramaboli, for his encouragement and motivation during data collection stage of this work.

Messrs M Nyanga, WM Sibanga and D Pepe, for their readiness to provide help at all times and data collection.

Mrs. NM 'Mota (Principal Secretary, Ministry of Forestry and Land Reclamation), for granting me study leave to complete my studies.

Mr. N Maile (Deputy Principal Secretary, Ministry of Forestry and Land Reclamation), for his encouragement and readiness to offer a helping hand at all times during my study.

Mrs. L Thulo (Former Director, Department of Range Resources Management) for granting me opportunity to pursue this important study.

Mr. P Moeletsi, for encouragement and untiring support to me and my family.

Institutions

Department of Livestock and Pasture Sciences, University of Fort Hare, for provision of all forms of resources and facilities to undertake this study.

Matopos Research Station, Zimbabwe, for provision of resources necessary for data collection used in this study.

Government of Lesotho, National Manpower Development Secretariat, for financial support.

Ministry of Forestry and Land Reclamation, Lesotho for granting me opportunity to undertake this important study.

Department of Range Resources Management of the Ministry of Forestry and Land Reclamation, Lesotho for granting me this precious opportunity to finish this chapter in life.

DEDICATION

I dotingly dedicate this work to my angelic wife ’Me ’MAPONTŠO and my lovely kids SEFABATHO, MATŠENG, PONTŠO and MAMELLO.

ABSTRACT

To proffer a sustainable solution to ecological degradation in rangeland ecosystems as a consequence of fire, grazing and browsing, an understanding of rangeland ecological processes is vital. Due to the complexity of ecological processes and their interrelationships, it is usually difficult or expensive to directly measure status of ecological processes. Therefore, biological and physical characteristics are often used to indicate the functionality of ecological processes and site integrity. Long-term effects of fire, grazing and browsing on characteristics of the vegetation and organic matter and their subsequent effects on selected rangelands ecosystem ecological processes was conducted at Honeydale section of the University of Fort Hare farm in the Eastern Cape Province of South Africa and Matopos Research Station in Zimbabwe.

In this study, attributes of biotic community integrity (species richness, composition and diversity), soil stability (basal cover, standing dead grass biomass, tuft to tuft distance, tufts diameter, canopy distance and stem to stem distance), productivity and plant vigour (grass yield, total canopy volume, plant height, canopy height, canopy diameter, main stem diameter, sprouts diameter and number of sprouts) and hydrologic function and nutrient cycling (grass litter biomass, soil organic carbon and microbial biomass carbon) were used to estimate long-term effects of burning, grazing and browsing by goats on the functionality of ecological processes in the rangeland ecosystem.

Burning did not have differential effect on grass species richness (P>0.05), woody species diversity as well as compositional percentage for *D.eriatha*, *C.plurinodis*, *S.fimbriatus*, *A.karro* and *E.rigida*.

Burning increased decreasers and increaser II species proportions and reduced ($P \leq 0.05$) grass yield, total canopy volume, tree height, canopy height main stem diameter and sprouts diameter.

Long-term burning, grazing, and goats browsing had differential effects on site stability. The effects on basal cover, tuft to tuft distance, tufts diameter, canopy distance and basal distance as a consequence of long-term burning, grazing, and goats browsing were not significantly different, whereas the effects on standing dead grass biomass as a result of long-term burning frequencies were significantly different. Long-term effects of burning followed by ten-year period of fire exclusion had significantly different effects on tuft-tuft distance but did not have statistically different effects on tufts diameter, canopy distance and basal distance.

Long-term burning grazing and browsing had significantly different effects on attributes of hydrologic functions and nutrient cycling in the rangeland ecosystem (grass litter biomass, SOC and BMC). Long-term effects of burning followed by ten-year period of fire exclusion had significantly different effects on grass litter biomass, and SOC.

Through their effect on vegetation and organic matter characteristics, burning, grazing and browsing could influence functionality of selected rangeland ecological processes such as biological community integrity, productivity and plant vigour, site stability, hydrologic function and nutrient cycling.

Table of Contents

List of Tables

List of Figures

1 Introduction

1.1 Background

There is no theoretical reason to conclude that ecosystems would be more stable without existence or involvement of human beings. However, many ecosystems around the world are undergoing dramatic degradation due to the influence of human activities. There are numerous and obvious examples of human destructive interaction with the ecosystem e.g. fire and overgrazing. Hurni (1990) explains that fire can have detrimental effects to fire-prone terrestrial ecosystem resulting in physical, chemical, biological and hydrologic degradation which consequently threaten most ecosystems by reducing agricultural production and making restitution more difficult. Gonza´lez-P'erez et al. (2004) reveals that, after fire, several interactive factors that affect soil biota and organic matter occur; these include direct sterilization, formation of ash, fire-altered organic matter and changes in canopy and vegetation. In the same way ecological disturbance as a consequence of fire, threatens species which are endemic to localities (Bowles et al. 1990).

Long-term disturbance of vegetation on a site by either fire or herbivory could have effect on the ability of rangeland to perform certain key functions. Trollope and Coetzee (1978) demonstrate that rangelands that have been overgrazed by cattle and sheep are prone to invasion by bush vegetation; this is a special case where grazing management programmes do not include goats. Direct measures of disturbances on rangelands ecosystem are difficult or expensive due to the complexity of ecological processes and their interrelationships. Instead, biological and physical characteristics are used as indicators of the functionality of these processes.

1.2 Problem statement

Fire is an important component of most ecosystems. The importance of fire advanced by many scholars (Trollope & Coetzee 1978, Mills & Fey 2004, Guerrieri *et al.* 2004, Scholes & Archer 1997 and Tomanek 1948) is not without credibility. However, fire can also be destructive. There are constant debates and research studies among scientists about the use of fire in varied ecosystems. Despite numerous research studies on the matter, this enigmatic state still persists. Effectively, fire is not the only factor that can impact negatively on ecosystems, intense browsing and grazing can also have detrimental consequences on some biotic elements in the ecosystems (Zaady *et al* 2001, Kathryn *et al*. 2007). Impacts of fire, grazing and browsing on vegetation parameters have been extensively covered in previous studies by scholars/researchers such as Trollope & Trollope 1999, Di Tomaso & Johnson 2006 and Keeley *et al*. 2003). However, inconsistencies in the results demonstrate that this matter is not yet fully understood. In addition, the effect of fire, grazing and browsing reported in a wide range of previous studies including Warrnambool 1995, Trollope and Trollope 1996, Manson *et al*. 2007 and Short *et al*. 2003 show that more understanding is a prerequisite. In particular, information from such studies is limited in respect to how long term disturbances of a site by fire and herbivory impact on functionality of ecological processes e.g. integrity of the biotic components.

It is therefore, very important to further investigate long-term effects of perturbations of rangelands by fire, grazing and browsing on vegetation characteristic. The questions that the study sought to answer were (i) could long-term burning, grazing and goats browsing effects on vegetation characteristics and organic matter help to predict functionality of ecological processes of rangelands ecosystem and (ii) how could ecological processes on rangelands ecosystem be affected when fire is excluded from a site that was previously subjected to long-term fire treatments? This study will contribute significantly to the knowledge base regarding fire usage in various ecosystems.

1.3 Rationale and motivation

Grazing and fire are major forces shaping patterns of vegetation in many ecosystems and both disturbances could have substantially variable effects (Harrison *et al*. 2003). These disturbance interactions suggest that fire and grazing must be handled with great care to background rangeland ecosystem functions. As a result, knowledge of how plants at both community and species level in fire prone ecosystems respond to fire frequencies is fundamental for management of biodiversity. It would thus, be interesting to learn more about fire, grazing and browsing effects on vegetation dynamics to expand the knowledge base.

Although the influence of long-term burning in varied ecosystems has been considerably researched (Gross 2005, Harrison *et al*. 2003, Tester 1989 and Brockway & Lewis 1997), rather less attention has been devoted to some of the less eminent elements of ecosystem such as organic matter and microbial biomass activities. Organic horizon is a critical component of ecosystem sustainability. It provides a protective soil cover that mitigates erosion, aids in regulating soil temperature and provides habitat and substrates for soil biota (Neary *et al.* 1999). Although, Neary *et al.* (1999) argue that short and long-term effect of fire on below ground microorganisms, and the resulting effect on ecosystem sustainability, is uncertain and often debatable, Mills & Fey (2004), Blair *et al*. (1998) and Rice *et al*. (1998) confirm that burning has effects on soil organic matter and soil fertility in grasslands. Mills and Fey (2003), advance that it is important to monitor changes in soil organic matter because it has a direct effect on soil physical properties (porosity, bulk density, and infiltration rate) and soil factors affecting plant nutrient supply.

Effects of burning on woody plant species is also an important phenomenon in rangeland ecosystems. Although, proliferation of woody vegetation species has been researched and widely documented (Brown & Archer 1999, Merrill *et al.* 2003), information is limited on the degree of damage inflicted by fire on recruitment of individual species in different localities. It is therefore clear, that knowledge on how fire affects aboveground organic matter, microbial activities and recruitment of different woody plant species in different ecosystems need to be enhanced. Fire combined with grazing and browsing could have a synergistic effect (Combined effect that is greater than the sum of their individual effects) on rangeland ecosystem. Effects of fire, grazing and browsing and their respective ecological importance in varied ecosystems should be a topic of continuing study and discussion. Fire is generally accepted as a management tool; however, its impacts in combination with grazing and browsing on both biotic and abiotic components of the ecosystems necessitate intensive study. Fire effects in the rangelands may be exacerbated by intensive grazing and browsing (Vermeire et al. 2004). On the one hand, goats as well as frequent burning can control bush encroachment, on the other goats can further damage the structure of bush clumps by browsing from the sides and exposing the interior to the forces of desiccating winds and erosion by water (Stuart-Hill, 1992).

Livestock grazing is considered a disturbance of both biotic and abiotic parameters that may lead to degradation of rangelands. To this effect, when grazing is used as management tool for restoration in managed ecological systems, Zaady et al. (2001) aver that (i) the densities of plant species decrease (~20%), (ii) vegetation community composition is affected (~50-61%) and (iii) exposed soil surface increases (~50%).

It is on the basis of the abovementioned argument that this study is geared towards discovering which fire frequency will have more detrimental effects and to what species. This is an important base towards attainment of restoration and ecologically sustainable landscape. This study makes immense theoretical contribution in science debates about ecological consequences of fire, grazing and browsing in fire prone ecosystems as a reference material.

1.4 Research Objectives

1.4.1 General objective

The general objective of the study was to investigate long-term effects of perturbations of a site by fire, grazing and browsing on characteristics of the vegetation and whether this can have effects on selected rangelands ecosystem ecological processes such as biological community integrity, soil stability, productivity and plant vigour and hydrologic function and nutrient cycling.

1.4.2 Specific research objectives

The specific objectives of the study are:

1. To investigate the effects of perturbation by long-term burning, grazing and browsing on vegetation characteristics and selected rangeland ecosystem ecological processes,

2. To investigate if fire exclusion from sites previously exposed to long term burning could have effects on post-fire vegetation characteristics and selected rangeland ecological processes.

1.5 Hypotheses

1) It is hypothesized that long-term perturbation of rangelands by burning, grazing and browsing can affect the vegetation characteristics and selected rangeland ecological processes such as biological community integrity, soil stability, productivity, plant vigour, hydrologic function and nutrient cycling.

2) If the hypothesis in (1) is true, then long-term perturbation of a site by different burning frequencies could have effects on vegetation characteristics and on ecological processes functions.

3) It is further hypothesized that fire exclusion from sites previously exposed to long term burning can have effects on the vegetation characteristics

4) If the hypothesis (3) is true, it is then fire exclusion from sites previously exposed to long-term burning will also have effects on other ecological processes.

1.6 Delineation and limitation

Usage of selected terms is provided below:

Browsing	Utilization of bush by goats
Burning	Prescribed burning
Grazing	Utilization of grass by cattle
Long-term	Over ten-year period
Organic matter	Standing dead grass biomass (moribund), above ground grass litter, soil organic matter and microbial C and N.
Rangeland	Natural grazing areas
Vegetation	Grass and bush
Soil and site stability	The capacity of a site to limit redistribution of loss of soil resources (including nutrients and organic matter) by wind and water.
Hydrologic function	The capacity of the site to capture, store, and safely release water from rainfall, run-on and snowmelt (where relevant), to resist a reduction in this capacity and to recover this capacity following degradation.
Biotic integrity	The capacity of a site to support characteristic functional and structural communities in the context of normal variability, to resist loss of this function and structure caused by disturbance, and to recover following such a disturbance.

Limitations in this study were: (i) use of experimental design without replications in one experimental site and (ii) missing or broken set of data (long-term). These limitations were imposed by the long term nature of the experiments spurning over 30 years.

1.7 Assumptions

It was assumed that accidental fires would not occur and affect the experiments.

2 Literature Review

2.1 Interaction between plants

Scientist investigating impacts inflicted by any form of perturbation to biotic elements need to consider that they are dealing with complex and intertwined parts of the ecosystem. Populations of species in an ecosystem live together in a physical contact, mutually benefiting from each other's presence. Destroying or enhancing one species in a local ecosystem may affect the whole system. Each species in an ecosystem, no matter how small, plays an important role and preserving such species could be of greater utility to the stability of ecosystems. Ecosystem stability is not static, but is a dynamic balance. Ecosystem stability is characterized by resistance (how consistent is the change following perturbation) and resilience (rate at which population density in an ecosystem returns to equilibrium after it has been disturbed away from equilibrium) (Elmqvist *et al*. 2003). In an ecosystem, interaction exists between biotic and abiotic components.

Interaction between plants is an important phenomenon that needs to be considered when studying consequences of any form of disturbance to plants or their immediate environment. According to Guerrieri *et al.* (2004) interaction between neighbouring plants is very important for plant growth. To add to this, Callaway (1995) clarifies that in savanna ecosystem, woody and graminaceous plants interact in many ways e.g. interaction mechanisms may be positive (facilitation) and negative (competition). Scholes and Archer (1997) further reports that the interactive effects of trees on grasses ranges from positive to neutral, and to negative depending on (*a*) the ecophysiological or specific characteristics of the tree, grass growth forms (canopy architecture, rooting patterns), photosynthetic pathway (C_3, C_4, CAM), photosynthetic habit (evergreen, deciduous), and resource requirements (light, water, nutrients), (*b*) availability of resources as influenced by interannual variability in the amount and seasonality of precipitation and topoedaphic properties, (*c*) extent of selective grazing, browsing, or granivory and (*d*) frequency, intensity, and extent of disturbances such as fire.

Competitive interaction between nutrients in homogeneous environments may be size symmetric (plants acquire nutrients in proportion to their biomass) (Casper & Jackson 1997, Berntson & Wayne 2000), while in heterogeneous habitats competition can be asymmetric, (larger individuals pre-empt resources, and deplete them before smaller plants can gain access (Fransen *et al*. 2001Weiner & Damgaard 2006). Environmental conditions are generally considered an important factor altering interaction between plants. Environmental conditions may modify competition between woody and herbaceous/graminaceous plants in arid and semi-arid systems by favouring trees in some years and grasses in other years; trees may have a net facilitative effect on grasses in some years and a net competitive effect in other years (Scholes & Archer 1997).

Herbaceous/graminaceous vegetation may affect woody plants and their recruitment in the ecosystem. With their relatively shallow, dense, fibrous root systems, grasses may successful compete with trees for resource in the upper soil horizons e.g. by intercepting water and nutrients and reducing their percolation to deeper portions of the soil profile where tree roots may be more abundant (Simmons *et al*. 2007). Similarly, by influencing fire frequency and intensity as fuel load, grasses may out-compete woody plants (Scholes & Archer 1997, Simmons *et al*. 2007). In the same way, Fetene (2003) reports that *Hyparrenia hirta* can be competitively aggressive towards *Acacia etbaica* by inhibiting the growth of tree seedlings when the *Acacia* are planted within the grass community. On the contrary, encroachment of trees could affect grass production resulting in increased grazing pressure (Scholes & Archer 1997).

Ecosystem perturbations, or disturbances, can be natural or induced. Human beings and their activities reduce the capacity of ecosystems to cope with disturbance and change (Scheffer *et al*. 2001). For instance, when human beings modify an ecosystem to gain something, it often has negative effects on other components of ecosystems, leading to trade-offs (Rodríguez *et al*. 2006). Some decisions about the ecosystem often focus on the immediate provision of an ecosystem service, at the expense of this same ecosystem service or other services in the future.

Fire that is used by farmers for management purposes can result in some negative externalities. An example of negative externality of ecosystem perturbation by use of fire is greenhouse gases and global warming. Some authors blame fire for its contribution in greenhouse gases and global warming (Murphy *et al*. 2009, Franklin 2008, Bonnicksen 2008, Edwards 2008, Smith & Cluck 2005). Burning of vegetation releases large amounts of greenhouse gases and other particulates into the atmosphere and these have a bearing on global warming and climate change (Le Houérou 1996). The consequences of global warming and climate change include: increased frequency and intensity of storms, hurricanes, floods and droughts, increased frequency of forest fires, melting glaciers, polar ice and rising sea levels. Saxe *et al*. (2001) add that in the context of global warming, increases in temperature could be inextricably linked to increases in (CO_2), drought, vapour pressure deficit (VPD) and fire frequency in some regions. Soil chemical, biological and physical properties are also affected by fire. Fire is not the only factor that can have impacts on the ecosystem; but also grazing and browsing. Fire, grazing and browsing have potential to either harm or benefit the ecosystem.

2.2 **Effects of fire on vegetation**

2.2.1 Fire effects on herbaceous vegetation

Burning is the simplest and least expensive practice to improve poor quality grassland (Higgins *et al.* 1989) but its impact can be both harmful and beneficial to vegetation. Higgins *et al.* 1989 indicate that fire can have effect on herbaceous plants but suppression or promotion of a particular plant species depends primarily upon the date of the fire in relation to the phenology of the particular species. According to Anderson *et al*. (1970), burning could affect dormant and actively growing plants differently. For example, when the area is burned, actively growing species are much more susceptible to injury and death than dormant species or those just initiating growth. It is upon this presumption that (Higgins *et al*. 1989) believe that the proper time to burn can be based on physiological stages (e.g. root reserves) or morphological stages (Higgins *et al*. 1989). Fire severity (which is closely related to fuel amounts and distribution, weather, and moisture content of soil and fuel) is also a major factor affecting fire damage to plants (Wright & Bailey 1982). Most of the time, wild fires have drastic effect on pastures. Burning can result in reduced grazing capacities. According to the Department of Primary Industries (1995), depending on the time of burning, pasture typically recovers its grazing capacity after fire (Table 2.1.).

Table 2.1: Effect of fire on carrying capacity

Month	**Carrying capacity (% of normal)**
June	20
July	30
August	40
September	50
October	60
November	70
December	70
January	70
February	70
March	70

Source: Department of Primary Industries 1995

Numerous factors affect the response of plants to fire. The biotic and abiotic factors generally recognized are grassland type, fire history, season, fuel and soil moisture conditions, wind speed and direction, air temperature, and time of day of the fire. Higgins *et al*. 1989 submit that, because of the complexity and the lack of data concerning burns in the same community under similar circumstances, results of fire effects are often confusing and misleading. It is generally believed that moderate defoliation of vegetation is beneficial for healthy rangeland ecosystem.

Withdrawal (failure to defoliate) of fire in grassland can as well have effect on grass production as much as burning itself because excessive litter accumulating under light or no grazing or lack of fire could cause degeneration of grass stands and lower yields (Tomanek 1948). It is upon this observation that seasonal timing of burning different herbaceous plants is critical for their survival given that some plants may be actively growing and susceptible at the time of the fire while others will be dormant and less susceptible (Wright & Bailey 1982). In the same way, Vogl 1974 notes that many annuals and short-lived perennials are usually encouraged by burning if the fires occur at the appropriate time because they experience reduced competition and full sunlight on post-burn sites.

Fire causes damage to vegetation; regular low-intensity fires at critical seasons can reduce fuel load, lower pest infestations, return nutrients to the ground and encourage plant diversity (Furley *et al* 2008). In addition to this, Trollope & Trollope (1999) reports that range condition burning system was to remove moribund (accumulated dead growth from the previous season) and/or unacceptable grass material in Eastern Cape Province in 1968 and later extended to the Kruger National Park in 1982. This system maintains a balance between herbaceous and woody vegetation and encourages free movement of wildlife to less preferred areas hence minimizing the overuse of preferred areas (Trollope & Trollope 2004). Additionally, failure to defoliate vegetation on rangeland could lead to accumulation of excess litter material. Huge accumulation of moribund in the rangeland lowers quality of forage resulting in tillers within the tuft becoming smothered. Rendering replacement of such tillers is impossible because basal buds are killed by dead herbage (Hardy & Camp 1999). Factors influencing fire behaviour need to be given consideration in the usage of fire in rangelands.

Furley *et al* (2009) indicate that the influence of fire behaviour, intensity and frequency, timing of burns, and the overall impacts on vegetation structure, species composition, species resilience in varying conditions of rainfall, soil fertility, herbivory and human interaction can be intricately interwoven and to some extent site-specific. To this end, Scholes *et al*. (2003) and, van Wilgen *et* *al*. (2003) submit that fire influences on savanna vegetation is controversial. Slightly different from this, Furley *et al* 2008 list the following general observations as a consequence of prolonged fire on:

- lower proportions of trees to shrubs and herbaceous plants that result in reduction of ground cover
- reduction in tree total above ground biomass (tree height decreases inversely with fire frequency)
- constant tree and woody shrub density through seedling, recruitment and resprouting, though, a few number of individual species could be affected
- minimum fire effect on plant composition
- trees higher than 3m are less susceptible to burns
- minimum fire impact on subsurface rooting structures except with extraordinary intensities and
- significant fire effects on soil nutrient dynamics which in turn influences plant growth.

To add on the above observations, Furley *et al.* 2009 continue with a list of long-term consequences of burning thus:

- pronounced fire effect on the structure of woody vegetation when it occurs in higher rainfall areas
- burn season, prevailing weather during fire and whether the vegetation has senesced could influence fire impact on vegetation
- fire intensity and severity depends on fuel load, moisture content and meteorological conditions and

- micro-environmental variations (such as soils or moisture availability) can impact burning and recovery of vegetation.

In the similar vein, Hartnett *et al*. (2004) emphasize that the ability of the vegetation to recover from severe fires relates to favourable climate and local factors such as bark thickness, coppicing, suckering and resprouting from basal stems or rootstocks and the supporting role of mycorrhizae. In support to this, Furley *et al.* (2009) claim that repeated burning at short return intervals cause plant composition change in that fire-tolerant species became more dominant while extreme burning over a prolonged period had a persistent effect for long after the fire.

On this bases, DiTomaso and Johnson (2006) reports that, life history of plants can often determine their direct susceptibility to fire; fire is most effective on both annual grasses and broadleaves. However, many annual grasses and forbs found in rangelands generally germinate with the first rainfall; thus they are difficult to control with prescribed fire because fuel loads are typically not sufficient before seeds maturation. To effectively control annual grass species, it is critical to either destroy the seeds with fire before they shatter or to kill the plant before the seeds become viable (DiTomaso *et al*. 1999). Unlike annuals, controls of biennial species require either multiple-year burns or an integrated approach using other control options (Keeley *et al*. 2003). They are not controlled by a single burn event. Correct timing and choice of burning method are important considerations when controlling unwanted vegetation by fire. George (1992) specifies that duration of heat exposure to the inflorescence can be increased by use of back fires. In addition to this Keeley *et al*. (2003) connote that large wildfires may greatly alter post-fire plant communities by providing ideal habitat for a number of exotic species. Recurring fires also play a role in away fire affects vegetation.

No matter how detrimental fire is, recurring ones stimulate certain plants to develop adaptive mechanisms (Schwilk & Ackerly 2001), such effects include, Serotiny (Seeds failure to germinate due to absence of fire to clear away competing plants,) (Van Wilgen 2005). To be specific, Rice (2005) reports that fire can reduce native and exotic annual grasses but increase native forbs and exotic annual forbs in annual grassland pastures in the California Central Valley.

Still, fire has effects on some important phonological stages (Briske 1991) e.g. tillering. Tillering is a mechanism for perennation of established grass swards (Waller et *al*. 1985). Grasses can produce numerous tillers hence can persist under severe conditions such as heavy grazing and frequent fires (Sims *et al*. 1972). Reduced tillering is not always due to stress, but also the developmental morphology of the grass can reduce growth in perennial grasses because new tillering formation is dependent on development of axillary buds (Gatsuk *et al*. 1980). Some perennial plants species are provided with unique characteristics that enable them survive damage from fire.

Many perennial species have competitive advantage in colonizing open or post-burn sites because they are capable of vegetative reproduction. This aids the species to survive damage from fire or other catastrophes (Vogl 1974). However, the effect of fire on perennial plants could vary with stage of development, fire intensity, and relative position of the perennation buds.

Species that have their organ of perennation on above-ground stems are easily killed by fire; those with perennation buds at or below the soil surface are less susceptible to damage by fire. Too hot or prolonged fire is detrimental to perennials because high temperatures destroy the perennating buds (Daubenmire 1968). Burning can affect wetlands plants as well; wetland grasses and sedges can be enhanced with properly timed, less intense burns. In contrast, a slow moving fire which would burn deep into the organic soil or peat of wetland substrates (root burn) will have an impact on all hydrophytes (Yancey 1964).

2.3 **Effects of fire on bush and trees**

Burning could as well have effects on woody species, however, plant age, soil moisture at time of burn, intensity of fire, season of burn, health of the plants, and frequency of droughts all play a part in how fire affects shrubs in the long run (Higgins *et al*. 1989). Fire has the ability to alter sprouting in shrubs and woody plant species. In support of this, Bond & Midgley (2001) indicate that sprouting in woody plants varies among species, among life history stages of species and among disturbances of differing severity. Additionally, Bond & Midgley (2001) give details that for a plant to be able to sprout after sustaining an injury, it needs surviving meristems and stored reserves to support regrowth. In general, burning can also have a dramatic impact on growth in height of trees and coppice. Furley *et al*. (2009) strengthen this by reporting differences detected in their study regarding tree heights under burn treatments compared to the unburnt plots (Table 2.2.). Furley *et al*. (2008) study further reports that burning treatments did not affect the floristic composition of trees. To control woody species by burning, many factors need to be considered.

Table 2.2: Effect of frequency of burning on tree height in 1962 and 2007

Fire treatment	Average tree height (m)	
No burn	1962	2007
No burn	2.83	15
Annual burn	0.18	6.7
Biennial burn	0.46	11.3
Triennial burn	0.88	11.2
Quadriennial burn	0.27	10.6

Source: (Furley *et al*. 2008)

Most woody species (shrubs, vines, or trees) are difficult to control with prescribed fire because they readily resprout from the base following mechanical or fire damage. In support of this, DiTomaso and Johnson (2006) point out that other shrub and tree species that do not resprout can be controlled using prescribed fire. Though high-intensity fires can kill tree seedlings, saplings and small trees, and damage the above-ground parts of larger woody plants, retarding their growth and reproductive organs (Donaldson 1966), mature woody plants are seldom killed by fire (Frost *et al.* 1986). Trollope and Trollope (1999) are of the opinion that the interaction between fire and browsing by wild ungulates plays a major role in bush encroachment control. The role of the fires in this case, is rather to maintain the bush at an available height for browsing species. Fire is needed to maintain healthy ecosystems and biodiversity and many vegetation species are stimulated to germinate (Smoke-stimulated germination), sprout, flower (Fire-stimulated flowering), and seed en masse, following fires (Van Wilgen 2005). Fire can further affect both vegetative and sexual reproduction in tree species however; tree suckers are more tolerant to burning than seedlings Hoffmann (1999). Fire can also affect succulent plants.

Succulent plants such as cacti are relatively fire susceptible (Wright & Bailey 1980). Prickly pear cactus (*Opuntia polyacantha*) is adversely affected by repeated burning (Martin 1983). Burning at intervals of 5 to 6 years prevents development of dense stands of prickly pear. Burning renders cactus species attractive to animals because spines are destroyed by fire (Higgins *et al*. 1989).

2.4 Effects of fire on soil

Fires can have an impact on soil nutrients, organic matter and microorganisms.

2.4.1 Effects of fire on soil nutrients

Fire could increase or decrease soil nutrient amounts in the soil depending on the intensity and duration of the burn. Too much heat exuded when fire burns can aggravate fire damage on soil nutrients. The ensuing Table 2.3 shows long term effects of fire on soil nutrients and other chemical properties as presented by Materechera *et al*. (1998).

Table 2.3: Effects of different burning frequencies on soil chemical properties

Chemical properties	1-year burn	2-year burn	3-year burn	4-year burn	6-year burn	No burn	SED
pH	6	5.93	6.27	6.05	6.11	5.89	0.4
Electric Conductivity (us/cm)	127.45	104.35	142.55	116.2	102.4	115	32.4
Available P (g/kg)	0.041	0.028	0.024	0.023	0.033	0.035	0.02
Total N (g/kg)	1.92	1.47	1.58	1.48	1.44	1.24	0.74
Organic Carbon (g/kg)	12.66	10.93	12.76	12.22	11.64	10.93	4.2
Exchangeable K (mg/kg)	299.0	373.4	373.4	360.7	397.7	328.6	65.1
Exchangeable Ca (mg/kg)	1600.1	1348.9	1561.6	1698.3	1742.9	1240.5	407.5
Exchangeable Mg(mg/kg)	264.4	140.0	232.6	220.3	208.2	126.5	89.7
Exchangeable Na (mg/kg)	1203.7	1291.4	1182.8	1183.0	1255.4	1117.2	1611

Note: SED = Standard error of difference

Source: Materechera *et al*. 1998.

Heat can lead to volatilization of some elements and modification of soil particles. Affirming this, White *et al* (1973) show that nutrients in mineral form are affected by the changing physical properties of soil particles due to heating and subsequent cooling. In particular, fire cause volatilization of Nitrogen, in most cases the amount due to volatilization is influenced by amount of green material, and fuel moisture (Dunn & DeBano 1977). Fire can also result in an increase in Nitrogen amounts. Increases in all forms of Nitrogen could be due fixation, which is commonly more active following fires (Mayland 1967). This process is generally facilitated by both heterotrophic (cannot survive on its own) bacteria as well as symbiotic fixation taking place within nodulated plant roots (Isaac & Hopkins 1937). Similar to Nitrogen, Phosphorus is also affected by burning. Schripsema (1977) reports that burning releases Phosphorus, however, this varies by sites (Christensen 1976; Raison 1979). On the contrary, White and Gartner (1975) argue that available Phosphorus in the soil increases only if temperatures do not exceed (200^0C). In a similar manner, availability of other nutrients such as Potassium (K), Calcium (Ca), and Magnesium (Mg) increase after fire (Christensen 1976 and Raison 1979). Additionally, Copper (Cu), Iron (Fe), and Zinc (Zn) availability increase if an area is burned for consecutive years (Ohr & Bragg 1985).

Also soil pH could be affected by burning. Vlamis *et al*. (1955) reports that pH could rise on neutral but not acid soils. The rise in pH is according to Schripsema (1977) due to mineral substances that are released as oxides or carbonates. Ash is dominated by carbonates of alkaline and alkaline earth metals (Youngberg 1953 and Daubenmire 1968). Fatunbi's *et al.* (2008) study on the long-term effects of different burning frequencies on the dry savannah grassland in South Africa also report high pH on burnt plots than the unburnt plots. Fire could also have effects on soil properties.

DeBano *et al*. (1977) reports that fire could alter several soil properties, including soil structure, texture, porosity, wetability, infiltration rates, and water holding capacity. DeBano *et al*. (1977) however, advice that the extent of fire effects on the soil properties varies considerably depending on fire intensity, fire severity, and fire frequency. By altering soil physical properties and soil hydrology, fire can also have indirect effects on plants. Plant uptake of nutrients and water is slowed in structurally degraded soils through the combined effects of lower soil moisture and lower soil porosity (Nye & Tinker 1977). In the same way, fire can have effects on plant roots. Root growth is reportedly impeded by increased bulk density and soil strength as a consequence of fire (Gerard *et al*. 1982). However, Hungerford *et al.* (1990) argue that, most fires do not cause enough soil heating to produce significant changes to soil physical properties. Hungerford *et al*. 1990 further state that where fires do cause direct changes to soil physical properties, their indirect effects on soil hydrology and erosion will vary greatly depending on the condition of the soil, forest floor, topography, and climate. According to Ne'eman and Izhaki (1999), the impact of fire on soil is largely dictated by intensity and duration, however, the soil type and climatic conditions following the fire are also influential. Frost *et al*. (1986) show that the frequency of burning has little direct effect on the soil properties as most effects result from changes in vegetation. Such effects include reduced organic matter.

2.4.2 Effect of fire on soil organic matter and microbial activities

The decline of organic matter in the ecosystem is multifaceted. In many cases burning is blamed for its contribution to the loss of organic matter in the soil. Removal of vegetation cover e.g. by burning tends to reduce organic matter and microbial activities in the soil due to reduced inputs which consequently affect the aggregate stability and infiltration (Mills & Fey 2003). Similarly, greater intensities of fire may reduce amounts of organic matter in the organic layer because intense fires consume almost the entire organic layer (Czimczik *et al*. 2005). On the contrary, less intense fires consume only parts of the organic layer converting some organic matter to black carbon. To this end, Neff *et al.* (2005) reports that during and immediately after fire, there is a significant lower stock of soil organic matter and litter horizon no longer contains recognizable unburned plant material. Soil rich in organic matter provide ideal conditions for microbial activities and strong plant growth. In Table 2.4 below, Fatunbi *et al.* (2008) demonstrate effects of long-term fire on macro fauna population.

Table 2.4: Effects of long term fire treatments on the soil macro fauna population density

Treatment	Fauna biomass (kg/ha)
1-year burn	33.7
2-year burn	33.5
3-year burn	38.9
4-year burn	29.6
6-year burn	20.6
No burn	25.7

Source: Fatunbi *et al.* 2008

Important processes of organic matter degradation in the soil require presence of microbes. Microbes in the soil are could be impacted upon by fire. In similar way, Jose´ *et al*. (2004) point out that fire has potential to have impacts on vital microbial processes in soils such as decomposition and mineralization, nitrogen cycle (e.g. nitrogen fixation, nitrification, and denitrification), plant nutrient uptake via mycorrhizal associations, microbial nutrient immobilization, the production of biomass to fuel ecosystem food webs, and the breakdown of toxic materials.

2.5 Effects of grazing and browsing

Effects of grazing and browsing have been an important focus of inquiry by researchers for decades, for example the effect of grazing on floristic composition (Cingolani *et al*. 2003) plant cover (Fernandez *et al*. 2006, Shourkaie *et al.* 2007) have been reported. Zaady *et al*. (2001)

reported a significant decrease in total protein content in plants (17-19%) in the beginning of the grazing season and at the peak of the season (5-6%) due to grazing. Furthermore, Zaady *et al*. (2001) show that grazing can significantly increase the digestible material in grazed plots (63.7%) compared to ungrazed plots (57.4%). On the contrary, Walters *et al.* (2003) study of the effects of grazing on the vegetative and soil parameters in the tallgrass prairie produced the following mixed results: (i) no significant difference in soil pH on both ungrazed and grazed areas, (ii) no significant grazing influence on soil depth and species richness and (iii) an increase in invasive species richness on grazed areas.

Grazing and browsing can have a wide range of effects on terrestrial ecosystems (Kathryn *et al*. 2007). For instance, these effects are the removal and consumption of herbage, which can vary across terrestrial ecosystems from less than 1% to greater than 60% and trampling on soil and vegetation (McNaughton *et al.* 1989). In addition, grazers and browsers have effects on ecosystems by altering rates of nutrient cycling and changing nutrient availability to plants (Bardgett 2005). Excessive defoliation of plants by grazing and browsing can affect their root system. Removal of too many leaves has a profound effect on the root system Lyons and Hanselka (2001) for example, when 80 percent of the leaf is removed, the roots stop growing for 12 days. Lyons and Hanselka (2001) continue to reveal that when 90 percent of the leaf is removed, the roots stop growing for 18 days and root growth drops by half when 60 percent of leaf is removed.

Consequently heavy grazing and browsing can have impacts on grass cover (McEvoy *et al*. 2006). To back up on this, Escos *et al.* (1997) assert that grazing limits the capacity of seed production by plants during the growing season. It further goes without saying that, it decreases competitiveness and increase death of the most palatable species and favours the less useful species (Silori & Mishra 2001). Differently, (Pettit *et al*. 1995) conclude that excessive grazing enhances soil erosion and depletes the nutrient pool. Despite the negative impacts posted by grazing, it is noteworthy however that cow dung may enhance species richness and water infiltration rate of pastures. Removing cow dung may decrease biomass production and water infiltration of grazed and non-grazed plots. As such, exclusion of herbivores in the rangelands may have undesirable ecological consequences (Taddesse *et al*. 2003).

While efforts to eradicate or minimize unwanted bush/scrub in grazing lands, are generally accepted (Trollope & Trollope 2004 and Tomaso & Johnson 2006), Stevens (1998) is of the opinion that bush/scrub vegetation is either good or bad depending on whether the farm owner is engaged in goat /cattle production or a person desiring wildlife habitat. He advocates for a practice called "brush sculpting" (Management of brush/bush/scrub or timber for multiple benefits in a manner that is both environmentally and economically sound) e.g. livestock and wildlife production. In place of bush clearing using different methods, mechanical, biological (e.g. goats) or chemical, one has to know the plants present in the farm, their values and how to manipulate them. Where large areas of dense trees or shrubs are not beneficial to many wildlife species or cattle, a person raising goats may desire such dense stands of shrubs. Stevens (1998) suggests that with the ability to identify various species of trees and shrubs and the knowledge of their utility to both wildlife and livestock, brush sculpting can be a valuable approach to managing brush on pasture and rangeland.

Animals such as goats eat leaves and branches creating uniform effect as they browse. They eat along fence line before turning inward towards the centre of an area consequently clearing brush that has grown into thicket (Segerstrom 2006). On this matter, Heste *et al*. (2006) found that browsing has no significant effect on clump density, however, within individual bush-clumps, browsing showed more impact on structure than species composition, with smaller, shorter bush-clumps, containing fewer species but much greater stem-densities. Apparently, goats tend to increase woody browsing height in winter (Du Plessis *et al*. 2004). Although species presence/absence is little affected by browsing, many species show differences in abundance, growth and location within browsed and unbrowsed bush-clumps (Heste *et al*. 2006). Several studies have shown that woody plants that increase in abundance under heavy grazing in the rangelands reduce the carrying capacity for domestic livestock (Van Vegten 1983, Perkins & Thomas 1993).

It is generally believed that not only overgrazing is the cause for woody plant encroachment due to changed grass-tree competitive interactions, but also due to loss of fuel leading to a disrupted fire regime (Midgley & Bond, 2001). However, some studies do not support this theory; for example, Wiegand *et al*. (2005) argue that woody plant encroachment has nothing to do with heavy grazing. Other researchers (Bond & Midgley 2000, Polley *et al.*, 1997) further argue that, woody plants proliferation is a result of increases in global Carbon levels. Theories that support this are that, rising CO_2 levels favours C_3 relative to C_4 synthesis; increasing growth of C_3, and elevated CO_2 may reduce transpiration rates of grasses resulting in deeper percolation of water to the roots of woody species (Bond & Midgley 2000).

Increase in grazing intensity can cause a decrease in organic matter content in rangeland soils; for example, Abril & Bucher (1999) report a decrease in organic matter content on highly degraded site as a consequence of grazing intensity. However, Waters & Martin (2003) recorded different results when examining the effects of grazing on vegetative and soil parameters in the tallgrass prairie, in this case, grazing increased soil organic matter content.

2.6 Interactive effects of fire, grazing and browsing

The objective of burning has always been to reduce litter and standing dead herbage/moribund, improve availability and palatability of forage by killing aerial stems, and stimulating crown growth (Willms *et al.* 1980). However, grazing and burning can have adverse consequence on the rangeland. It is upon this premise that (Anderson *et al.* 1970) believe that overgrazing, coupled with burning too frequently can caused changes in botanical composition of herbaceous vegetation and reduce livestock gains.

Rationally, livestock farmers would prefer a situation where grass dominates over woody species in their farms for their animals to graze. To less knowledgeable person/laymen, fire is always an option when bush encroachment threatens. Fire alone cannot effectively control bush encroachment, to be successful, a combination of tools is required. For example, woody species are difficult to control with prescribed burning because of profuse resprouting from the rootstocks that often require multiple burns (DiTomaso & Johnson 2006). According to Bester (1996) fire is best used as a preventative rather than curative measure against bush thickening. This is because aggressive woody plants species encroach grazing areas are hard to control. To this effect, annual goat browsing and/or combination with frequent fire (<4 years) can alter canopy structure and seed production without damaging the grass cover (Smart *et al*. 1985). Fire-grazer-browser interaction can influence tree-grass mixtures; high grass biomass can affect tree biomass by fuelling fires, whereas, grazing reduces the fuel load and hence affects fire frequency, intensity, or continuity of spread (Scholes & Archer 1997). While browsing helps to keep woody plants within the flame zone, fires keep woody plants browseable (Scholes & Archer 1997).

Fire-grazer-browser relationship is an important consideration under savanna ecosystem. Savannas provide large and growing proportion of the world's human population with rangelands for their livestock. Savannas are characterized by the coexistence of grasses and woody species. Worldwide, the ecological and economic function of savannas is threatened by shrub encroachment (Smit 2004). The characteristic nature of savanna ecosystems whereby trees and grasses co-exist is determined by the indirect interactive effects of herbivory and fire (Van Langevelde *et al.* 2003). Van Langevelde *et al.* (2003) substantiate this theory by pointing out the following: (i) an increase in the level of grazing leads to reduced fuel load, which makes fire less intense and, thus, less damaging to trees and, consequently, results in an increase in woody vegetation. The system then switches from a state with trees and grasses to a state with solely trees. (ii) Browsers may enhance the effect of fire on trees because they reduce woody biomass, thus indirectly stimulating grass growth. This consequent increase in fuel load results in more intense fire and increased decline of biomass. The system then switches from a state with solely trees to a state with trees and grasses. In relation to this Langevelde *et al.* (2003), maintains that the interactive effects of fire and herbivory have a large impact on the woody and grass biomass in savanna ecosystems. In the final analysis Langevelde *et al.* (2003) state that an increase in grass biomass leads to more intense fires and more damage to trees, this subsequently allow grass biomass to increase. The decrease in grass biomass that leads to less fire intensity could effectively encourage bush encroachment.

Upon this, Lamprey *et al.* (1980) and Trollope & Trollope (1996) observe that by reducing grazing intensities and increasing browsing intensities in areas that have become encroached by bush, the cover of woody species can be significantly reduced with fire as compared to situations in which grazing intensity is kept high.

3 Materials and Methods

Description of this chapter is divided into (1) study area and experimental description and (2) data collection, vegetation sampling and analysis.

3.1 Study area and experimental description

3.1.1 Geography, location and climate

The study is composed of two study sites; one part of the study was conducted in South Africa and the other in Zimbabwe (Figure 3.1).

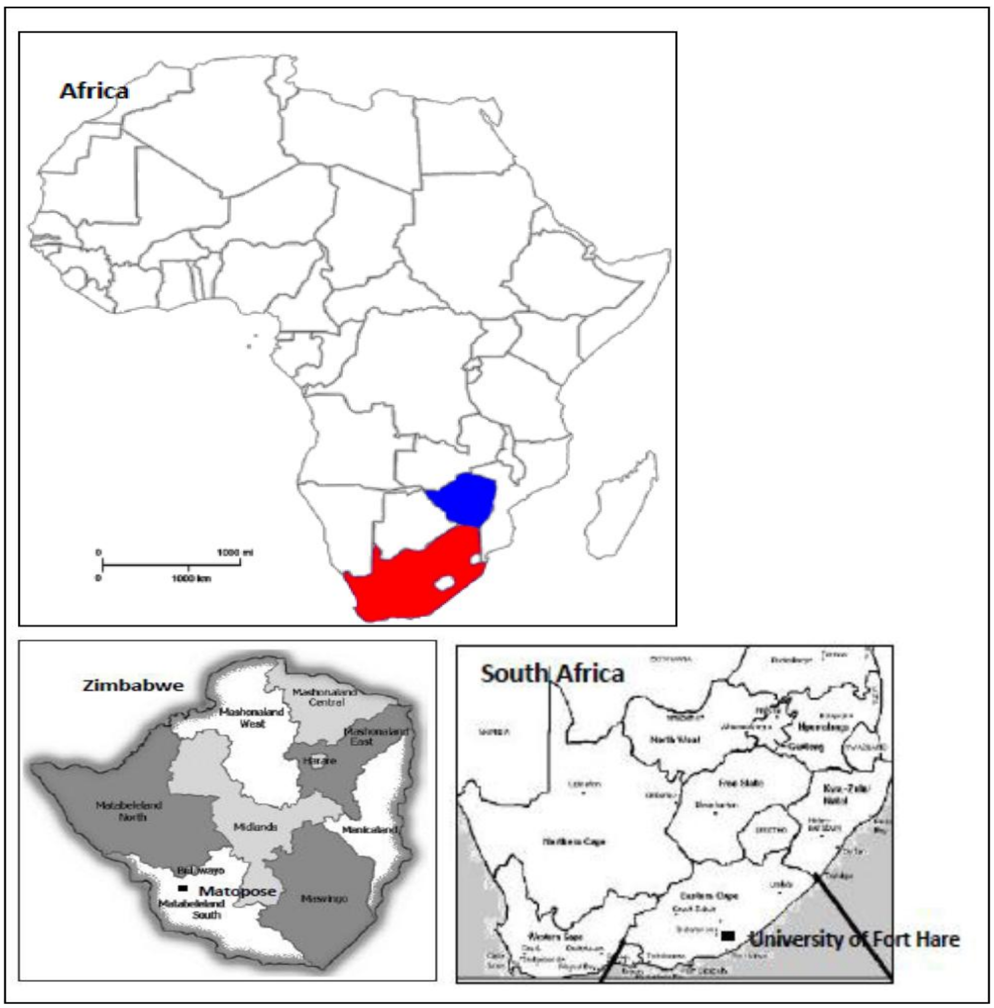


Figure 3.1: Map of Africa depicting location of Zimbabwe, Matopos Research Station and South Africa, University of Fort Hare

In South Africa, the study was conducted in the Province of Eastern Cape. The Eastern Cape is a South African Province that came into being in 1994 and constitutes areas from the former homelands of the Transkei and Ciskei as well as the former Cape Province. Eastern Cape has diverse landscape which is mostly hilly to mountainous. The mountains include Graaff-Reinet, Rhodes, Sneeuberge, Stormberge, Winterberge and Drakensberg. The highest point in the province is Ben Macdhui at 3001m. The Province is bordered by Lesotho in the northeast. Domestically, the province borders Western Cape in the west, Northern Cape in the northwest, Free State in the north and KwaZulu-Natal in the far northeast. The Province covers 168 966 square kilometres land area (13.9% of the entire country land area - the country's second-largest province after the Northern Cape (Burger and Delien 2009).

The study site in the Eastern Cape was Honeydale section of the University of Fort Hare Research Farm. University of Fort Hare, Alice Campus is located on the Tyhume river, in Alice. It is situated about 50 km west of King Williams Town. The farm is located at 32^{o} 47’ S and 26^{o} 52’ E with an elevation of 517.9 m asl on the false thorn veld of Eastern Cape. The area has undulating terrain dominated by Eastern Thorn Bushveld (Low & Rebelo 1996). The climate is semi-arid with about 480mm annual rainfall, most of which occurs in summer, the annual average temperature is 18.7°C.

Another part of the study was carried out in the province of Matabeleland South, Zimbabwe. The study site was in a tropical savanna ecosystem at Two-Tree Kop (Red Thornveld), Matopos Research Institute. The Station is situated at longitude 28°30'E, latitude 20°23 at an altitude of 1340m above sea level. Matopos Research Institute is about 30 km south of Bulawayo adjacent to the Rhodes Matopos National Park (UNEP-WCMC 2006).

The mean annual temperature in this province is 19.16°C. It is very hot and dry in October. The average maximum temperature ranges from 21°C in July to 30°C. The average annual rainfall is 590mm. Most rain falls from December to February while June to August is usually without rain. Matopos receives both limited and variable rainfall (Average annual rainfall is about 618 mm) which occurs between October and April (UNEP-WCMC 2006). Long term averages for monthly rainfall and temperature ranges for Matopos is provided in Figure 3.2;

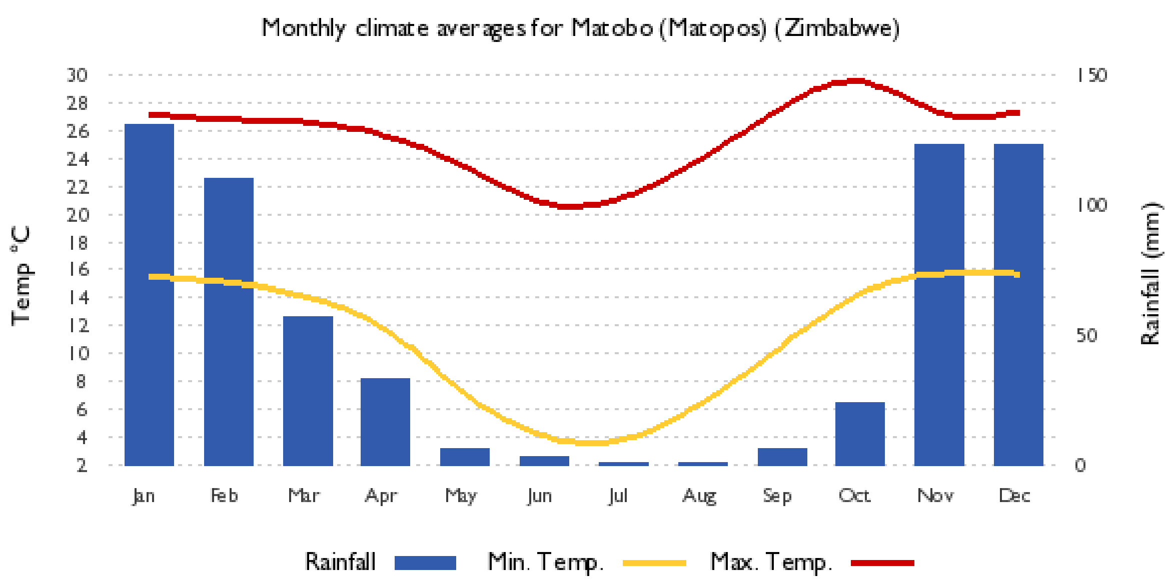


Figure 3.2: Average climate data on the WorldClim 50 year monthly climate data (UNEP-WCMC, 2006)

3.1.2 Experimental design

This research study constituted three parts or studies which are (i) Study I: Effects of long-term burning frequencies, (ii) Study II: effects of burning, grazing and browsing and (iii) Study III: effects of burning frequency followed by ten-year period of fire exclusion. Studies I and II were carried out at Honeydale section of the University of Fort Hare Research Farm. Study III was conducted in Two-Tree Kop (Red Thornveld) and Sand Veld (Hazelside) Matopos, Zimbabwe.

The part of the study that was carried out in Zimbabwe could not be conducted in South Africa where burning trials were maintained since their inception (1970) to date. In Zimbabwe the fire trials were suspended in 1998. The study in Matopos, Zimbabwe added another dimension on effects of prolonged burning followed by fire removal which was not possible in South Africa. Although, the designs of the burning experiments were different in South Africa and Zimbabwe, the study was able to generate some important information on the response of selected vegetation and organic matter characteristics on a site that was previously exposed to prolonged burning at different frequencies.

Fire/burn trial at Fort Hare University farm was a Randomized Complete Block Design with two replications; it consisted of six treatments namely: No burn /control, 6-year burn, 4-year burn, 3-year burn, 2-year burn and 1-year burn. Burning, Grazing and Browsing experiment at Fort Hare University farm was a Randomized Complete Block Design without replications; the treatments involved were: Follow-up-burn, Grazing (winter grazed), Goats Browsing (Winter browsed), Control (trees removed periodically and winter grazed). Before the site was exposed to grazing and browsing (Burning, Grazing and Browsing experiment), veld conditions surveys were conducted to determine the stocking rate of livestock and carrying capacity. The stocking rate was determined every year because carrying capacity changes in response to climate related variations, changes in botanical composition, and vigour of vegetation. This resulted in varied number of stock grazed and browsed on the site each year. The fire trial in Matopos, Zimbabwe was a Randomized Complete Block Design with three replications; the treatments were 1-year burn, 2-year burn, 3-year burn, 5-year burn and No burn.

3.2 Data collection, vegetation sampling and analysis

Description of this section is presented under the following studies: Long-term effects of fire, grazing and goats browsing on Biotic Integrity, Long-term effects of fire, grazing and goats browsing on soil stability, Long-term effects of burning, grazing and browsing on site productivity and Long-term effects of burning, grazing and goats browsing on site hydrologic function and nutrient cycling. For all the study sites, data collection was carried out in 2008.

3.2.1 Long-term effects of fire on Biotic Community Integrity

This study was conducted in South Africa and Zimbabwe. In South Africa, the study was carried out in two sites at Honeydale University of Fort Hare research farm. In Zimbabwe, the study was conducted at Tree Kop (Red Thornveld), Matopo. At Honeydale, University of Fort Hare research farm, the study investigated (i) the long term effects of burning on species richness, composition and diversity of grass and woody plants and (ii) the long term effects of burning, grazing and goats browsing on species richness, composition and diversity of grass and woody plants. At the experimental site in Zimbabwe, the study investigated (iii) the long term effects of burning followed by ten-year fire exclusion on species richness, composition and diversity of grass and woody plants; this site had been subjected to long term fire treatments and later fire removed from the site. The selected attributes used to estimate Biotic Community Integrity on a site were species richness, composition and diversity.

For all the study sites, the burn was applied when the grasses were dormant, during July and August. The burn was applied as a head fire when the following environmental condition prevailed: (i) fuel moisture < 40 percent, (ii) air temperature ≤ 25°C, (iii) relative humidity < 30 percent and wind speed between 0 – 20km/h. These requirements are necessary prior to burning to ensure reduced damage to vegetation and easy control of the burning process.

Grasses were assessed using step point method as detailed in Trollope (1986), Trollope & Potgieter (1986), Scogings *et al*. (1994) and Trollope *et al*. (2000) where a pointed iron rod was dropped (200 times) vertically every two-steps and the number of strikes of living, rooted, grass plant and nearest species recorded and identified. All the species were recorded using taxonomic nomenclature. The iron rod was dropped randomly covering all plots. There were 12 plots (100m x 50m) and 15 (30m x 30m) for University of Fort Hare and Matopos respectively. Woody species were assessed using a 2m wide belt transect (Trollope 1986, Trollope *et al*. 2000). Ten 80m x 2m and five 20m x 2m transects were used for university of Fort Hare farm and Matopos respectively. Vegetation data that was used to estimate species richness, composition and diversity at University of Fort Hare farm had been collected over a period of ten years (from

1990 to 2009); such long term data was not available for Two-Tree-Kop, Matopos study site, hence, data collected in 2009 was used.

Simpson's Index of Diversity, 1 – D, was used in the analysis of data using the equation:

$$\mathbf{D = \frac{\sum n(n-1)}{N(N-1)}}$$

D = Diversity index

n = the total number of organisms of a particular species

N = the total number of organisms of all species

All data sets were subjected to analysis of variance (ANOVA) using the General Linear Models (GLM) Procedure of SPSS-PC Version 15.0 (SPSS 1999) at 5% level of significant. Where differences occurred between means, the Duncan multiple range test was used. Differences between treatment means were considered significant at $p \leq 0.05$. Descriptive statistics was also used to determine relative abundance of grass and woody species. Cross tabulation descriptive statistics was used to calculate species composition.

3.2.2 Long-term effects of fire, grazing and goats browsing on soil stability

Basal cover was estimated using a step-point method, where a pointed iron rod was dropped (200 times) vertically every two-steps and the number of strikes of living, rooted, grass plant and nearest species recorded and identified in each plot (Trollope 1986, Trollope & Potgieter 1986, Scogings *et al*. 1994, Trollope *et al*. 2000). The basal cover was expressed as a percentage of the number of strikes in relation to the total number of points recorded. Basal cover could not be determined for the part of the study that was carried out in Two-Tree-Kop, Zimbabwe because of the unavailability of long term data.

Standing dead grass biomass was determined by cutting living and dead grass leaves for each species on site at 3cm cutting height within 8 and 6 quadrates (0.5cm by 0.5) at University of Fort Hare Farm and Two-Tree-Kop respectively. Grass samples were collected using quadrates (Smit 2005). The cut grass was separated by species and bagged separately. The dead grass leaves were separated from the fresh grass in the laboratory. The samples were air dried for four weeks and dry weight determined for dead standing grass biomass.

The distance between tufts of neighbouring grass species within quadrates (0.5 by 0.5m) per plot was taken and species recorded using taxonomic nomenclature (Scogings *et al.* 1994, Buitenwerf et *al.* 2011). There were 8 and 6 quadrates for University of Fort Hare site and Two-tree-Kop site respectively. Tuft to tuft and tufts width distances were determined with the use of Vernier caliper and ruler. Tree to tree and canopy distances were obtained by taking measurements between neighbouring trees species from 3 quadrates (15 by 15) and (10m by 10m quadrates) for University of Fort Hare farm and Two-Tree-Kop respectively; the distance was determined with help of a measuring tape. All tree species were recorded using taxonomic nomenclature.

During the study, the burning treatment was applied when the grasses were dormant, during July and August. The burn was applied as a head fire when the following environmental condition prevailed: (i) fuel moisture < 40 percent, (ii) air temperature ≤ 25^{o}C, (iii) relative humidity < 30 percent and wind speed between 0 – 20km/h.

Data sets were subjected to analysis of variance (ANOVA) using the GLM Procedure of SPSS-PC Version 15.0 (SPSS 1999) at 5% level of significant. Where differences occurred between means, the Duncan multiple range test was used. Differences between treatment means were considered significant at $p \leq 0.05$. The Pearson correlation coefficients were estimated for all paired combinations of the response variables and the correlations were considered significant at $p < 0.001$.

3.2.3 Long-term effects of burning, grazing and browsing on site productivity and plant vigour

To estimate effects of burning, grazing and goats browsing on grazing and browse potential, grass data was collected using pasture disc meter (Trollope and Potgieter 1986). For this study, grass data had been collected for ten years 1990-1999) from Honeydale section of the University of Fort Hare Research Farm. Two hundred pasture disc meter (PDM) readings (observations) for grass yield were considered per plot giving a total of 2400 observation for twelve plots under fire frequency treatment. A total of 800 PDM readings were considered for four plots under burning, grazing and goat browsing treatments. Grass yield PDM data was only available for University of Fort Hare Research Farm experimental sites; such data was not available for Two-Tree-Kop experimental site, Matopos, Zimbabwe.

Another set of grass data for determination of grazing status/ecological groupings and relative species abundance for both sites at University of Fort Hare Research Farm and Matopos was collected using quadrates (Smit 2005). In this study a 0.5m by 0.5m quadrate was used. A quadrate was thrown at random 8 times on each plot (0.5ha) at University of Fort Hare Research Farm and 6 times for each plot (0.09ha) at Matopos. Grass species within each quadrate were identified and recorded.

Tree equivalents were determined using quadrates (Scogings *et al*. 1994). Quadrates used in this study measured 15m by 15m and 10m by 10m for University of Fort Hare and Matopos respectively. Tree height data was collected using a 2m graduated aluminium rods. Three quadrates were considered for each plot. Tree equivalents were calculated by multiplying average height of trees by number of trees/ha divided by 1.5m (Smith & Hardy 1999). Physiognomic structure and vigour of woody species was determined by taking canopy height, plant height, canopy diameter, number of sprouts, diameter of main stem and sprouts measurements in all study sites. Measurements were taken within a 15m by 15m quadrat at University of Fort Hare farm (two study sites). In Matopos, measurements were taken inside a 10m by 10m quadrates.

Canopy height measurements were obtained by taking only the height of the canopy excluding stem height, the 2m graduated aluminium rods was raised to take measurements from the top to the base of the canopy of each woody plant species situated inside the quadrates; the measurements were recorded in meters. The plant height was obtained by measuring both the stem height and the canopy height of each woody species that was found inside the quadrat using the 2m graduated aluminium rods; the measurements were given in meters. Canopy diameter was obtained by measuring the canopy spread of each woody plant found inside the quadrate. Number of sprouts was obtained by physically counting number of sprouts within a quadrate. Vernier caliper and a ruler were used to get the measurements for the diameter of stems and sprouts.

Grass species data was classified into 3 grazing value groups namely: high, average and low as described by Van Oudtshoorn (2002) who used factors such as; production, palatability, nutrient value, growth vigour, digestibility and habitat preference influence grazing value of grass. The tree data collected in the survey was converted to tree equivalents (TE) to give a measure of total canopy volume to predict the forage productivity. Tree equivalents were calculated from the estimates of the number of trees per hectare plus their average height, any tree 1.5m in height is equated to a TE. Tree equivalents were calculated using this formula:

Average height on a hector divided by 1.5m multiplied by number of trees per hectare = TE/ha (Camp and Hardy 1999).

All data sets were subjected to analysis of variance (ANOVA) using the GLM Procedure of SPSS-PC Version 15.0 (SPSS 1999) at 5% level of significant. Where differences occurred between means, the Duncan multiple range test was used. Differences between treatment means were considered significant at $p \leq 0.05$. Descriptive statistics was also used to determine relative abundance of grass and woody species.

3.2.4 Long-term effects of burning, grazing and goats browsing on hydrologic function and nutrient cycling

Standing dead grass leaves were collected using quadrates (Smit 2005). The mixture of living and dead grass leaves for each species was cut (3cm cutting height) within a 0.5m x 0.5 quadrate in each plot and bagged separately. The dead grass leaves were separated from the fresh grass in the laboratory. Soil particles clinging to the litter were shaken off. Twigs and pods of trees were also removed. The samples were air dried for four weeks and dry weight determined for dead standing grass biomass. Four quadrates per plot were considered for both Honeydale University of Fort Hare farm site and Two-Tree Kop, Matopos site. The dead plant parts were later separated from the fresh grass in the laboratory.

About 1000g of composited soil samples from 0-10cm, 10-20cm and 20-30cm depths were collected randomly within each plot by soil auger. Soil was obtained from two levels at Two-Tree-Kop, Matopos; the site was too gravelly and difficult to dig and get soil from 20-30cm depth. Large organic particles and rock fragments were removed by hand. Soil clods were gently broken by hand. Soil organic carbon and microbial biomass carbon were determined using Organic carbon - Walkey- Black (Wet digestion using concentrated sulphuric acid) (Bartlett *et al.* 1994) and Microbial Biomass Carbon (MBC) - Fumigation extraction methods (Růžek *et al*. 2005). Soil organic carbon was determined for all soil samples. Microbial Biomass Carbon (MBC) was only determined for soil samples obtained from University of Fort Hare Farm.

3.3 **Data analysis**

Treatment effects on grass litter biomass, organic carbon and microbial biomass carbon were assessed with analysis of variance (ANOVA) using the GLM Procedure of SPSS 1999 at 5% level of significant. Were differences occurred between means, the Duncan multiple range test was used. Differences between treatment means were considered significant at $p \leq 0.05$. The Pearson correlation coefficients were estimated for all paired combinations of the response variables and the correlations were considered significant at $p < 0.001$.

4 Long-term effects of fire, grazing and goats browsing on biotic integrity

4.1 Introduction

Fire and herbivory are important phenomenon in rangeland management and ecosystem stability as they influence a site's ability to perform functions and provide products and services (Archer & Pyke 1999). Knowledge of how plants at both community and species level, in fire prone ecosystems respond to long-term burning is fundamental for conservation and ecosystem stability. Ecological perturbation by fire (Higgins *et al*. 1969) and herbivory (Harrison *et al.* 2003) can have impact on vegetation; plant species composition (Mori 2009), diversity and richness (Taft 2005).

The general objective of the study was to investigate effects of long term burning, grazing and browsing by goats on biotic community integrity. The selected indices of biotic community integrity examined were richness, composition and diversity of species.

Specific objectives of the study were to:

(i) investigate if long term burning frequencies, affect species richness, composition and diversity,

(ii) investigate effects of long term burning, grazing and browsing by goats on species richness, composition and diversity and

(iii) investigate if long term burning followed by ten-year period of fire exclusion affects species richness, composition and diversity.

It is hypothesized that:

(i) long-term perturbation of rangeland by burning, grazing and browsing do affect biotic community integrity of a site

(i) if the hypothesis (1) is true, then long-term perturbation of a site by burning can affect species richness, composition and diversity

(ii) if the hypothesis (1) is true, it is further hypothesized that long term burning, grazing and browsing by goats have differential effects on species richness, composition and diversity,

(iii) it is further hypothesized that long-term burning frequencies followed by ten-year period of fire exclusion have effects on species richness, composition and diversity

4.2 Materials and methods

The methodology is described in detail in chapter 3

4.3 Results

4.3.1 Effects of burning frequency on species richness, composition and diversity of grass and woody plants

4.3.1.1 Species richness

Burning treatments did not have different effects on species richness for grasses species ($p > 0.05$) (Figure 4.1). Species richness for grasses was neither enhanced nor reduced by different burn treatments. Richness for grass species was relatively lowest under no-burn (11) and highest under 6-year burn (12).

Species richness for woody plants was significantly different ($p \leq 0.05$) between treatments. Fire significantly reduced species richness of woody plant species ($p \leq 0.05$). Species richness was highest under no burn compared to under burn treatments (Figure 4.1.). Lowest species richness under 1-year burn was not significantly different ($p > 0.05$) from richness under 4-year and 6-year burns. Two-year and 3-year burns had more number of species than other burn treatments (Figure 4.1).

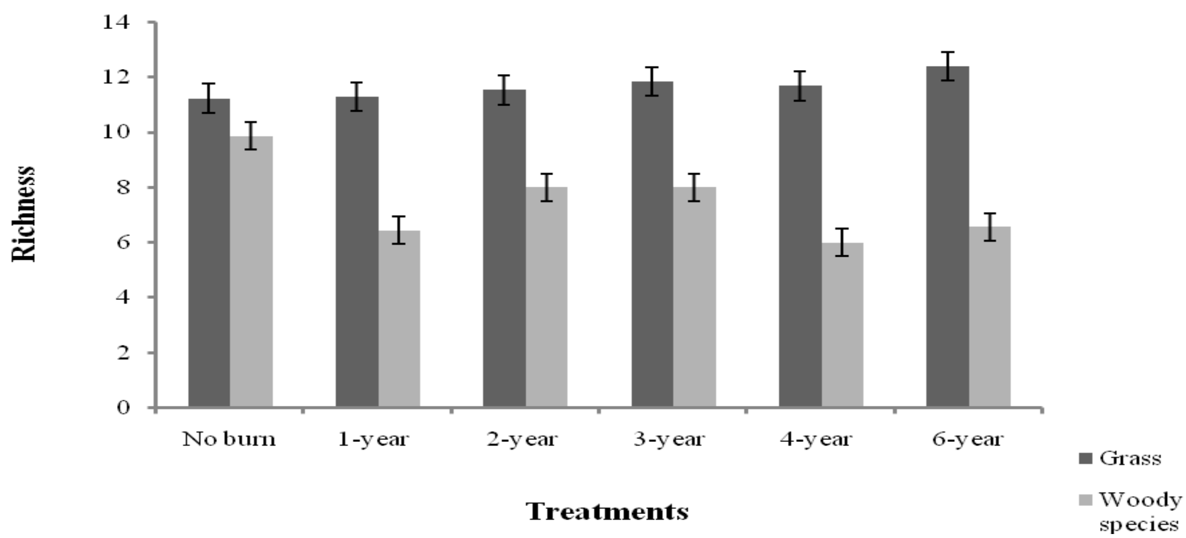


Figure 4.1: Species richness for grass and woody species under each burn treatment

4.3.1.2 Species composition

Frequency of *Sprobolu fimbriatus*, *Digitaria eriatha*, *Cymbopogon. plurinodis* and *Themida triandra* was increased by burning under all burn treatments; however, *T.triandra* did not maintain dominance under no-burn (Table 4.1). Grass species whose compositional percentage was reduced by burning under all burn treatments include: *Hyperhernia hirta*, *P.eqquineu* and *Microchloa caffra*. *Heteropogon contortus* only occurred under one-year and two-year burn treatments. *Melenis.decumbens* attained lowest value (0.4%) under 1-year burn and highest value (8%) under control. *Ariatida congesta* was present in all burn treatments and control but it was more on control. *Digitaria argyrograpta* was recorded under 3-year burn only. *Eragrostis capensis* occurred under 3-year and 6-year burns in negligible quantities. *Eragrostis chloromelas* occurred in percentages ranging from 5 to 7% in all burn treatments and control. *Eragrostis obtusa* was not present under 2-year burn. *Karochloa curva* occurred in all burn treatments and control. Karroo species were present in all burn treatments and control; it attained higher values under 6-year burn. *M.caffra* was not present under 1-year and 3-year burns, it attained 0.9% under 2-year burn and 0.4 % under 4-year, 6-year and control. *Panicum maxima* attained values ranging from 5.2% to 8%, it was present in all burn treatments and control, highest values for *P. maxima* were recorded under 2-year, 3-year burn and 1-year burns respectively.

Acacia karroo had relatively highest species composition value under all burn treatments (Table 4.2). *Ehritia rigida* was 25% (highest) under 1-year burn and 31% (lowest) species composition under no burn. *Diospyros lyciodes* scored highest percent species composition (20%) under 2-year burn and lowest (3%) under 1-year burn compared to under 3-year burn, 4-year burn and 6-year burn. Other species recorded less than 10% species composition in all burn treatments. *Ziziphus mucronata*, Rhus *refracta*, *Banksia ilicifolia* and *Lippia_javanica* did not occur in more than three burn treatments.

Table 4.1: Species composition (%) under different burn treatments (UFH Farm)

Species	1-year	2-year	3-year	4-year	6-year	No burn
A.congesta	0.40	0.90	0.80	1.30	0.40	2.60
C.dactylon	7.00	7.50	7.40	8.10	7.50	7.70
C.plurinodis	8.7	8.50	8.20	8.50	7.80	8.60
D.argyrograpta	-	-	0.40	-	-	-
D.erientha	8.70	8.50	8.20	8.50	7.80	8.60
E.capensis	0.40	-	-	-	0.80	-
E.chloromelas	7.00	6.60	7.00	6.80	5.10	6.00
E.curvula	8.30	8.00	5.80	5.90	5.90	3.90
E.obtusa	0.40	-	1.20	0.80	0.40	0.90
E.mutica	7.00	4.70	5.30	8.50	7.10	4.70
Forbs	8.70	8.50	7.40	8.50	7.10	8.60
H.contortus	0.90	0.50	-	-	-	-
H.hirta	-	-	-	-	-	0.40
K.curva	0.90	0.90	0.80	0.40	0.80	3.00
Karroo spp	0.40	3.30	1.20	2.50	5.50	3.00
M.decumbens	0.40	3.80	6.20	5.90	7.80	8.20
M.caffra	-	0.90	-	0.40	0.40	0.40
P.Eqquineu	-	-	0.40	-	-	0.40
Pmaxima	7.00	8.00	7.80	3.80	6.30	5.20
P.stapfiana	8.70	8.00	8.20	8.50	7.10	6.90
S.neglecta	7.40	3.80	7.00	3.80	5.10	3.00
S.africanus	0.40	0.90	-	0.80	1.60	1.70
S.fimbriatus	8.70	8.50	8.20	8.50	7.80	8.60
T.triandra	8.70	8.50	8.20	8.50	7.80	7.70

Coddia rudis occurred in negligible (<0.20%) quantities in other burn treatments but 1-year and 4-year burns. *Rhus lucida* was present in all burn treatments with relatively highest percentages under 1-year, 2-year and 3-year burns. *Maytenus heterophylla* occurred in all burn treatments and control with percentages ranging from 0.6 to 6.6%. *Opuntia* was present in all burn treatments and control; the highest percentage (3.8) of *Opuntia* was recorded under no burn than under burnt plots. *Rhus maccawnii* was present only under 6-year burn. Information regarding species composition for other woody species considered in this study is presented in Table 4.2.

Table 4.2: Woody species composition (%) under different burn treatments (UFH Farm)

Species	1-year	2-year	3-year	4-year	6-year	No burn
A.karroo	62.90	44.30	51.10	49.20	48.50	38.00
B.ilicifolia	-	-	-	-	-	0.80
C.rudis	-	0.30	0.10	-	0.20	0.20
D.lyciodes	3.20	20.30	14.20	10.20	21.50	14.10
E.rigida	25.10	26.10	23.10	25.20	22.50	31.70
G.occidentalis	1.30	0.70	1.90	3.50	3.10	4.00
L.javanica	-	0.60	-	8.80	0.40	-
M.heterophylla	0.60	1.00	4.10	6.60	1.10	4.70
M.polyacantha	-	0.30	-	0.10	-	-
Opuntia	0.60	1.10	0.70	0.10	1.40	3.80
R. maccawnii	-	-	-	-	-	0.30
R.refracta	-	-	1.70	-	-	0.10
R.lucida	6.30	3.30	3.00	0.10	0.50	1.00
Z.mucronata	-	-	-	0.20	0.30	0.30

Response of grass and woody plant species to frequency of burning at Fort Hare University Farm is presented in Table 4.3.

Table 4.3: Grass and woody species and their relative response to frequency of burning (UFH Farm)

Species	**Increase with frequency of burn**	**Decrease with frequency of burn**	**Inconsistent with frequency of burn**	
Grasses	*A.Congesta*	*E. curvula*	*C.dactylon*	*K.curva*
	P.stapfiana	*E.obtusa*	*C. plurinodis*	*S.neglecta*
	T.triandra	*M.decumbens*	*D.erientha*	*S.fimbriatus*
		S.africanus	*E.chloromelas*	*S.fimbriatus*
			E.mutica	
Woody species	*A.karroo*	*G.occidentalis*	*C.rudis*	*R. maccawnii*
	R.lucida	*M.heterophylla*	*D.lyciodes*	*R.lucida*
	E.rigida		*L.javanica*	*R.refracta*
			M.polyacantha	*Rhus*
			Maytenus	*X. rudis*
			Opuntia	*Z.mucronata*

4.3.1.3 Diversity of species

Diversity of grass species between burn treatments was relatively the same; though, there were slightly more species under 4-year burn and slightly fewer under 1-year burn compared to other burn treatments. One-year, 2-year and 3-year burns (frequently burnt plots) produced slightly fewer species compared to 4-year, 6-year and no burn treatments (less frequently burnt plots).

Diversity of woody species was slightly different between burn treatments. There was slightly more woody species on unburnt plots than on burnt plots. Generally, higher and lower values for richness were under no burn and 1-year burn respectively (Table 4.4).

Table 4.4: Simpson`s Index of Diversity 1 - D for grass and woody species under each burning treatment (UFH Farm)

	Diversity index	
Burn treatments	**Grass**	**Woody species**
No	0.937	0.8
1-year	0.927	0.734
2-year	0.933	0.789
3-year	0.933	0.794
4-year	0.962	0.796
6-year	0.936	0.785

*The index values ranges between 0 and 1, the greater the value, the greater the sample diversity

4.3.2 Long-term effects of burning, grazing and browsing on richness, composition and diversity of grass and woody plants

4.3.2.1 Species richness

Burning, grazing and browsing did not have differential effect ($p > 0.05$) on species richness (Figure 4.2). Treatments neither increased nor decreased species richness for both grasses and woody plants. Woody species were relatively more under goats browsing and grazing.

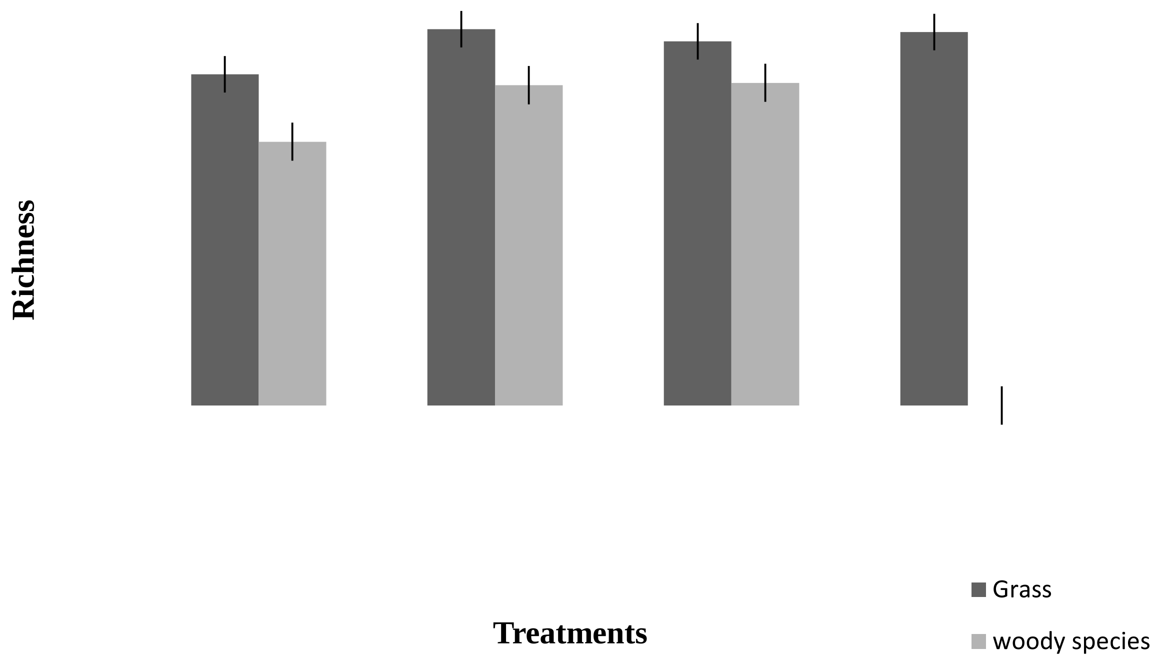


Figure 4.2: Species richness for the grasses and woody species under follow up burn, grazing, goat browsing and control

4.3.2.2 Species composition

Grass species compositional percentages under burning, grazing and goats browsing are presented in Table 4.5. Grass species that were recorded at the site were all present under control (> 17 species). The grass species were 15 under grazing and browsing. There were relatively fewer species (14) under follow up burn. *Cymbopogon plorinodis*, *D.erientha*, forbs, *P stapfiana*, *S.fimbriatus* and *T.triandra* frequencies were highest in all treatments (>8%). The same species were highest in compositional percentage under follow up burn than under grazing, goats browsing and control. *M.caffra* was more under follow up burn than under other treatments. *A*

Cynodon dactylon, E.curvula and S.neglecta frequency were highest under grazing, goats browsing and control. *E.capensis* occurred under goats browsing and control only while *S. africanus* was present under grazing and control.

Other species such as *A.difusa, E.mutica*, Forbs and *Karroo species* were present in unequal proportions under different burn treatments and control. Traces of *A.difusa* (0.7%) were present under control only. *E obtuse* was present under all treatments and control in percentages ranging from 0.9 to 5.2, *E. mutica* occurred in higher percentages (7.3 to 8.6) in all treatments and control. Forbs had percentages ranging from 8 to 9.5. Karroo species had highest percentages under follow up burn and lowest under goat browsing

Table 4.5: Grass species composition (%) for each treatment (UFH Farm)

Species	Follow up burn	Grazing	Goats browsing	Control
A.difusa	-	-	-	0.70
C.dactylon	-	8.00	2.90	5.10
C.plorinodis	9.50	8.00	8.10	8.00
D.erientha	9.50	8.00	8.10	8.00
E.capensis	-	-	7.40	0.70
E.chloromelas	5.20	8.00	5.10	8.00
E.curvula	4.30	8.00	5.10	5.80
E.obtusa	0.90	5.10	4.40	2.20
E.mutica	8.60	7.30	8.10	8.00
Forbs	9.50	8.00	8.10	8.00
Karroo spp	7.80	3.60	2.90	7.30
M.caffra	9.50	1.50	7.40	6.60
Others	1.70	0.70	0.70	0.70
P .stapfiana	9.50	8.00	8.10	8.00
S. negleta	5.20	8.00	7.40	5.80
S. africanus	-	1.50	-	0.70
S. fimbriatus	9.50	8.00	8.10	8.00
T. triandra	9.50	8.00	8.10	8.00

Acacia karroo had highest species composition (> 65%) under all treatments compared to other species. *Eritia rigida* was the second highest in species composition, recording values close to 10% under all treatments. Other species that attained less than 6% species composition under all treatments were *Brachylaena spp, L. javanica, M.heterophylla* and *M.polyacantha* were present in only two treatments. Traces of *Asparagus* species were found under follow up burn and goats browsing. *C.rudis* was present under all treatments with species composition values ranging from 1 to 4.6%. *D.lycioides* occurred under all treatments; was more under follow up burn than under other treatments. *G.occidentalis* was present in high percentages under grazing. *L.camara* occurred under goat browsing only. *L.ferocissimun* was present in small amount under goats browsing only. *M.heterophylla* occurred under all treatments. *Opuntia spp* was present under all treatments with percentages ranging from 0.2 to 1.2. *S.myrtina* was found under all treatments. *R.refracta* was present under all treatments. *R.lucida* had highest percentage under grazing than under follow up burn and goats browsing. More information regarding woody species compositional percentage under Follow-up burn, Goat browsing and grazing at Fort Hare University Farm is provided in Table 4.6.

Table 4.6: Woody species composition (%) in each treatment (UFH Farm)

Species	Follow-up burn	Goat browsing	Grazing
A.karroo	74.40	71.40	65.30
Asparagus spp	0.10	0.40	-
Brachylaena spp	-	0.30	0.10
C.rudis	1.30	1.30	4.60
D.lycioides	4.70	3.80	1.00
E.rigida	12.30	8.60	9.90
G.occidentalis	2.90	4.70	6.40
L.camara	-	1.20	-
L.ferocissimun	-	0.60	-
L.javanica	0.20	0.70	1.30
M.Heterophylla	0.20	1.40	2.20
M.polyacantha	-	-	1.70
Opuntia spp	0.20	1.20	0.20
R.lucida	2.60	2.40	5.60
R.refracta	0.60	0.80	0.20
S.myrtina	0.40	1.30	1.40

Information on grasses and woody species that had species composition percentage of 8 and higher is summarized in Table 4.8. Grass species that attain higher species composition percentage (8%) in this study were more under grazing than under other treatments. There were seven species attaining percentage higher than 8 under Follow up burn and control. Fewer species (6) got species composition higher than 8 under goats browsing. Percentage composition of forbs was only lower than 8% under grazing. Only two woody species (*E.rigida and A.karroo*) attained species composition higher than 8% in this study. List of grass and woody species that recorded more than 8% species composition under follow burn, grazing, goats browsing and control are presented in Table 4.7.

Table 4.7: List of herbaceous and woody species that were more than 8% under follow burn, grazing, goats browsing and control (UFH Farm)

	Follow up burn	**Grazing**	**Goats browsing**	**Control**
	C plorinodis	*C dactylon*	*C plorinodis*	*C plorinodis*
Grasses	*D erientha*	*C plorinodis*	*D erientha*	*D erientha*
	E mutica	*D erientha*	*E mutica*	*E chloromelas*
	E capensis	*E capensis*	*P sptapfiana*	*E mutica*
	P sptapfiana	*E chloromelas*	*S fimbriatus*	*P sptapfiana*
	S fimbriatus	*E curvula*	*T triadra*	*S fimbriatus*
	T triadra	*P stapfiana*		*T triadra*
		S negleta		
		S fimbriatus		
		T triandra		
Woody plants	*A.karroo*	*A.karroo*	*A.karroo*	
	E.rigida		*E.rigida*	

4.3.2.3 Diversity of grass species

Diversity of grass species was high in all treatments with some slight differences (Table 4.8). There was relatively higher (0.94) diversity of grass species under goats browsing and lower (0.92) under follow up burn. Diversity of woody species under grazing was more (0.6) than under goats browsing and follow up burn (0.4).Woody species were not present on control.

Table 4.8: Simpson`s Index of Diversity 1 - D for grass and woody species under follow up burn, grazing and goats browsing (UFH Farm)

	Diversity index	
Treatments	Grass	**Woody species**
Follow up burn	0.924	0.428
Grazing	0.933	0.554
Goats browsing	0.936	0.43
Control	0.935	

*The index values ranges between 0 and 1, the greater the value, the greater the sample diversity

4.3.3 Long-term effects of burning followed by ten-year period of fire exclusion on cover, richness, composition and diversity of grass and woody plants

4.3.3.1 Species richness

Species richness for herbaceous plants was significantly increased by burning ($p \leq 0.05$) (Figure 4.3). Grass species values for richness were 10 and 11 under 2-year burn and 1-burn respectively; it was lowest under no burn (7). Grass species richness ranged from 7 to 11 under burn treatments. Burnt plots had more species than unburnt plots.

Significant effect ($p \leq 0.05$) of burning on species richness for woody plants was still evident after ten-year period of fire exclusion in this study. Species richness was highest (29) on unburnt plots compared to under burnt plots (1from 11 to 13). Different fire frequencies did not have differential effect ($p > 0.05$) on species richness for woody species ten years later after fire was excluded. Species richness was relatively lowest under 5 year burn. Species richness under 1-year, 2-year and 3-year burns was 12.3, 11.7 and 12.3 respectively.

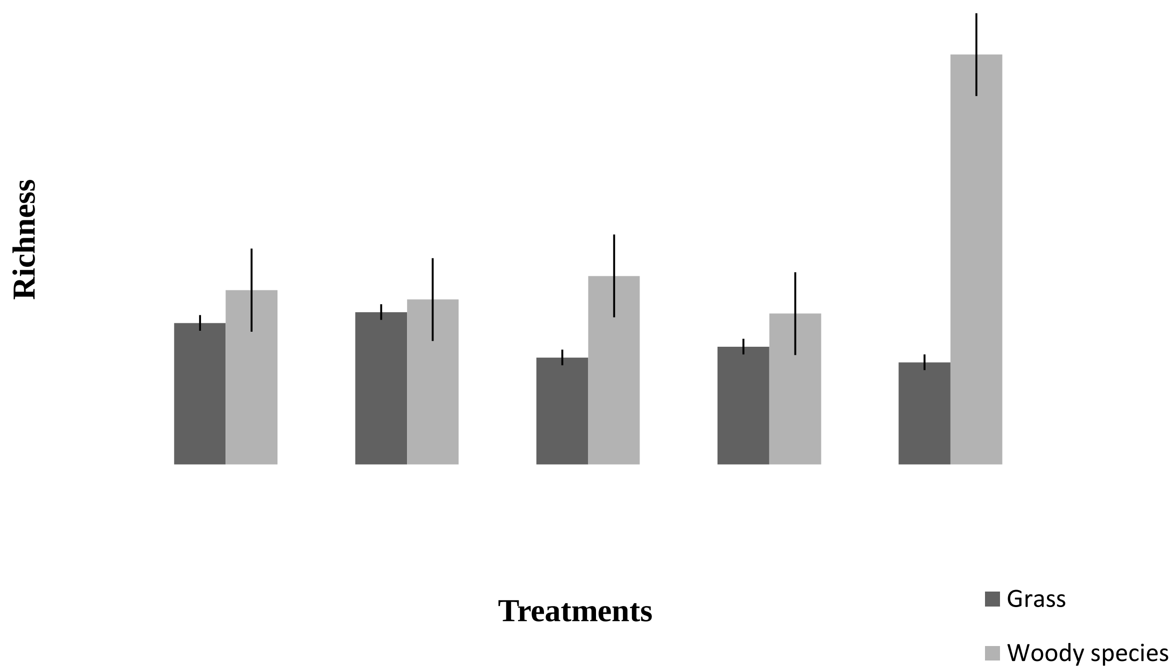


Figure 4.3: Species richness for grasses and woody species under different burn treatments (Matopos, Zimbabwe)

4.3.4 Species composition

Individual grass species behaved differently under burn treatments and no burn in this study. *H. contortus* maintained high species compositional across all burn treatments. *Panicum maximum* had highest species composition percentage than other species under 1-year burn and no burn.

Percent species composition values for *T.triendra* were lowest (0.8%) under 1-year burn and highest (11%) under 2-year burn. *Setaria incrassata* was most abundant species under 2-year, 3-year and 5- than other species. *Heteropogon contortus* was highest under 2-year burn and *C.virgata*, *E.rigidior*, *S.jeffresyii* and *S.pappophoroides* were lowest. *Schinzii jeffresyii*, *D.pentzii*, *E.rigidior*, *E.superba*, *I.afrum*, *L. simplex*, *P.patens*, *S.interpillosa* and *B.negropedata* did not occur in more than two burn treatments. *E.rigidior* was found in small percentages under 1-year and 2-burns. *A.barbicollis* was present in abundance under 1-year burn (12%) and was present under all burn treatments and control. *B. insculpta* attained higher (6.4%) values under no burn than under burn treatments. *B.negropedata* was recorded under no burn treatment only.

C. plurinodis was present under all burn treatments attaining low percentages under 3-year (1.7%) and 5- year (1.5%) burns. *D.milanjiana* recorded more than 9% under all burn treatments and control. *E.trichophora E.trichophora* was found in higher percentage (16%) under annual burn. *H. filipendula* was registered under 2 - year burn only. *M.nerviglume* attained 9% under 2-year burn; it was also present under 3 – year burn and no burn. Traces of *T.berteronianus* were recorded under all burn treatments: however, the percentages were low (from 1.5 to 4). *U. mosambicensis* was present under 1-year, 3-year and 5-year burns. Grass species composition percentages for each burn treatment and control are shown in Table 4.9.

Table 4.9: Grass species composition (%) for each burn treatment (Matopos, Zimbabwe)

Species	1-year	2-year	3-year	5-year	No burn
A.barbicollis	11.70	3.70	0.80	7.40	3.20
B. insculpta	3.10	2.20	0.80	-	6.40
B.negropedata	-	-	-	-	7.40
C. plurinodis	4.70	5.20	1.70	1.50	4.30
C.virgata	1.60	0.70	-	-	-
D.milanjiana	10.90	14.20	9.20	13.20	9.60
D.pentzii	-	1.50	-	-	-
E.rigidior	0.80	0.70	-	-	-
E.superba	-	0.70	-	-	-
Eragrostis spp	1.60	3.00	0.80	1.50	2.10
E.trichophora	16.40	1.50	5.00	0.70	3.20
H.contortus	16.40	19.40	27.50	11.00	16.00
H.filipendula	-	1.50	-	-	-
I.afrum	-	-	-	4.40	-
L. simplex	-	0.70	-	-	-
P.patens	-	-	-	-	1.10
P.muximum	18.80	-	-	2.90	14.90
M.nerviglume	-	9.00	6.70	-	1.10
S.jeffresyii	-	0.70	-	-	-
S.interpillosa	-	-	-	-	8.50
S.incrassata	9.40	20.90	33.30	46.30	12.80
S.pappophoroides	0.00	0.70	-	0.70	-
T.berteronianus	1.60	2.20	4.20	1.50	-
T.triandra	0.80	11.20	5.80	8.10	9.60
U.mosambicensis	1.60	-	4.20	0.70	-

The woody species that were found in all treatments were *Z.mucronata, O.trichocarpum, G.senegalensis, G.monticola, D.lycioides, C.hereroenses, A.rehmanniana, A.nilotica, A.gerrardii* and *A.karroo*. Species such as *C.apiculatum, C.erythrophyllum, D.cinerea* and *C.imberbes* were found in four treatments; all these species were present under no burn. Species recorded under three, two and one treatments are shown in (Table 4.10). *Acacia* species that were found in this group (*A.gerrardii*, *A.karroo, A.rehmanniana* and *A.nilotica*) were present under no burn in percentages ranging from 0.5 to 5. In this study *A.karroo* was highest in percent species composition than other species under all burn treatments attaining 31.6%, 34.1%, 26.9% and 49.7% for 1-year, 2-year, 3-year and 5-year respectively. The highest compositional percentage for Acacia species recorded under no burn treatment in this study was 5% and the species that recorded this value was *A. gerrardii*.

Species such as *A.caffra, A.robusta, A.schweinfurthii, B.discolor, T.sericea, C.glabrum, F.indica, P.gardeniifolia, S.birrea* and *C.adenogonium* were found in smaller proportions under at least one treatment; *Acacia* species such as *A.caffra, A.robusta and A.schweinfurthii*) were not present under no burn. Except *E. virosa* (26%), species that were found under two treatments only ranged from 0.4 to 1.5 in compositional percentage; these species were *A.garckeana, A.nebrownii, C.mossambicense, E.virosa, L.discolor, R.lancea, B.africana* and *C.edwardsii*. Notably, *Acacia* species were not present under no burn treatment.

Species that were present under three treatments were few; they attained percentages ranging from 0.4% to 4.5%. These species were *A.amara, A.galpinii, A.nigrescens, B.africana, C.albopunctatum, C.marlothiis, R.pyroidess, E.divinorum, E.rigida, G.flavescens, P.capensis and C.molle*. Species such as *C.molle* and *A.galpinii* and *A.nigrescens* were not present under no burn. *Acacia* species that was found under no burn treatment was *A.garckeana*. Species such as *E.divinorum, E.rigida, P.capensis* and *R.pyroidess* were not present under 1-year and 2-year burns. Species that were present under four treatments were *C. apiculatum, C. imberbes, D. cinerea* and *C. erythrophyllum*; all these species were present under 1-year burn and no burn.

Table 4.10: Woody species composition percentage for each burn treatment (Matopos, Zimbabwe)

	Species	1-year	2-year	3-year	5-year	No burn
Species present in all treatments	*A.gerrardii*	14.2	7.8	3.7	11.1	5.2
	A.karroo	31.6	34.1	26.9	49.7	0.9
	A.nilotica	16.7	32.2	18	5.5	3.3
	A.rehmanniana	0.4	8.3	1.2	2.5	0.5
	C.hereroenses	0.4	0.5	5.3	1	0.2
	D.lycioides	3.9	1	0.4	5.5	0.2
	G.monticola	1.1	0.5	3.2	1	3.5
	G.senegalensis	6	2.5	3.7	6.5	8.3
	O.trichocarpum	8.2	3.5	12.6	4.5	10.2
	Z.mucronata	0.4	2	2.9	4.5	4.2
Species present in 4 treatments	*C.apiculatum*	1.4	-	9	0.5	3.5
	C.erythrophyllum	0.7	0.5	0.4	-	0.7
	C.imberbes	0.7	0.5	4.9	-	0.9
	D.cinerea	6.7	2	-	1	0.5
Species present in 3 treatments	*A.amara*	1.8	1.5	-	-	0.7
	A.galpinii	0.4	1	0.4	-	-
	A.nigrescens	0.7	1	0.4	-	-
	B.africana	0.4	0.5	-	-	1.2
	C albopunctatum	0.4	-	0.4	-	0.2
	C.marlothiis	1.1	0	-	-	0.7
	C.molle	0.4	0	0.8	-	-
	E.divinorum	-	-	1.2	1	7.1
	E.rigida	-	-	0.8	1	0.7
	G.flavescens	0.40	-	0.8	-	4.5
	P.capensis	-	0.5	-	0.5	2.3
	R.pyroidess	-	-	0.4	1	4.2
Species present in 2 treatments	*A.garckeana*	0.7	-	-	1	-
	A.nebrownii	0	0.5	-	-	-
	C.mossambicense	-	0	1.2	-	-
	E.virosa	-	-	-	0.5	25.7
	L.discolor	-	-	0.4	-	0.2
	R.lancea	-	-	-	1.5	1.4
	B.africana	-	-	0.4	-	0.2
	C.edwardsii	0.4	-	-	-	0.9
Species present in 1 treatments	*A.caffra*	0.4	-	-	-	-
	A.robusta	1.1	-	-	-	-
	A.schweinfurthii	-	-	0.4	-	-
	B.discolor	-	-	-	-	0.7
	C.adenogonium	-	-	-	-	0.2
	C.glabrum	-	-	-	-	0.2
	F.indica	-	-	-	-	0.5
	P.gardeniifolia	-	-	-	-	1.9
	S.birrea	-	-	-	-	0.2
	T.sericea	-	-	-	-	0.2

Grass and woody species that were examines in this study varied in percent species composition; some species recorded higher values while others were in negligible proportions. Grass and woody species that recorded more than 10% species composition under every burn treatment and no burn are shown in Table 4.11.

Table 4.11: List of dominant grass and woody species under each burn treatment (Matopos, Zimbabwe)

	1-year	2-year	3-year	5-year	No burn
Grasses	*A.barbicollis*	*D.milanjiana*	*H.contortus*	*D.milanjiana*	*D.milanjiana*
	D.milanjiana	*H.contortus*	*S.incrassata*	*H.contortus*	*H.contortus*
	E.trichophora	*S.incrassata*		*S.incrassata*	*P.muximum*
	H.contortus				*S.incrassata*
	P.muximum				
Woody species	*A.gerrardii*	*A.karroo*	*A.karroo*	*A.gerrardii*	*E.virosa*
	A.karroo	*A.nilotica*	*O.trichocarpum*	*A.karroo*	*O.trichocarpum*
	A.nilotica				

A few woody species increased, decreased or were inconsistent with frequency of burning; Table 4.12 shows a list of woody species and their response to burn treatment.

Table 4.12: Woody species that increased and decreased inconsistently with frequency of burn or present under no burn only (Matopos, Zimbabwe)

Increase with frequency of burn	**Decrease with frequency of burn**	**Inconsistent with frequency of burn**		**Present under no burn only**
C.erythrophyllum	*Z.mucronata*	*A.gerrardii*	*A.amara*	*T.sericea*
	C.hereroenses	*A.karroo*	*A.galpinii*	*C.adenogonium*
	D.cinerea	*G.monticola*	*A.nigrescens*	*C.glabrum*
		D.lycioides	*B.africana*	*F.indica*
		A.rehmanniana	*C albopunctatum*	*P.gardeniifolia*
		C.apiculatum	*C.edwardsii*	*S.birrea*
		C.imberbes	*B.africana*	*B.discolor*
		C.marlothiis	*R.lancea*	
		C.molle	*C.edwardsii*	
		R.pyroidess	*P.capensis*	
		E.rigida	*E.divinorum*	
		G.flavescens	*A.nilotica*	
		G.senegalensis		

4.3.4.1 Species diversity of herbaceous and woody plant

Diversity of species was high for grasses, it ranged from 0.8 to 0.9; it was relatively highest (0.9) under no burn than under unburnt plots. Diversity of grass species was relatively lower (0.8) under 5-year burn compared to under other burn treatments. Diversity of species for woody species ranged from 0.6 to 0.9, it was higher under no burn than on burnt plots. Diversity of woody species was relatively low under 3-year burn compared to under other burn treatments (Table 4.13).

Table 4.13: Simpson`s Index of Diversity 1 - D for grass and woody species under different burn treatments (Matopos, Zimbabwe)

	Diversity index	
Burn treatments	Grasses	Woody species
1-year	0.874	0.839
2-year	0.866	0.773
3-year	0.809	0.569
5-year	0.759	0.873
No burn	0.904	0.912

*The index values ranges between 0 and 1, the greater the value, the greater the sample diversity

4.4 Discussions

Discussions of results are divided into (i) long term effects of burning on species richness, composition and diversity, (ii) long term effects of burning, grazing and goats browsing on species richness, composition and diversity and (iii) long term effects of burning followed by ten–year period of fire exclusion.

4.4.1 Long-term effects of burning frequency on richness, composition and diversity of grass and woody plants

4.4.1.1 Species richness

Even though the difference in species richness is not very clear between burn treatments, the pattern that could be established is that, the richness was slightly higher under 3-year, 4-year and 6-year burn treatments compared to under relatively short burn intervals (1-year and 2-year) and no burn. The results suggest that short burning intervals could, to some extent, hamper species richness. These findings are consistent with the findings reported by Uys *et al*. (2004) who did not find a clear different response of grass species richness to fire treatments. Conversely, Peterson & Reich (2008) reported more species richness for grasses under annual treatment over other treatments. Their study suggested that annual and biennial fire frequencies enhanced richness of grass species by preventing shrubs and trees from competitively excluding grasses. It should, however, be noted that annual environmental gradients e.g. rainfall (Le Roux and Morris 1977) can have influence on species richness.

Low species richness for woody plants on burnt plots compared to unburnt plots are consistent with the results reported by Peterson and Reich (2008) who also found out that richness of woody species decline with increasing burning frequency. Species richness is one of the indices of biotic community integrity which is an important attribute for functioning of the ecological processes Reduction in woody species richness on burnt plots compared to unburnt plots in this study suggests that fire has a potential to degrade biotic community integrity site for a site and therefore, ecological processes functioning. This effect could alter a site ability to provide certain ecosystem services. In the present study, trend for species richness as a consequence of different burning frequencies was not clear.

4.4.1.2 Species composition

Grass species such as *C.dactiylon*, *C.plurinodis*, *E.chloromelas*, *E.curvula*, *E.mutica*, Forbs, *M.caffra*, *P.maxima*, *P.stapfiana*, *S.neglecta*, *S.fimbriatus* and *T.triandra* recorded higher species composition values on burnt plots than on unburnt ones, suggesting that they could be sustained better on areas that receive burning than those which are not burnt. Higher species composition values for *A.congesta*, *K.curva*, *M.decumbens* and *S.africanus* under unburnt plot compared to under burnt ones could mean that these species are more sustained on areas that are not burnt than those which receive burning. Most species did not show any clear response to frequency of burning, however a few increased (*A.Congesta*, *P.stapfiana*, *T.triandra*) and decreased (*E. curvula*, *E.obtusa*, *M.decumbens* and *S.africanus*) with frequency of burning. Even though Karoo species (Karoo bushes) did not show a clear response to burn frequency, they recorded the lowest percentage under annual burn and the highest under six-year burn; suggesting that some degree of their control is possible with increasing burn frequencies. *Panicum maxima* was lowest under four-year burn, six-year burn and no burn treatments, suggesting that fire enhances its existence.

Some woody species such as *A.karroo*, *D.lyciodes*, *R.refracta*, *R.lucida* recorded higher species composition values on burnt plots than on unburnt ones while *L.javanica*, *M.polyacantha*, *X. rudis* did not occur on unburnt plots; suggesting that these species could persist better under burning environments than where fire is excluded. *Eritia rigida* scored more than 10% species richness under both burnt and unburnt plots; however, the highest value was under no burn suggesting that even though the species is not adversely affected on burning environments, it could do much better where fire is excluded. Other species that recorded higher species composition values on unburnt plots than burnt ones include *Opuntia*, *G.occidentalis* and *M.heterophylla*. Most woody species did not show clear response to frequency of burning, but a few increased (*A.karroo*, *R.lucida* and *E.rigida*) and decreased (*G.occidentalis* and *M.heterophylla*) with frequency of burning.

4.4.1.3 Species diversity

Though the diversity of grass species between burn treatments was approximately the same, some slight differences existed. The results of this study show that 1-year, 2-year and 3-year burning to some extent reduce diversity of grass species while 4-year, 6-year and control support relatively high species diversity. These results imply that high species diversity of grass plants could be attained by burning of rangelands after every four years while annual burning could be detrimental.

Diversity of woody species increased progressively from 1-year burn to 4-year burn and dropped a little under 6-year burn. Higher diversity index values for woody species under unburnt plots compared to under burnt ones suggest that diversity of woody species could be enhanced when fire is excluded.

4.4.2 Long-term effects of burning, grazing and browsing on basal cover, species richness, composition and diversity of grass and woody plants

4.4.2.1 Species richness

Although the difference in basal cover and richness was not significant, follow up burn recorded slightly higher basal cover and lowest grass and woody species richness compared to grazing and goats browsing. Grazing and goats browsing treatments which had slightly higher basal cover than control, obtained lower grass species richness compared to control. It should be noted that severe defoliation of grass by animals could result in decreased basal cover (Du Toit & Aucamp 1985).

4.4.2.2 Species composition

Species composition percentage values for *C. plorinodis*, *D erientha*, Forbs, *M caffra*, *P stapfiana*, *S fimbriatus* and *T triandra* were highest under follow up burn compared to under other treatments. These grasses were also dominant in terms of species composition under grazing, goats browsing and control. As expected, most grass species (*C plorinodis*, *D erientha*, *E chloromelas*, *E mutica*, *Forbs*, Others, *P stapfiana*, *S fimbriatus* and *T triandra*) performed uniformly under grazing and control. Grazing and Control are similar treatments except that control had woody species removed. In this study, *S negleta*, *M caffra*, *Forbs*, *D erientha*, *E obtuse*, *E capensis* and *E mutica* had species composition values higher under goats browsing than under control, suggesting that cattle as compared to goats could lower their quantities. Another reason could be that, these grass species perform better when growing together with woody plants. A few species such as *C.dactylon*, *E.chloromelas*, Karroo species and *E.curvula* recorded high values for species composition under control than under goats browsing. Du Toit & Aucamp (1985) notes that severe defoliation of grasses by animals could cause changes in relative species composition for example decreased grass cover and increased forbs.

Acacia karroo dominated in species composition under all treatments, but it was more pronounced under follow up burn. Under grazing, where lenient disturbance is experienced, A.*karroo* species composition values were lower compared to under follow up burn and goats browsing. This could mean that, disturbances such as burning and browsing revitalize *A.karroo*. The performance of *E.rigida* in terms of species composition gives the impression that it thrives better when it receives burning than where fire is excluded. Woody species that recorded higher species composition values under grazing than under follow up burn were *C.rudis*, *G.occidentalis*, *R.lucida*, *S.myrtina* and *X.rudis*; their species composition percentage could have been affected by burning.

4.4.2.3 Diversity of species

Diversity of grass species was high under all treatments; the treatment did not have clear differential effects on species diversity. Diversity of woody species was low in all treatments, however, was more under grazing compared to under follow up burn and goats browsing. The reason could be that burning and browsing disturbances affect diversity of woody species more than grazing.

4.4.3 Long-term effects of burning followed by ten-year period of fire exclusion on species richness, composition and diversity of grass and woody plants

4.4.3.1 Species richness

Even though the study was conducted after ten years of fire exclusion, similar results to those reported by Peterson & Reich (2008) where more species richness for grasses under 1-year and 2-year burns compared to other burn treatments and low species richness for woody plants on burnt plots compared to unburnt plots were found. These findings validate the fact that the effects of fire could be long lasting on a site. Low species richness for grasses under unburnt treatment compared to burnt ones demonstrates that effects of fire could not be reversed easily.

4.4.3.2 Species composition

Grass species that increased in species composition with increasing burning frequency was *B. insculpta* and that decreased with increasing frequency of burning was *S.incrassata*. Most species of grass did not show clear increase or decrease in species composition as a consequence of fire frequency. Unexpectedly, *T.triandra* recorded higher species composition values under unburnt plot than under burnt ones. Under normal circumstances, this species increases if a site is burnt regularly. May be exposure to burning followed by fire exclusion could affect vitality/vigour of this particular species hence its biotic integrity. *B. insculpta* as well registered higher species composition value under unburnt plot than under burnt ones. *Aristida barbicollis* increased in species composition with increasing burning frequency from 1-year burn to 3-year burn. Grass species such as *T.berteronianus*, *S.incrassata* and *H.contortus* decreased in species composition with increasing burning frequency from 1-year burn to 3-year burn.

Flueggea virosa, *E.divinorum*, *G.flavescens*, *G.monticola*, *G.senegalensis*, *P.capensis* and *R.pyroidess* had higher species composition values under unburnt plot than on burnt plots suggesting that they could thrive better in the absence of fire. *Berchemia.discolor*, *S.birrea*, *P.gardeniifolia*, *F.indica*, *C.glabrum*, *C.adenogonium* and *T.sericea* were present only under no burn; it could be that these species are more adapted to areas that are free from fire. Species that recorded more composition percentages on burnt plots than on unburnt ones were *A.amara, A.gerrardii, A.karroo, A.nilotica, A.rehmanniana, B.africana, C.albopunctatum, C.apiculatum, C.hereroenses, C.imberbes, C.marlothiis, D.cinerea, D.lycioides, E.rigida, G.senegalensis, L.discolor, O.trichocarpum, R.lancea* and *Z.mucronata*, perhaps these species thrive better on burning environments.

4.4.3.3 Species diversity

Unburnt plots recorded higher diversity of species for both grasses and woody than burnt ones. In this study diversity of grass species increased with increasing burn frequency. Diversity of woody species also increased with increasing frequency of burning from 3-year burn to 1-year burn. The findings imply that fire effects could be long lasting. Land managers are therefore, needed to be more careful in use of fire as a management tool.

4.5 Conclusion

In this study, it was found out that burning reduce richness for woody species but did not produce consistent trends. Burning followed by fire exclusion for ten years reduced grass and could not produce consistent effect on woody species richness. The study has shown that effects of burning, grazing and browsing by goats on species composition for both grass and woody plants could depend on species; plant species composition either increased, decreased or remained constant. Different burn treatments did not have differential effect on both grass and woody species diversity. Burning, grazing and browsing by goats did not have clear effects on diversity of grass species. Burning followed by fire exclusion for ten years reduced grass species richness and diversity of both grass and woody species. By reducing species richness of woody species, increasing or decreasing compositional percentage of both grasses and woody species, burning could have an effect on biotic community integrity.

5 Long-term effects of fire, grazing and goats browsing on site stability

5.1 Introduction

Site stability is used here to describe the ability of a site to stay essentially unchanged or ability to return to the reference state following perturbation (Griffiths *et al*. 2001). Ecological disturbances of sufficient magnitude or duration such as fire and herbivory can shape ecosystem characteristics and create both favourable and unfavourable local environment (Folke *et al*. 2004). Prolonged disturbance by fire and herbivory could influences the capacity of a site to limit redistribution and loss of soil resources including nutrients and organic matter by wind or water as well as the site's ability to perform functions and provide products and services (Archer & Pyke 1999).

Soil degradation through accelerated erosion by wind and water, could cause irreversible damage to rangeland ecosystems. Board on Agriculture and National Research Council (1994) emphasizes that soil degradation damages the soil itself but also disrupts nutrient cycling, water infiltration, seed germination, seedling development, and other ecological processes that are important components of rangeland ecosystems. Site stability is one of major criteria for determining status of rangeland ecosystem, however, studies on the effect of fire on ecosystem often fail to establish how severe defoliation of vegetation on a site by either burning or herbivory could degrade soil and render it liable to erosion hazards and enhance disfunctioning of ecological processes. Such studies fail to recognize that soil stability is central to the functionality of rangeland ecosystem processes.

It is, therefore, very important to study if prolonged perturbation of a site by fire and herbivory could influence site stability. A study to investigate effects of fire, grazing and goats browsing on selected indicators of site stability such as basal cover, standing dead grass biomass, tuft to tuft distance, tuft diameter, canopy distance and stem to stem distance conducted at University of Fort Hare research farm Honeydale section and Two-Tree-Kop, Matopos Research institution, Zimbabwe.

The general objective of the study was:

To investigate if long term burning, grazing and browsing by goats could have an effect on basal cover, standing dead grass biomass, tuft to tuft distance, tuft diameter, canopy distance and stem to stem distance hence, site stability which could ultimately lead to altered functioning of rangeland ecosystem ecological processes.

Specific objectives were to:

(1) investigate if long term burning frequencies have differential effects on selected indices of site stability such as basal cover, standing dead biomass, tuft to tuft distance, tuft diameter distance, stem to stem distance and canopy distance ,

(ii) compare long term burning, grazing and browsing by goats effects on selected indicators of site stability namely; basal cover, standing dead biomass, tuft to tuft distance, tuft diameter distance, stem to stem distance and canopy distance and

(iv) investigate if long-term burning frequencies followed by ten-year fire exclusion affect basal cover, standing dead biomass, tuft to tuft distance, tuft diameter distance, stem to stem distance and canopy distance.

It was hypothesized that

(i) General hypothesis, long term burning, grazing and browsing by goats have effect on site stability.

(ii) if the hypothesis in (1) is true, it is hypothesized that long-term different burning frequencies have differential effects on selected indices of site stability such as basal cover, standing dead biomass, tuft to tuft distance, tuft diameter distance, stem to stem distance and canopy distance,

(iii) burning, grazing and browsing by goats affect basal cover, standing dead biomass, tuft to tuft distance, tuft diameter distance, stem to stem distance and canopy distance than gazing and goats browsing by goats and

(iv) long-term burning frequencies followed by ten-year fire exclusion affect basal cover, standing dead biomass, tuft to tuft distance, tuft diameter distance, stem to stem distance and canopy distance.

5.2 **Materials and methods**

A detailed description is provided in chapter 3

5.3 **Results**

This section is divided into three parts namely: (i) long-term effect of burning frequency on grazing and brows potential (University of Fort Hare Research Farm) (ii) long-term effect of burning, grazing and goats browsing on grazing and brows potential (University of Fort Hare Research Farm) and (iii) long-term effect of burning frequency followed by ten-year period of fire exclusion frequency on grazing and brows potential (Two-Tree-Kop, Matopos).

5.3.1 Long-term effects of burning frequency on basal cover, standing dead grass biomass, tuft to tuft distance, tuft diameter distance, stem to stem distance and canopy distance

5.3.1.1 Basal cover

Burning treatments did not have different effects on basal cover ($p > 0.05$). Basal cover was neither enhanced nor reduced by different burn treatments. Basal cover was relatively lowest under 4-year burn (12%) and highest under 2-year burn (15%) (Table 5.1). Basal cover was relatively more under 1-year (13.13%), 2-year (14.83%) and 3-year (13.65) burns compared to under 4-year burn (12.47%), 6-year burn (12.79%) and no burn (13.09%).

Table 5.1: Basal cover (%) under each burn treatment (UFH)

Burn treatments	Basal cover %	
	Means	SE
No burn	13.1^{ns}	± 2.18
1-year	13.1^{ns}	± 2.04
2-year	14.8^{ns}	± 2.31
3-year	13.7^{ns}	± 2.52
4-year	12.5^{ns}	± 1.83
6-year	12.8^{ns}	± 2.17

ns = no significant statistical difference

The biomass values of standing dead grass recorded from different burn treatments were significantly different ($p \leq 0.5$). A higher value for standing dead grass biomass (18g/m2) was under 6-year burn than under other burn treatments (Figure 5.1). Dead grass biomass under 1-year, 2-year, 3-year, 4-year and no burn treatments was not significantly different (p>0.5), the grass biomass did not exceed 15g/m^2.

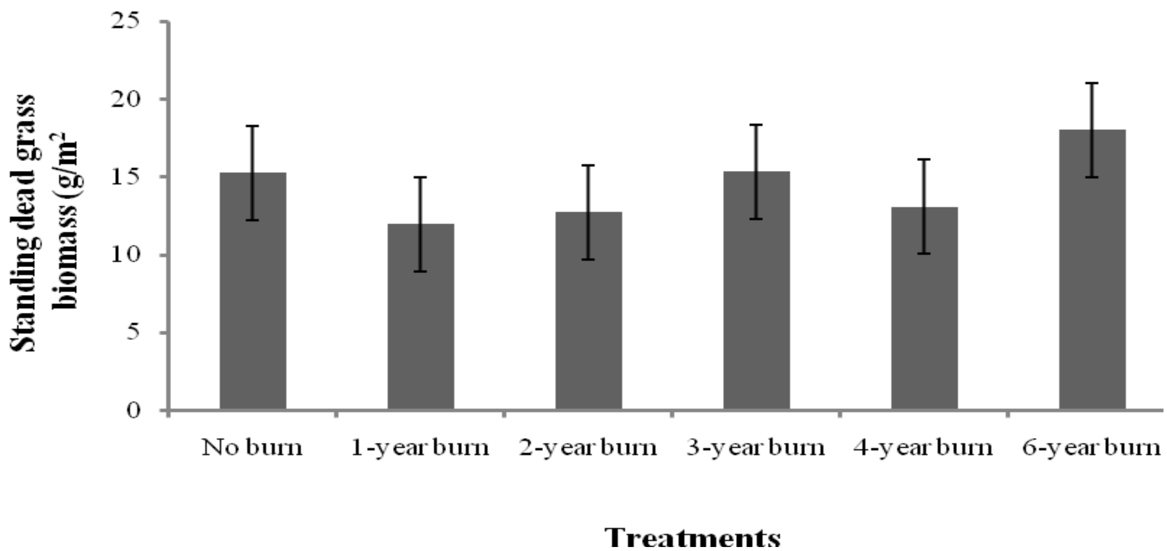


Figure 5.1: Standing dead grass biomass (g/m^2) for each burn treatment (UFH)

Burning did not have significant effects on tuft to tuft distance between grass plants ($p > 0.05$). The tuft to tuft distance means for 1-year, 2-year, 3-year, 4-year, 6-year and no burn are presented in Table 5.2. Relatively more tuft to tuft distance was under 2-year burn (9cm). It was relatively low under 1-year burn (4cm).

Table 5.2: Tuft to tuft mean distance (cm) and standard errors for grasses under each burn treatment (UFH)

Treatments	Distance (cm)	SE
No burn	5.66 ^{ns}	±2.47
1-year	4.26^{ns}	±1.21
2-year	9.43 ^{ns}	±1.31
3-year	6.87 ^{ns}	±0.72
4-year	5.27 ^{ns}	±0.91
6-year	6.93 ^{ns}	±1.06

ns = no significant statistical difference

Different burn frequencies did not have differential effect on the diameter of tufts for grasses. However, relatively the tuft diameter was more under 6-year burn and no burn (>7cm). Tuft diameter values were relatively low under 4- year burn (4cm). Means for diameter of tufts for grass plants under no burn, 1-year, 2-year, 3-year, 4-year and6-year are shown in Table 5.3.

Table 5.3: Tuft diameter (cm) and standard errors for grasses under each burn treatment (UFH)

Burn treatments	Diameter (cm)	Std. Error
No burn	7.24 ^{ns}	±0.59
1-year	4.52 ^{ns}	±1.19
2-year	4.40 ^{ns}	±0.98
3-year	4.27 ^{ns}	±0.56
4-year	3.88 ^{ns}	±0.89
6-year	7.37 ^{ns}	±0.71

ns = no significant statistical difference

The results of analysis of variance showed that there was no significant difference ($p > 0.05$) in woody plants canopy distance and stem-to-stem distance between burn treatments, however, greater canopy distances (>1m) were under no burn, 4-year burn and 6-year burn. Canopy distance was relatively low under 2 year burn (1m). Stem to stem distance was relatively low (1m) under 3-year burn and more under no burn (1.6m). Canopy distance and stem to stem distance means and standard errors are presented in Table 5.4.

Table 5.4: Canopy distance and stem to stem distance means and standard errors for woody plants under each burn treatment (UFH)

Dependent Variable	Burn treatments	Distance (m)	Std. Error
Canopy distance	No burn	1.408 ^{ns}	±0.217
	1-year	0.88 ^{ns}	±0.16
	2-year	0.55 ^{ns}	±0.16
	3-year	0.86^{ns}	±0.16
	4-year	1.34 ^{ns}	±0.20
	6-year	1.13 ^{ns}	±0.19
Stem-to-stem distance	No burn	1.46 ^{ns}	±0.34
	1-year	1.44 ^{ns}	±0.24
	2-year	1.03 ^{ns}	±0.26
	3-year	0.99 ^{ns}	±0.25
	4-year	1.58 ^{ns}	±0.31
	6-year	1.62 ^{ns}	±0.31

ns = no significant statistical difference

5.3.2 Long-term effects of burning, grazing and browsing on basal cover, standing dead biomass, tuft to tuft distance, tuft diameter distance, stem to stem distance and canopy distance

Burning, grazing and browsing did not have differential effects on basal cover ($p > 0.05$) Treatments neither increased nor decreased grass basal cover. Basal cover was relatively high (4.8%) under follow up burn and low (3.8%) under control (Table 5.5).

Table 5.5: Grass basal cover (%) under follow up burn, grazing, goats browsing and control (UFH)

Treatments	**Basal cover**	
	Means	SE
Follow up burn	4.76^{ns}	±1.55
Grazing	4.22^{ns}	±1.67
Goats browsing	3.99^{ns}	±1.45
Control	3.80^{ns}	±1.55

ns = no significant statistical difference

Dead grass biomass was not significantly different between burning, grazing and goats browsing treatments ($p > 0.05$). Dead grass biomass means (g/m^2) for follow up burn, goats browsing, grazing and control are presented in Figure 5.2. Standing dead grass biomass was relatively more under goats browsing ($16 g/m^2$) and low ($13 g/m^2$) under control.

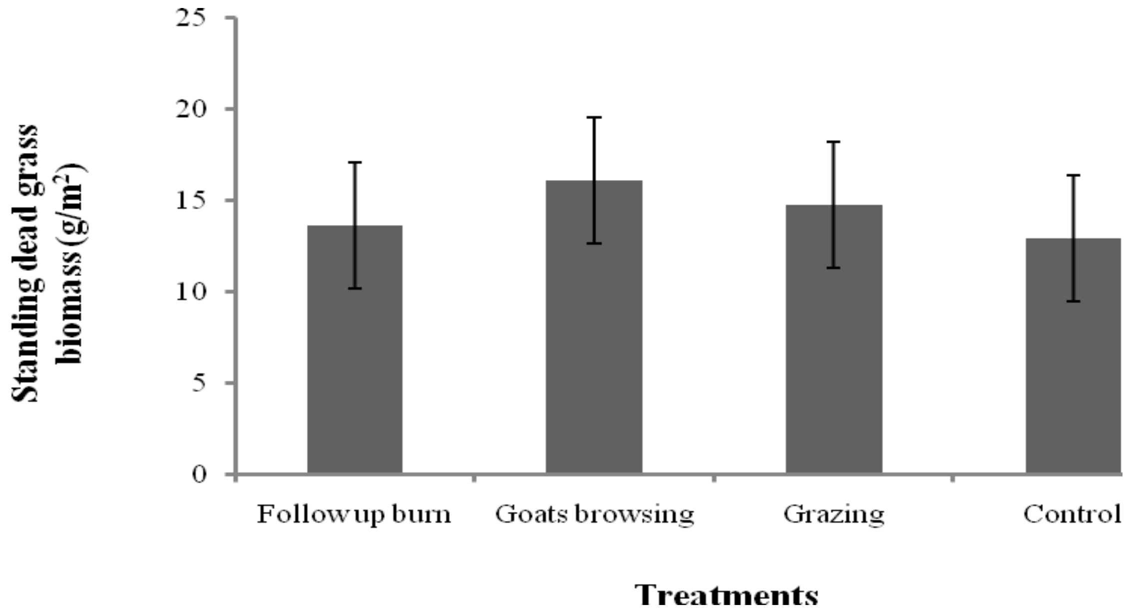


Figure 5.2: Standing dead grass biomass (g/m2) under each treatment (UFH)

The results of analysis of variance showed that tuft to tuft distance was not significantly different ($p > 0.05$) between treatments. Tuft to tuft distance means for follow up burn, goats browsing, grazing and control are shown in Table 5.6. There was relatively more tuft to tuft distance under follow up burn (6.5cm) than under grazing, goats browsing and control. The distance between the tufts was relatively small (4.5cm) under goats browsing compared to under other treatments.

Table 5.6: Tuft to tuft distance (cm) and standard errors for grasses under each treatment (UFH)

Burn treatments	Distance	Std. Error
Follow up burn	6.46 ^{ns}	±0.53
Goats browsing	4.46 ^{ns}	±0.68
Grazing	5.36 ^{ns}	±0.54
Control	4.68 ^{ns}	±0.64

ns = no significant statistical difference

Diameter of tufts was not significantly different ($p > 0.05$) between treatments. Tufts diameter means attained under follow up burn, goats browsing, grazing and control are given in Table 5.7. Relatively more diameter of tufts (5.8cm) was under grazing and small under control (5.2cm).

Table 5.7: Tufts diameter means (cm) and standard errors for grasses under each treatment (UFH)

Treatment	Diameter	Std. Error
Follow up burn	5.37 ^{ns}	0.40
Goats browsing	5.16 ^{ns}	0.40
Grazing	5.77 ^{ns}	0.41
Control	5.18 ^{ns}	0.66

ns = no significant statistical difference

Both canopy and basal distance (stem to stem) means for woody plants were not significantly different ($p > 0.05$) between treatments. The distance between the canopy (0.6cm) and stems (1cm) was relatively low under grazing compared to under other treatments. Means for canopy and stem to stem distance under burning, grazing and browsing are presented in Table 5.8

Table 5.8: Canopy distance and stem to stem distance means (m) and standard errors for woody plants under each burn treatment (UFH)

Dependent Variable	Treatments	Distance	Std. Error
Canopy distance	Follow up burn	1.02^{ns}	±0.30
	Goats browsing	0.97^{ns}	±0.34
	Grazing	0.59^{ns}	±0.14
Basal distance	Follow up burn	1.29^{ns}	±0.33
	Goats browsing	1.25^{ns}	±0.38
	Grazing	1.01^{ns}	±0.16

ns = no significant statistical difference

5.3.3 Long-term effects of burning followed by ten-year period of fire exclusion on standing dead grass biomass, tuft to tuft distance, tuft diameter distance, stem to stem distance and canopy distance

Standing dead grass biomass was not significantly different ($p>0.5$) between burn treatments. Dead grass biomass means for 1-year, 2-year, 3-year, 5-year and control are presented in Figure 5.3. Standing dead grass biomass values were relatively high under 5-year burn ($13g/m^2$) and low ($10g/m^2$) under unburnt plots compared to under burnt plots.

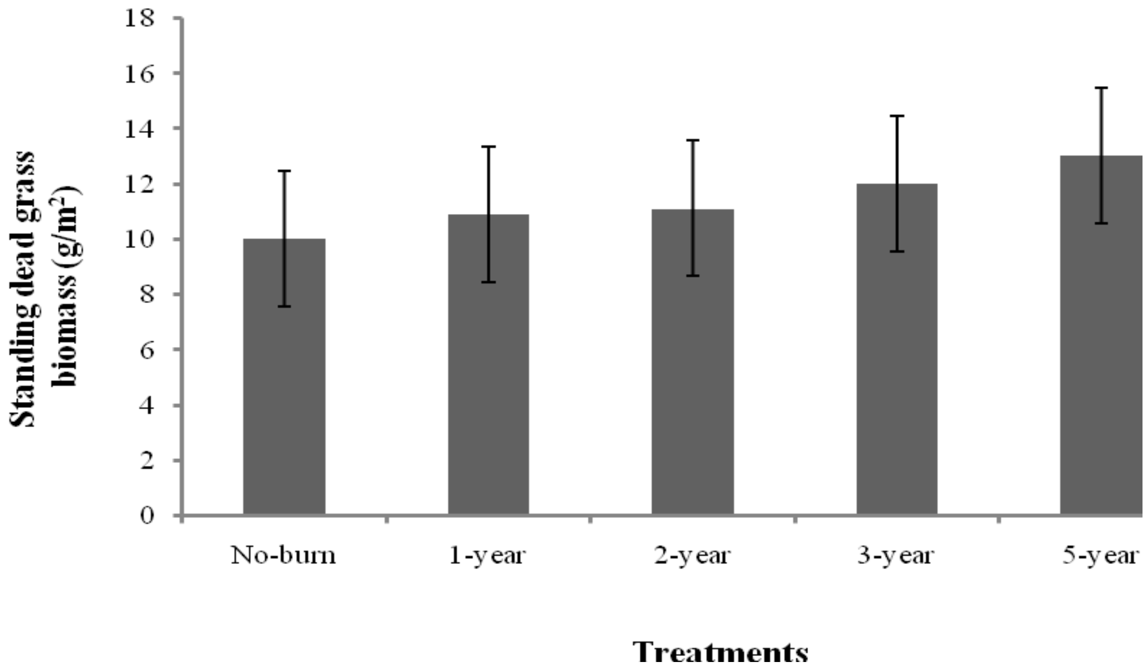


Figure 5.3: Standing dead grass biomass (kh/ha) under each burn treatment (Matopos, Zimbabwe)

Tuft to tuft distance was significantly different ($p \leq 0.05$) between burn treatments. No burn had significantly higher value (10.4cm) for tuft to tuft distance than other burn treatments. Burning reduced tuft to tuft distance, the range was from 6.6cm to 9.2cm. Five-year burn had relatively more (9cm) distance between tufts compared to other burn treatments (Table 5.9).

Table 5.9: Tuft to tuft (cm) and standard errors for grasses under each burn treatment (Matopos, Zimbabwe)

Burn treatments	Distance	Std. Error
No burn	10.361*	±0.625
1-year	6.63 ^{ns}	±0.50
2-year	6.70 ^{ns}	±0.56
3-year	6.59 ^{ns}	±0.61
5-year	9.27 ^{ns}	±0.58

ns = no significant statistical difference

* = Significant statistical difference

Tufts diameter was not significantly different ($p > 0.05$) between burn treatments. No burn had greater tuftS (2.9cm) than other burn treatments; however, the difference was not significant. Means diameters of tufts are presented in Table 5.10. Burn treatments had more tuft diameter under 5-year burn than under other treatments.

Table 5.10: Tufts diameter (cm) means and standard errors for grasses under each burn treatment (Matopos, Zimbabwe)

Burn treatments	Diameter	Std. Error
No burn	2.90^{ns}	±0.24
1-year	2.30^{ns}	±0.19
2-year	2.49^{ns}	±0.21
3-year	2.42^{ns}	±0.22
5-year	2.81^{ns}	±0.21

ns = no significant statistical difference

Different burning frequencies followed by ten-year period of fire exclusion did not have significant difference ($p > 0.05$) effects on both canopy and stem to stem distance. There was relatively greater canopy distance under 3-year burn (0.5m) than under control (0.2m). Relatively short stem to stem distance was under 1-year burn than under other treatments. Relatively higher stem to stem distance was under no burn (Table 5.11).

Table 5.11: Canopy distance and stem to stem distance means (cm) and standard errors for woody plants under each burn treatment (Matopos, Zimbabwe)

Dependent variable	Burn treatments	Distance	Std. Error
Canopy distance	No burn	0.23^{ns}	±0.08
	1-year	0.28^{ns}	±0.09
	2-year	0.41^{ns}	±0.11
	3-year	0.46^{ns}	±0.10
	5-year	0.42^{ns}	±0.10
Stem-to-stem distances	No burn	1.35^{ns}	±0.27
	1-year	0.86^{ns}	±0.30
	2-year	1.10^{ns}	±0.38
	3-year	0.95^{ns}	±0.34
	5-year	0.90^{ns}	±0.36

ns = no significant statistical difference

5.3.3.1 Correlations

Tuft diameter was significantly related ($p < 0.001$; $r = 0.258$) to tuft to tuft distance. The distance between the adjacent canopies (canopy distance) was strongly related ($p < 0.001$; $r = 0.897$) to the distance between stems of neighbouring woody plants.

5.4 Discussions

Although the difference in basal cover between burn treatments was not significant, there were some variations. The results show slightly improved basal cover under frequent burning (1-year, 2-year and 3-year burn treatments) compared to less frequent burning (4-year and 6-year burn treatments) and no burn. The findings of the present study are consistent with the results of a burning trial, in Botswana and Zimbabwe reported by O' Connor (1985). On the contrary, these results are not in agreement with the finding reported by Kutt & Woinarski (2006) and Kennan (1971 who reports reduction in basal cover with increasing burning frequency. Their results can also be toned down by the fact that burning effect on vegetation parameters could be a composite of many factors including type of fire and climatic factors associated with the plant growth; White and Currie (1983) allude to this.

Significantly more dead grass biomass under 6-year burn than under other burn treatments and no burn is hard to explain; this is more so, because, studies on effect of fire on moribund accumulation are scarce. Quantification of this parameter did not receive much scholarship in previous research works. The results of this study showed a general increase in dead grass biomass with increased burn interval, attaining significantly highest value under 6-year burn. This could be ascribed to removal of standing dead grass tissues each time burning occurs. Accumulation of dead grass tissues could depend on burn frequency. But also, effects of fire on vegetation parameters could be ascribed to differences in time of burning. Time of burning can have profound effects on the vegetation response to fire, for example, three weeks difference in time of burning has a dramatic long-term influence on the vegetation (Towne & Owensby 1984). It is believed that climatic variations could also influence the presence of dead grass tissues. For example, dead grass tissues weakly attached to the living mother tuft could be removed easily e.g. by wind. Dead standing grass tissues could get detached and become a litter material. With more moisture in the soil, the basement of dead grass tissues could rot and fall off. The findings of this study imply that evaluation of plat parameters could be made complex by a lot of other unforeseen factors.

The findings imply that burning could be effective when used to clear sites off unwanted dead grass debris where dormant season grazing (grazing period between plant quiescence in late fall and green up in early spring) to lower winter feed cost is no considered important. However, standing dead grass biomass is dependent on plant factors, physical site factors, animal factors, and economic and management factors (Riesterer *et al*. 2000). Large accumulations of dead grass debris could be ecologically detrimental as these could smother flush of regrowing tillers. In this study, the difference in tuft to tuft distance as well as tufts diameter was not significant; higher values for diameter of tufts were under 6-year burn and no burn treatment. There was also a slight progressive decrease in tufts diameter with decreasing burn frequency from 1-year to 4-year burn treatments.

The finding showed strong positive relationship between tufts diameter and tuft to tuft distance. This is reasonable because spatial arrangement can be an important factor affecting competition among plants. The bigger the plant gets, the more space is required to accommodate growth, Richards *et al*. (2010) allude to this. Czaran and Bartha (1992) confirm this by pointing out that the spatial extent of a plant is often used as an index of its potential to acquire resources such as water and nutrients. Although significant difference could not be established in both canopy distance and basal distance of woody plant as a consequence of different burning frequencies, the trend was that, higher values were under 4-year, 6-year and no burn treatments than under 1-year, 2-year and 3-year burn treatments. The results showed that the distance between the adjacent canopies (canopy distance) was positively related ($p < 0.001$; $r = 0.897$) to the distance between stems of neighbouring woody plants. It is therefore concluded on this matter that performance of an individual plant could be related to a number of factors including distance of the neighbouring plant (Gates 1980). In the light of the results as well as findings from other scientist, the researcher deserves the right to conclude that the effect of fire on vegetation parameters could be clouded by a number of factors which are in most cases interconnected.

5.4.1 Long-term effects of burning, grazing and browsing on tuft to tuft distance, tuft diameter, canopy distance and basal distance

While difference in both canopy distance and basal distance under follow up burn, goats browsing and grazing was not significant, follow up burn recorded higher values (for both canopy and basal distances) followed by goats browsing and then grazing. Literature on neighbourhood dynamics as a consequence of burning, grazing and browsing is limited. More studies on the subject are needed to validate findings of this study under different ecosystems. Lack of significant difference between treatments pertaining to basal cover reported in this study is fair because basal cover is generally more stable from year to year and changes less due to climatic fluctuations or utilization by animals. Under minimum to moderate disturbance, basal cover is not expected to change. This finding suggests that the experimental sites were not subjected to severe burning or utilization by animals. This implies further that magnitude of disturbance is very important to inflict recognizable damage to the site.

Insignificant difference between burning, grazing and goats browsing regarding tuft to tuft distance, stem to stem distance, canopy distance and tufts diameter was understandable. Nearness and distance of individual plant could not be associated with fire only because a number of factors including competition are involved. It is necessary to consider simultaneously the spatiotemporal patterns of the vegetation, the biotic environment and the disturbances in order to predict the consequences of external effects on vegetation (Bartha 1997). The findings imply that studies on effects of disturbance on vegetation parameters are very complex because so many factors are involved. It would not be easy to single out effects of a particular disturbance out of the array of other factors.

5.4.2 Long-term effects of burning followed by ten-year period of fire exclusion on tuft to tuft distance and tufts diameter

Plant to plant distance could be used to estimate density of plants. Wider distance (10.4cm) from neighbouring tufts of grass plants observed in the present study under no burn could be ascribed to limited defoliation that grass plants received. If grasses are not properly defoliated, old tillers could smother new ones that sustain growth of a grass plant, hence, tufts size and number are reduced (Hurdy 1999). Even though significant difference could not be established between burn treatments, tuft to tuft distance as well as tufts diameter were more under 5-year burn compared to under 1-year, 2-year and 3-year burn treatments, which are generally, short interval burns. In this study, long-term burning followed by ten years of fire exclusion could have played a role in the increase and reduction of tuft to tuft distance and dead grass biomass respectively, however, stem to stem distance, tufts diameter and canopy distance were not altered. This suggests that different vegetation characteristics respond differently to different disturbances of varying magnitude.

5.4.2.1 Correlations

Significant relationship between grass tuft diameter and tuft to tuft distance and the distance between the adjacent tree canopies (canopy distance) and distance between stems of neighbouring woody plants could be ascribed to a direct evidence for neighbourhood competition for light, nutrients and water. Nearest-neighbour principle assumes that competitive interference between neighbouring plants manifests through a reduction in the size of one or both of the competing neighbours (Shackleton 2002). If there is sigsnificant correlation between the distance separating the two neighbouring plants and their sizes then competition is inferred (Pielou 1962). The findings imply that fire effects on vegetation characteristics should be studied with caution because factors including competition could also play a role in spacing plants on a site

5.5 Conclusion

From this study the following conclusions were drawn: (i) long-term effects of burning frequency did not have differential effects on tuft-tuft distance, tufts diameter, canopy distance and basal distance, (ii) long-term effects of burning, grazing and browsing did not have effects on tuft to tuft distance, tufts diameter, canopy distance and basal distance and (iii) Long-term effects of burning followed by ten-year period of fire exclusion had effects on tuft-tuft distance but did not have effects on tufts diameter, canopy distance and basal distance. Tuft to tuft distance decreased under 1-year, 2-year, 3-year and 5-year burn treatments compared to under no burn. From this study, it is save to infer that individual forms of disturbance could not single-handedly influence changes in vegetation characteristics because many unforeseen factors also come into play. Through their effect on basal cover, standing dead grass biomass, tuft to tuft distance, tuft diameter, canopy distance and stem to stem distance long term burning, grazing and browsing by goats could influence site/soil stability which could ultimately lead to altered functioning of rangeland ecosystem ecological processes. However, myriad factors of diverse magnitude are need to be considered to correctly quantify effects of a disturbance or disturbances such as fire and herbivory on vegetation dynamics.

6 Long term effects of burning, grazing and browsing on site productivity and plant vigour

6.1 Introduction

Site productivity and vitality are important attribute of functioning ecological processes. Ability of a site to provide grazeable material (grazing potential) and browse for animals (browsing potential) are indicators of site productivity while sprouting could be indicative of vitality on a site. Plant characteristics are usually used to estimate performance of attributes of functioning ecological processes. Use of fire on rangeland ecosystem for decades, had been a source of controversy in academic and ecological circles.

Plants differ widely in their response and tolerance to fire and in their capacity to recover afterwards (Zolho 1988). In fire-prone habitats some long-lived tree species appear resilient to fire; sprouting allows woody plant species to persist in a site after a wide range of disturbances, where opportunities for seedling establishment are limited (Tierney 2002). All the same prolonged fire can have effects on sprouting (Everham & Brokaw 1996, Reich *et al*. 2003, Vesk & Westoby 2004 and Paciorek *et al*. 2000) and physiognomic structure (Moreira 2008) in woody species.

Savanna functioning is dependent, to a large extent, on a balance which exists between the bush component and the herbaceous layer, and, depending on objectives, land managers should be able to shift the balance in favour of either the bush or grass component (Smith & Hardy 1999).

Where cattle and game ranching enterprises are common, it is essential that a healthy grass cover is maintained between trees and shrubs. Management tools that are commonly used to maintain balance between bush and grass components in savannas include fire or burning. It is therefore, essential to enlarge the knowledge base on how vegetation responds to use of fire and how do the effects relate to proper functioning ecological processes. Attribute of functioning ecological processes include site productivity and vitality. The key objective of this study was to investigate long-term effects of burning, grazing and goats browsing on productivity and vitality/vigour of a site. Grazing potential, browse potential and sprouting were attributes used to estimate productivity and vigour.

Specific objectives of the study were to:

(i) investigate if long term burning frequencies have differential effects on site productivity and vigour

(ii) investigate if burning, grazing and browsing by goats have differential effects on site productivity and vigour

(iii) investigate if long term burning followed by ten-year period of fire exclusion reduce or enhance productivity and vigour of a site

The study tested the following hypothesis:

(i) long term burning frequencies have effects on site productivity and vigour

(ii) long term burning, grazing and browsing by goats have differential effects on site productivity and vigour.

(iii) long term burning followed by ten-year period of fire exclusion affect productivity and vigour

6.2 Materials and methods

See chapter 3 for detailed description of methodology

6.3 Results

Variables that were used in this study as indicators of a productivity to provide grazeable material (grazing potential) for livestock were total grass yield, grass ecological and grazing values for grasses. To estimate ability of a site to provide browse material for animals (browse potential) variables such as tree height, total canopy volume and physiognomic structure (plant height, canopy height, canopy diameter and main stem diameter). Potential of woody species to resprout as a consequence of disturbance was used to estimate plant vigour or vitality

6.3.1 Effect of burning frequency on grazing and brows potential

6.3.1.1 Grazing potential

Site productivity is an important attribute of functioning ecological processes; indicators of site productivity include ability of a site to provide grazing for animals. Analysis of variance for grass yield showed significant difference between burn treatments ($p \leq 0.05$). Significantly higher grass yield (6927kg/ha) was under plots protected from fire than under burn treatments (Table 6.1). Significantly low grass (4585kg/ha) yield was under 1-year burn treatment. Grass yield under 2-year and 3-year burns was not significantly different ($p > 0.05$).

Table 6.1: Mean of Grass yield under each burn treatment (UFH)

Burn treatments	Grass yield (t/ha)
No burn	6.93^{e}
1-year	4.58^{a}
2-year	5.39^{b}
3-year	5.69^{b}
4-year	6.01^{c}
6-year	6.37^{d}

Different letters indicate significant statistical difference

Grass ecological groups for each burn treatment and control are presented under Table 6.2. There were 4 ecological groups used in this work as provided by (Camp and Hardy 1999); they were decreasers (grass species which predominate in veld which is in good condition and decline in abundance when veld deteriorates in condition through over or under-utilization, these species tend to die out (a) in a veld which is too heavily grazed, (b) where grazing is extremely lenient and fire is excluded, or (c) where grazing is selective.), increaser I (species that are not abundant in veld which is in good condition, these species will replace Decreaser species where veld is too leniently grazed and fire is excluded), increaser II (grasses that are abundant in overgrazed areas with low rainfall, these species replace Decreaser species where veld is overgrazed) and increaser III (species that are rare in veld which is in good condition but increase in abundance in veld which is selectively over-grazed, they increase when palatable species have been weakened by overgrazing).

Grasses ecological group found in this study in terms of abundance (descending order) were increaser II (>59%), decreasers (21%), increaser III (>9%) and increaser I (< 9%). Decreaser species were highest (>24%) in percentage under 1-year, 2-year and 3-year burns lowest (<22%) under 6-year burn and no burn. Increaser I species were highest (>7%) in percentage under 6-year burn and no burn. Increaser II species percentage values were lower (<62%) under 6-year burn and no burn and higher (>62%) under other burn treatments. Increaser III percentage was high under no burn than under burn treatments (Table 6.2).

Table 6.2: Grass ecological groups for each burn treatment (UFH)

Burn treatments	**Grass ecological groupings** (%)			
	Decreaser	Increaser I	Increaser II	Increaser III
No burn	21.5	9	59.3	10.3
1-year	24.4	0.4	66.2	9.1
2-year	25	3.8	62.1	9.4
3-year	24.6	6.6	60.3	8.2
4-year	20.8	5.9	64	9.3
6-year	21.9	7.8	61	9.4

Percentages of grasses according to their grazing values under burn treatments and control are presented under Table 6.3. Grazing value refers to the quantity and quality of grazable material (Van Oudtshoorn 2002). Grasses with high grazing value were more than 40% in proportion while grasses with average grazing value were less than <16% under all burn treatments. Grass species with low grazing value attained less than 35% under all burn treatments (Table 6.3). Highest figure for grasses with high grazing value (49%) was under 2-year burn and lowest

(42%) under no burn. Highest (16%) figure for grasses with average grazing value was under 4-year burn and lowest (11%) under 2-year burn. Grass species with low grazing value were in abundance on plots protected from fire than under burn experiments. On the contrary, grass species with high grazing values were under plots that were subjected to different fire treatments than on plots protected from fire. One year and 2-year burns had a relatively reduced proportions of grasses with low grazing value (<28%) while on the one hand had preserved species with high grazing value (>48%) compared to other burn treatment and control.

Table 6.3: Grazing values (%) for grasses under each burn treatment (UFH)

Treatments	Grazing values		
	low	**Average**	**High**
No burn	34.4	12	42.1
1-year	26.9	15.7	48.4
2-year	27.7	11.8	49
3-year	31.2	13.5	46.4
4-year	29.6	16.1	43.3
6-year	31	13.4	43.1

6.3.1.2 Browsing potential

Ability of a site to provide browse for animals is an important indicator of site productivity.

Number of trees, tree height and total canopy volume

Tree heights were used to determine tree equivalents per hectare. Significantly ($p \leq 0.05$) tall trees (1.7m) as well as higher canopy volume (105 TE/ha) were under plots protected from fire than under burn treatments (Table 6.4). Burn treatments had highest (76 TE/ha) under 4-year burn and lowest (33 TE/ha) under 1-year burn. Trees were significantly more (1069 trees/ha) under 3-year burn and few (587 trees/ha) under 6-year burn.

Table 6.4: Woody species height, number of trees and tree equivalents (TE/ha) under each burn treatment (UFH)

Treatments	Tree Ht.(m)		No. trees/ha	TE/ha
	Means	SE		
No burn	1.69[a]	0.1	932	105.1
1-Year	0.62[b]	0.1	800	33.1
2-Year	0.83[c]	0.1	904	50.1
3-Year	0.85[d]	0.1	1069	60.9
4-Year	1.22[e]	0.1	938	76.0
6-Year	1.07[f]	0.1	587	41.8

Different letters indicate significant statistical difference

6.3.1.3 Physiognomic structure

The plant heights for woody species under each burn treatment are presented in Figure 6.1. The results showed greater ($p \leq 0.5$) height of woody species in unburnt plots than burnt ones; fire reduced height of woody plans significantly. Woody plants were taller under no burn than under 1-year, 2-year, 3-year, 4-year and 6-yearburnt treatments ($p \leq 0.5$). The average plant height was close to 2m on unburnt plots and ranged from just above 0.5m to 1.2m on burnt plots. On burnt plots, excluding 6-year burn, the height decreases with frequency of burning. Under burn treatments, the shortest woody plants were under 1-year burn and the tallest under 4-year burn. The average height of plants was not significantly different under 2-year burn and 3-year burn.

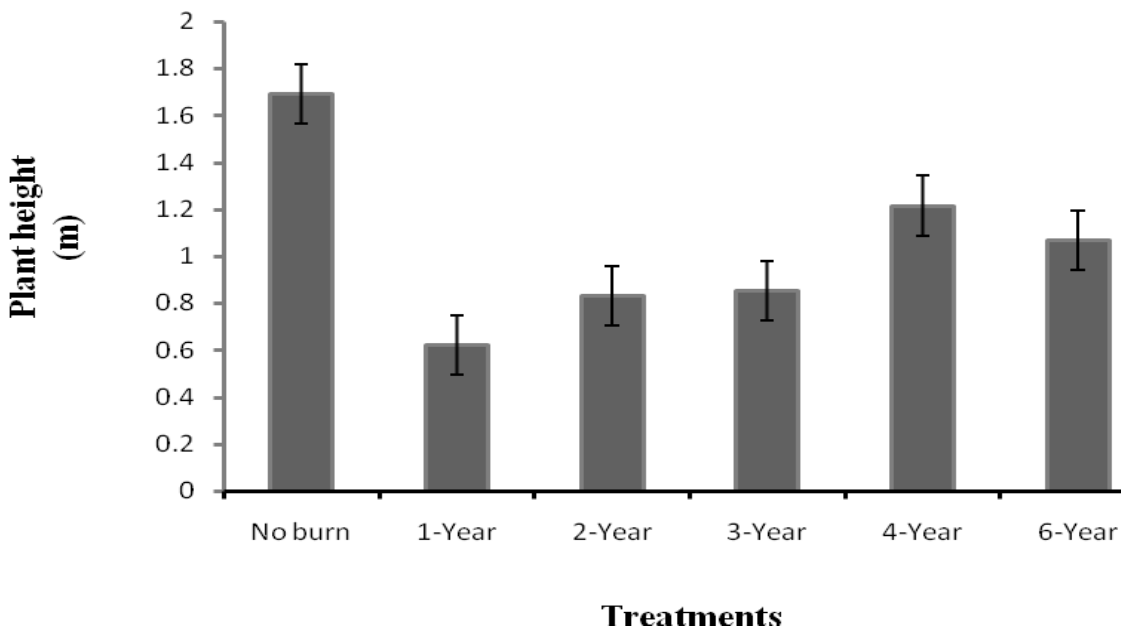


Figure 6.1: Plant height for woody plants in each burn treatments (UFH)

Fire significantly reduced canopy height for woody species. The canopy height for woody plant species was highest (1.4m) under unburnt plots ($p \leq 0.5$) than under burnt plots (Figure 6.2). Canopy height under burn treatments was shortest (0.5m) under 1-year burn however, this value was not significantly different ($p \geq 0.5$) from canopy height values under 2-year and 3-year burns. Under burnt plots, 4-year burn attained the highest canopy height value (1m) while 6-year burn was the second highest (0.9m).

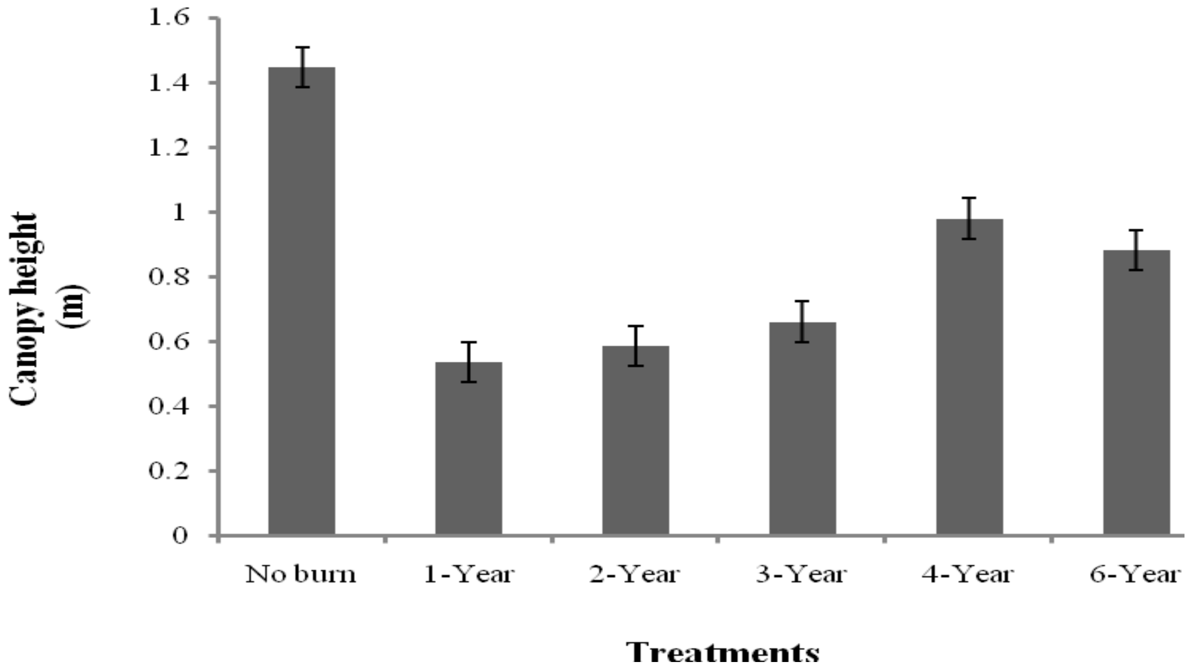


Figure 6.2: Canopy height for woody plants in each burn treatment (UFH)

Fire reduced the canopy diameter for woody species significantly ($p \leq 0.5$). Greater canopy diameters (1.6m) were under plots that were protected from fire than under burn treatments. Under burnt plots, canopy values were highest (1.3m) under 4-year burn and lowest (0.7m) under 3-year burn. Canopy diameter values under 4-year burn were significantly higher than values under 1-year, 2-year and 3-year burn treatments (Figure 6.3).

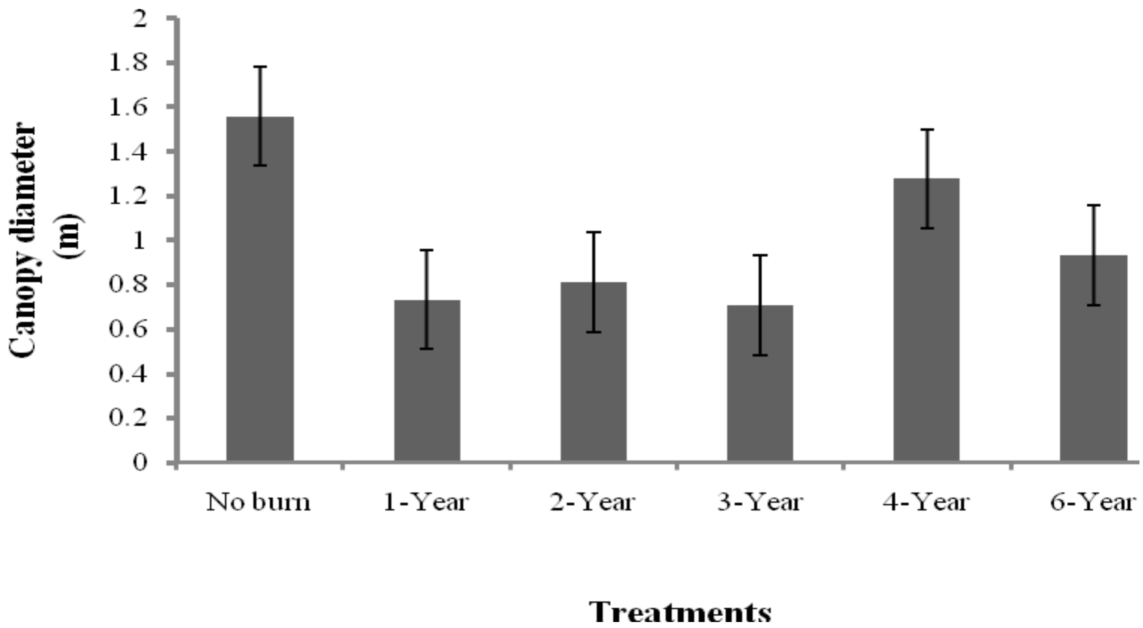


Figure 6.3: Canopy diameter for woody plants in each burn treatment (UFH)

Woody species under burn treatments had smaller ($p \leq 0.5$) main stem diameter than under plots protected from burn (Figure 6.4); the main stem diameter values under no burn treatment were significantly high (4.9cm). Burnt plots had low (0.8cm) main stem diameter values under 1-year burn and highest under 4-year burn (2.5cm). Main stem diameter values of woody species under 1-year, 2-year and 3-year burns were not statistically different (Figure 6.4).

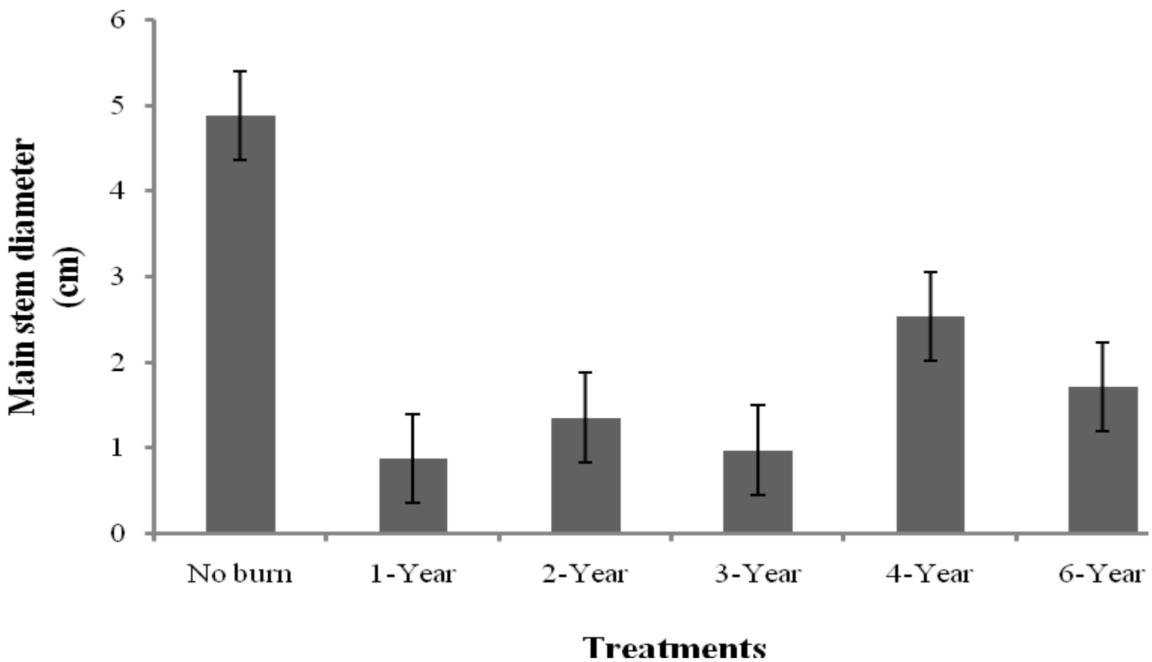


Figure 6.4: Main stem for woody plants in each burn treatment (UFH)

6.3.1.4 Plants vigour

The findings of this study show that fire reduces sprouts diameter (Figure 6.5); the mean sprouts diameter value was 3.4cm under no burn and ranged from 0.6cm to 1.8cm under burn treatments. Burn treatments had greater sprouts diameter under 4-year burn than under 1-year, 2-year, 3-year burn and 6-year burns. Lowest diameter value for sprouts was under 1-year burn. Diameter values for sprouts under 1-year, 2-year, 3-year burn were not significantly different ($p \geq 0.5$).

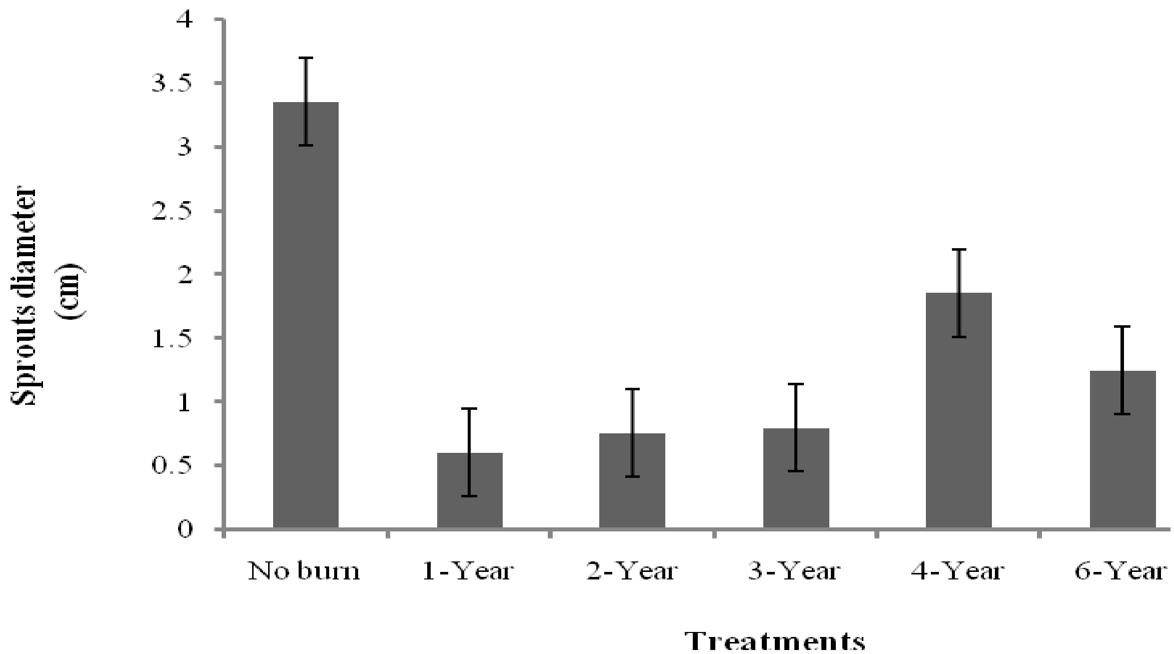


Figure 6.5: Sprouts diameter for woody plants in each burn treatment (UFH)

Sprouts production between treatments was significantly different ($p \leq 0.5$)), the number of sprouts for woody species in each burn treatment are presented in Figure 6.6. Sprouts were more ($p \leq 0.5$) under frequently burnt plots (1-year burn, 2-year burn and 3-year burn) than under 4-year burn, 6-year burn and no burn. Sprouts number was highest (7) under 3-year burn and lowest (2) under 6-year burn. Woody species under no burn had more sprouts than under 6-year burn.

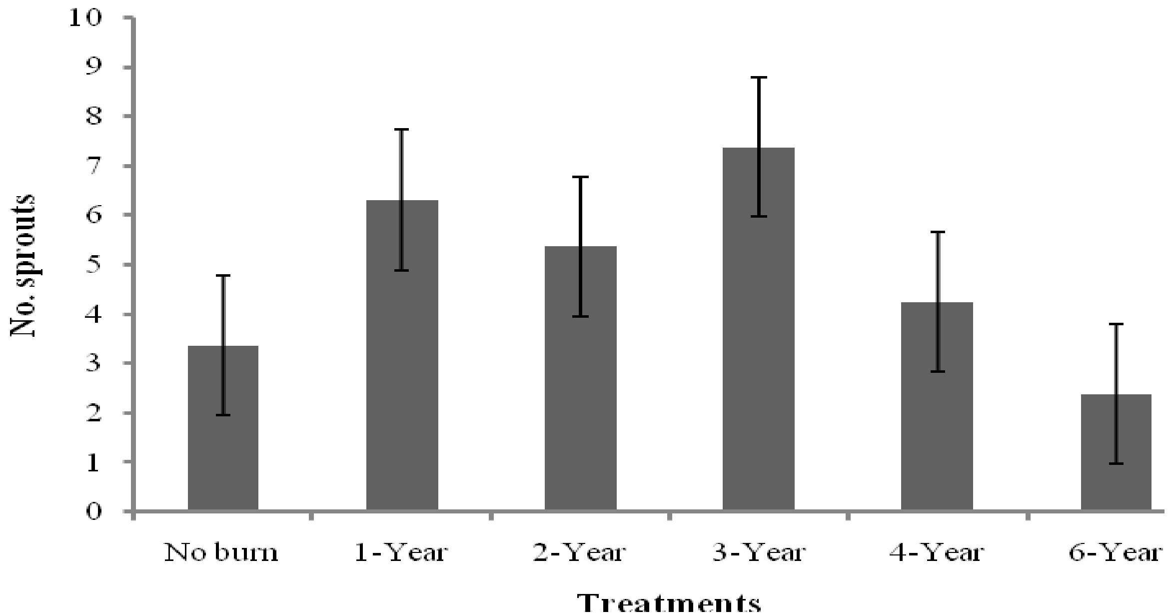


Figure 6.6: Number of sprouts for woody plants in each burn treatment and control (UFH)

6.3.2 Effect of burning, grazing and goats browsing on grazing and browsing potential

6.3.2.1 Grazing potential

Grass yield

The difference in grass yield between treatments was significant ($p \leq 0.05$). Grass yield (4392kg/ha) was significantly high ($p \leq 0.05$) under goats browsing (Table 6.5). Follow up burn significantly reduced grass yield (3510kg/ha) than other treatments. Grass yield under control and goats browsing did not differ significantly.

Table 6.5: Grass yield under each burn treatment (UFH)

Treatments	Grass yield t/ha
Control	4.17[c]
Follow up burn	3.51[a]
Grazing	4.14[b]
Goats browsing	4.39[c]

Different letters indicate significant statistical difference

Grass ecological groups and grazing values

Treatments had differential effect on grazing values for grass species. Control and Grazing relatively had lowest percentage (≤ 32) of decreasers than other treatments. Follow up burn induced more decreasers (37%) and less increaser II species (35%) compared to other treatments. Goats browsing increased occurrence of increaser II species (48%) than other treatments. Grazing had the most reduced (31%) proportions of decreasers than any other treatment. Goats browsing had the lowest Increaser III species percentage than other treatments (Table 6.6).

Table 6.6: Grass ecological groups for each treatment (UFH)

Treatments	**Grass ecological groups** (%)		
	Decreaser	**Increaser II**	**Increaser III**
Control	32	42.2	9.4
Follow up burn	37.1	34.6	9.5
Grazing	31.3	46.6	9.5
Goats browsing	32.4	47.8	8.1

Follow up burn relatively increased proportions of grass species with low grazing value and reduced grass species with average grazing value than Grazing, Goats browsing and Control (Table 6.7). Grazing induced high proportion of grass species with high grazing value (47%) than other treatments. Goats browsing had highest figure of species with average grazing value (16).

Table 6.7: Grazing values (%) for grasses under each burn treatment (UFH)

Treatments	Grazing values		
	Average	High	Low
Follow up burn	6.1	41.4	33.7
Grazing	13.1	47.3	27
Goats browsing	16.9	40.4	31
Control	10.9	42.9	29.8

6.3.2.2 Browse potential

Tree height and total canopy volume

The total canopy volume (TE/ha) was significantly ($p \leq 0.05$) high under Grazing (53/ha) than under other treatments. Browsing reduced total canopy volume (18 TE/ha) more than other treatments (Table 6.8).

Table 6.8: Tree species height, number of trees and tree equivalents under each burn treatment (UFH)

Treatments	Tree Ht.(m)	Std. Error	No. Trees/ha	TE/ha
Follow up burn	0.45[a]	0.1	604	18.2
Goats	0.46[b]			
browsing		0.1	576	17.8
Grazing	1.36[c]	0.1	583	52.9

Different letters indicate significant statistical difference

Physiognomic structure

Burning, grazing and goat browsing treatments had significantly different ($p \leq 0.5$) effects on height of woody species. Plant height of woody plants for burning, grazing and goats browsing is shown in Figure 6.7. Plants were taller (1.4m) under grazing than under other treatments ($p \leq 0.5$). Burning and goats browsing reduced plants height and were able to keep them bellow half a meter. Plant height (0.4m) under burning and goats browsing was not different statistically ($p>0.05$).

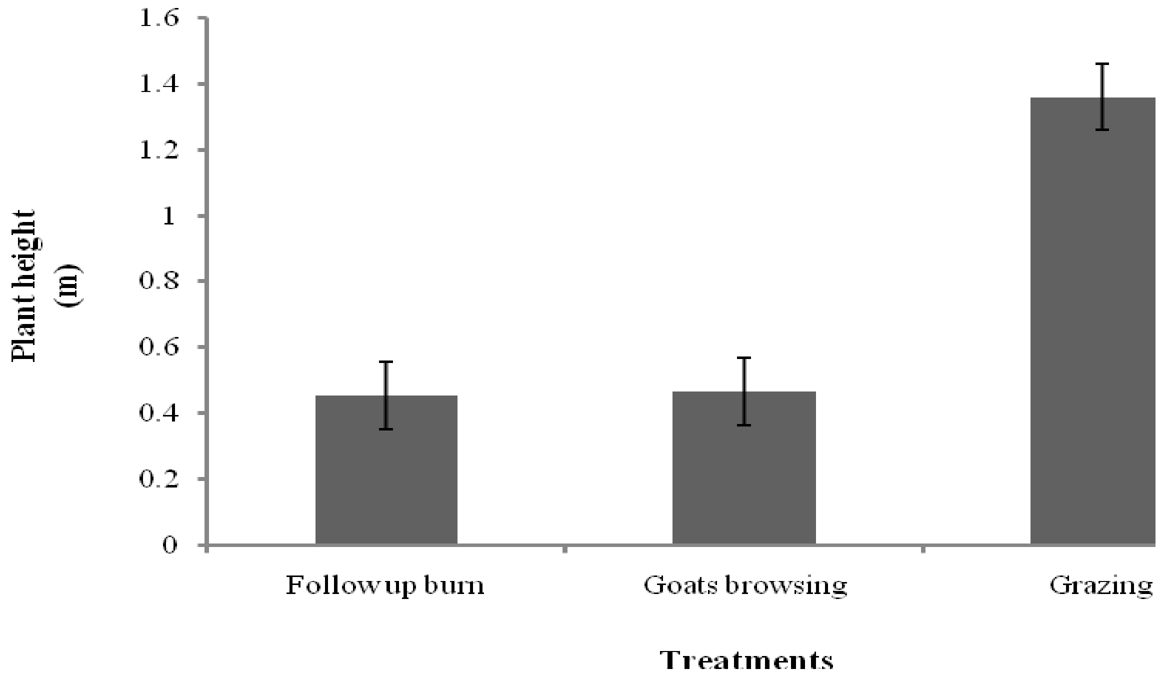


Figure 6.7: Plant height for woody species in each treatment (UFH)

Canopy height for woody plants was significantly different ($p \leq 0.5$) between burning, grazing and goats browsing treatments. Canopy height under grazing was more ($p \leq 0.5$) than under burning and goats browsing. The difference in canopy height obtained under burning and goat browsing was not significant; however, plants under goats browsing were relatively short (Figure 6.8).

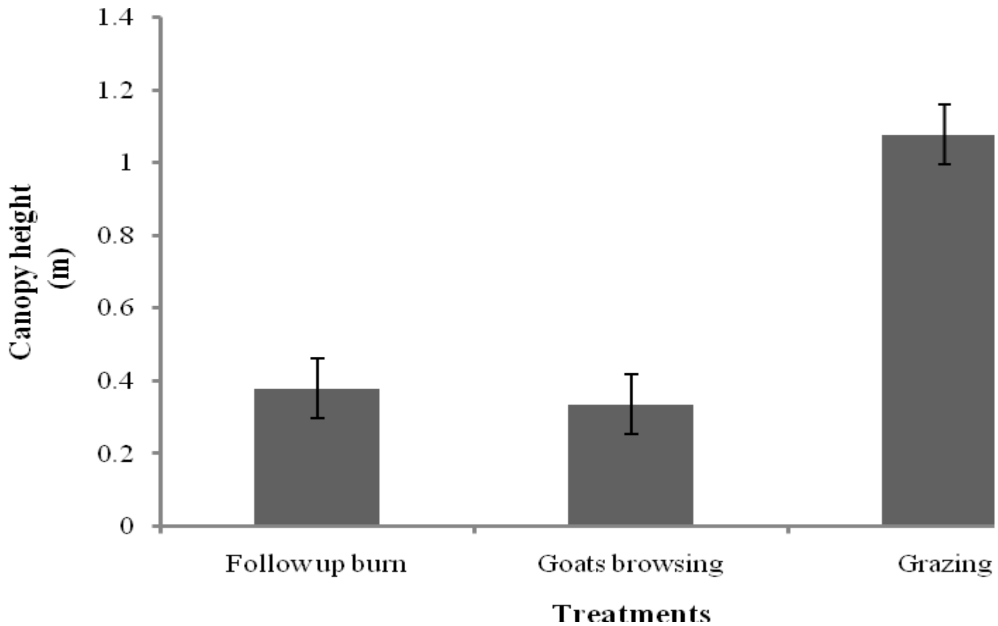


Figure 6.8: Canopy height for woody species in each treatment (UFH)

Canopy diameter for woody plants between burning, grazing and goat browsing was significantly different ($p \leq 0.5$). Significantly larger canopy diameter value was obtained under grazing (1m) than under burning and goat browsing (Figure 6.9). Burning and goats browsing reduced canopy height of woody species remarkably. Canopy diameter values under burning (0.4m) and goats browsing (0.3m) were also significantly different.

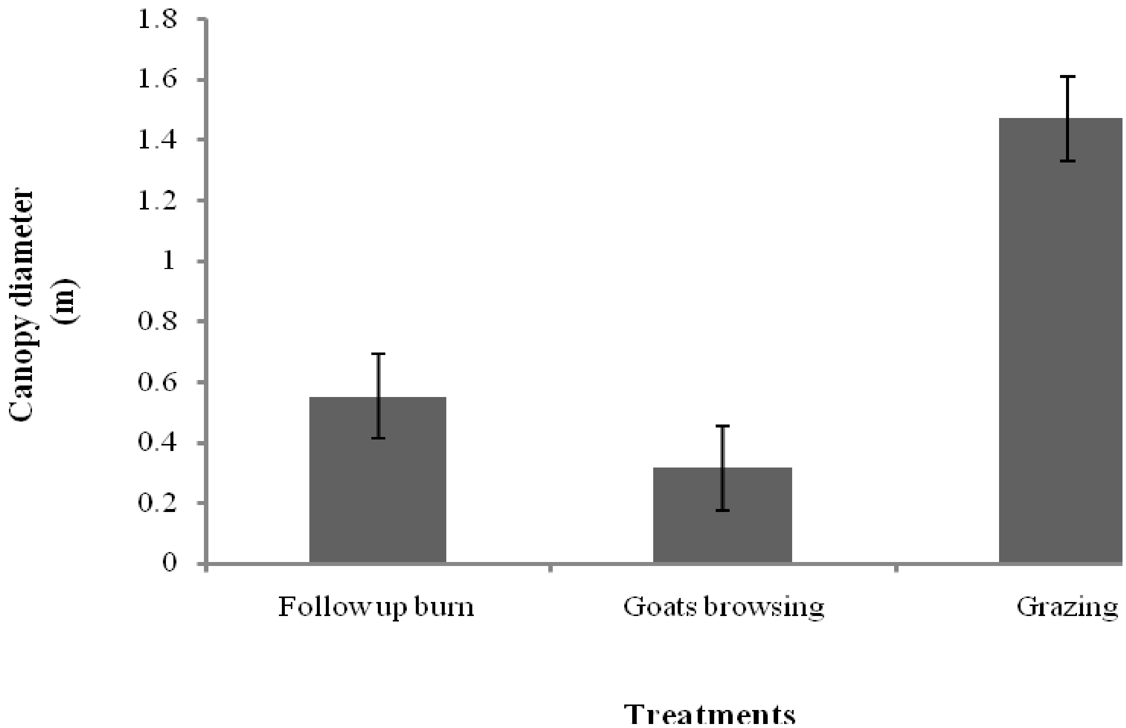


Figure 6.9: Canopy diameter for woody species in each treament (UFH)

There was a significant difference ($p \leq 0.5$) in diameter of main stems for woody plants under burning, goat browsing and grazing treatments. Goats browsing reduced ($p \leq 0.5$) diameter of main stems (0.4cm) for woody species than other treatments (Figure 6.10). Main stem diameter (2.4cm) under grazing was significantly high ($p \leq 0.5$).

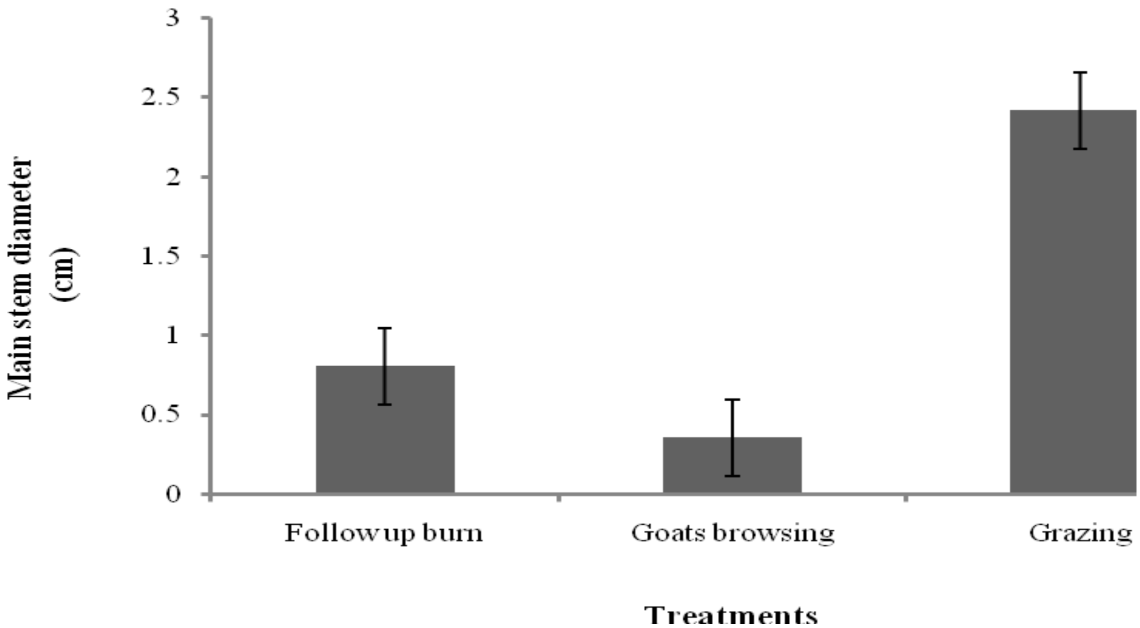


Figure 6.10: Main stem diameter for woody species in each treatment (UFH)

Vigour

There was significant difference ($p \leq 0.5$) between sprouts diameter values under burning, goats browsing and grazing. More sprouts diameter values ($p \leq 0.5$) were under grazing than under burning and goats browsing; whose values were not significantly different (Figure 6.11). In this study, goats browsing reduced the size of main stem for woody species the most. Between follow up burn and grazing experiments, the effect of the treatments on main stem diameters was not significantly different, however, follow up burn attained relatively low values for main stem diameter.

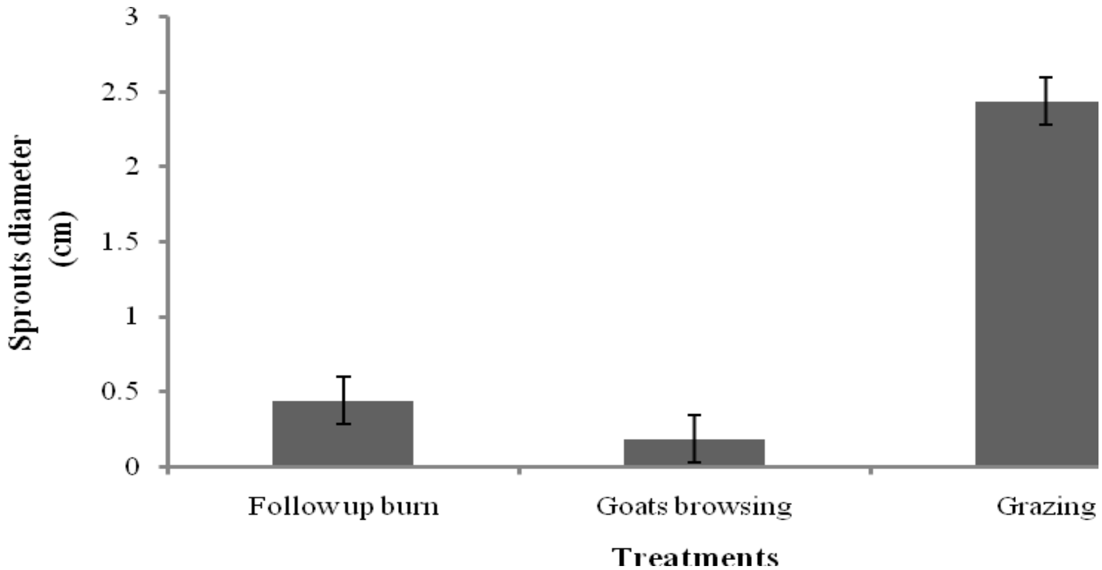


Figure 6.11: Sprout diameter for woody species in each treatment (UFH)

The number of sprouts produced by woody species under follow-up burn, grazing and goats plot was significantly different ($p \leq 0.05$) More sprouts ($p \leq 0.05$) were produced under follow up burn than under other treatments. The difference in number of sprouts produced under grazing and browsing was not significant (Figure 6.12) however, relatively low number of sprouts was recorded under goat browsing.

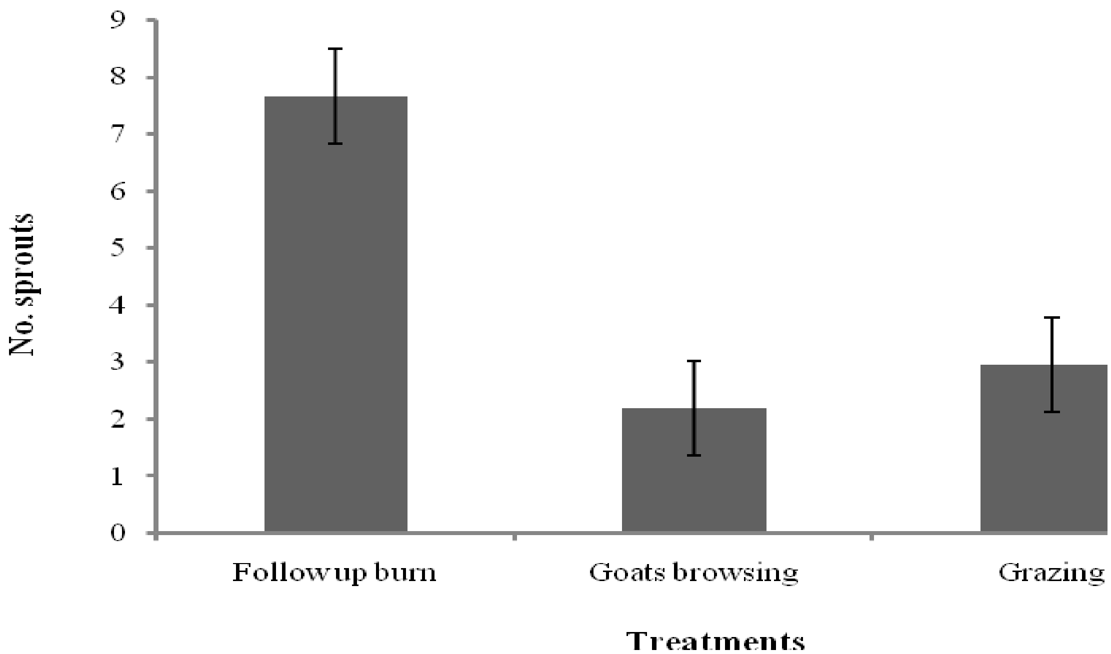


Figure 6.12: Number of sprouts for woody plants in each treatment (UFH)

6.3.3 Effect of burning frequency followed by ten-year period of fire exclusion frequency on grazing and brows potential of a site

6.3.3.1 Grazing potential

Grass ecological groups and grazing values

Burning frequency followed by ten-year period of fire exclusion had differential effect on grass species ecological groups (Decreaser, Increaser I and Increaser II). The percentage of decreasers was more under 5-year burn and no burn than under other burn treatments (Table 6.9). Five year burn had 71% decreasers; no burn had 63% while other burn treatments had percentages of decreasers ranging from 41 to 48. Increaser1 species were not present under 1-year and 5-year burns. Two–year burn induced more increaser I species than other burn treatments and control.

Burn treatments induced more Increaser II species than plots protected from fire. Percentages of Increaser II species range was from 29 to 50. There was 36% Increaser II species under no burn.

Table 6.9: Grass ecological groups for each burn treatment (Matopos, Zimbabwe)

Burn treatments	Decreaser%	Increaser I%	Increaser II%
No burn	62.6	1.1	36.3
1-year	40.5		59.5
2-year	48.1	11.2	40.7
3-year	48.3	6.7	45
5-year	70.6		29.4

The percentage of species with high grazing value was more (>62) under 5-year burn and plots protected from fire than under other burn treatments. With an exception of 5-year burn, burn treatments had percentages of species with high grazing value ranging from 40 to 48. Percentage of grass species with average grazing value was high under 1-year, 2-year and 3-year burns (≈ 40) than under 5-year burn and no burn. Five year burn had lowest percentage of grass species with average grazing value (17%). Grass species with low percentage of grazing value was under no burn and high under 1-year burn (Table 6.10).

Table 6.10: Grazing values for grasses under each burn treatment (Matopos, Zimbabwe)

Burn treatment	Grazing values (%)		
	High	Average	Low
No burn	62.6	28.8	8.6
1-year	40.5	39.9	19.6
2-year	48.8	39.4	11.8
3-year	48.3	40.8	10.9
5-year	71.3	17.6	11.1

6.3.3.2 Browse potential

Tree height and total canopy volume

Trees were tallest (3.5m) under plot protected from fire than under plots burnt at different frequencies (Table 6.11). Tree height ranged from 0.8m to 1.6m under burn treatments. Trees were more ($p \leq 0.05$) under 5-year burn and no-burn (> 4000 trees) than under 1-year, 2-year and 3-year burns. The total canopy volume (TE/ha) was high ($p \leq 0.05$) under no burn than under burn treatments. One year burn induced more total canopy volume (3327 TE/ha) than 2-year, 3-year and 5-year burns.

Table 6.11: Tree species height, number of trees and tree equivalents under each burn treatment (Matopos, Zimbabwe)

Burn treatments	Tree Ht. (m)		No. trees/ha	TE/ha
	Mean	**SE**		
No burn	3.49[c]	0.26	4767	11096.8
1-year	1.55[a]	0.20	3222	3327.5
2-year	0.99[ab]	0.18	2367	1555.7
3-year	0.83[b]	0.34	1144	634.8
5-year	0.89[ab]	0.34	4033	2385

Different letters indicate significant statistical difference

Physiognomic structure

The difference in plant height between burn treatments was significant ($p \leq 0.5$). The mean plant height value under plots protected from fire was higher ($p \leq 0.5$) than values recorded under other burnt plots. Plant height measurement was (3.5m) under no burn and this was significantly higher ($p \leq 0.5$) than plant height values under other burn treatments whose range was from 0.8m to 1.5 m. Between the burnt plots, more height was recorded under 1-year burn and lowest values were under 3-year burn. The reportedly lowest plant height under 3-year burn was not significantly different ($P > 0.05$) from heights obtained under 2-year and 5-year burn treatments (Figure 6.13).

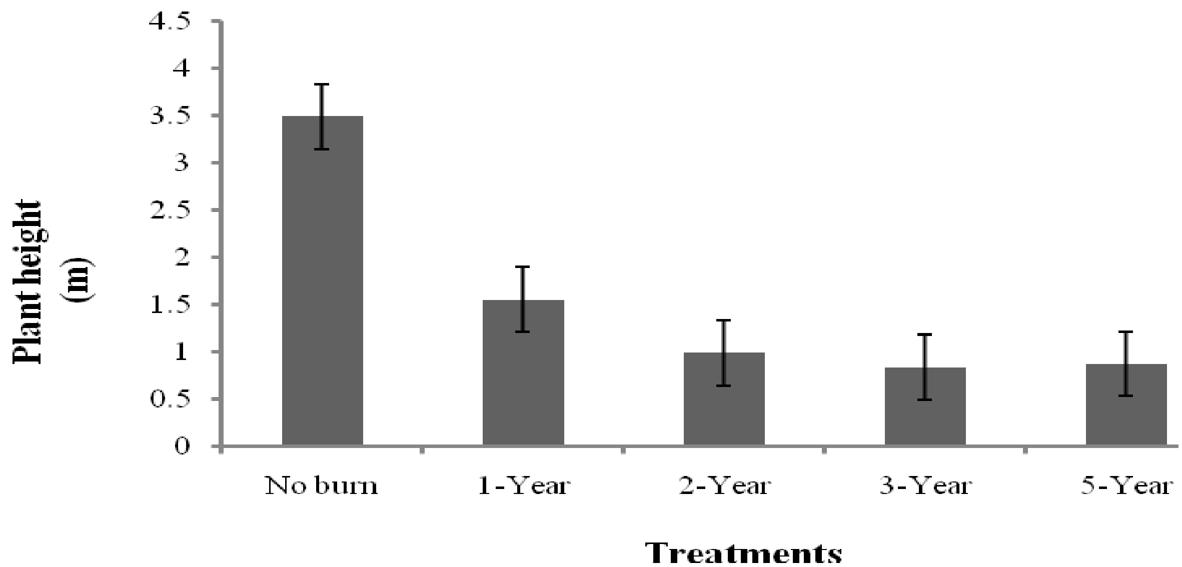


Figure 6.13: Plant height for woody plants in each burn treatment (Matopos, Zimbabwe)

The difference in canopy height between burn treatments was significant ($p \leq 0.5$). Unburnt plots attained significantly higher ($p \leq 0.5$) canopy height (2m) than burnt plots. In this study, fire reduced the canopy height of woody plant species. Canopy height did not differ significantly between 1-year, 2-year, 3-year and 5-year burn treatments; relatively high and low values for canopy height were under 1-year burn 3-year burn respectively (Figure 6.14).

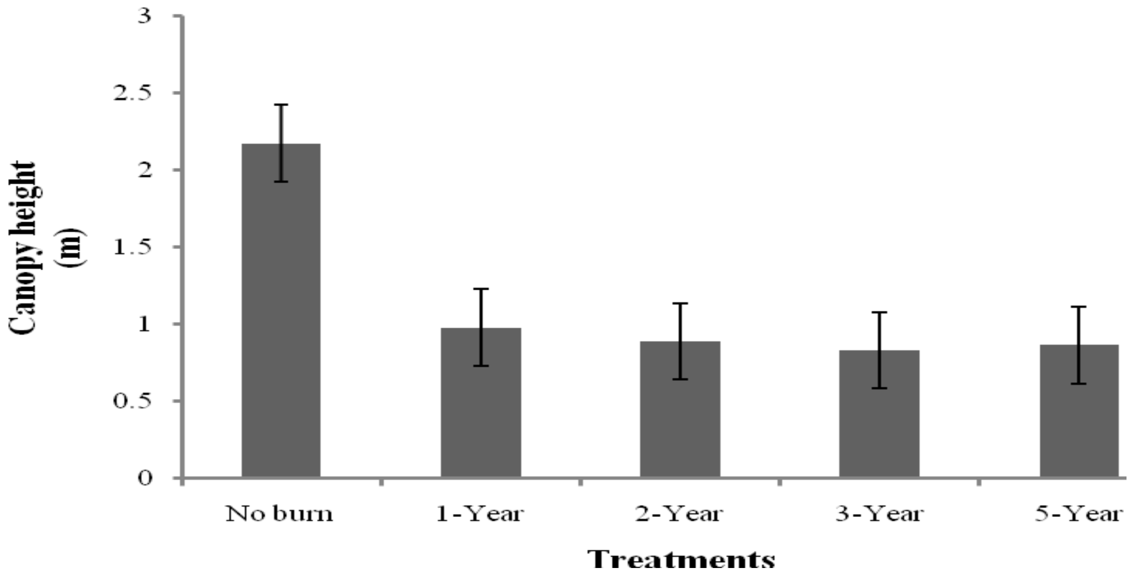


Figure 6.14: Canopy height for woody plants in each burn treatment (Matopos, Zimbabwe)

Canopy diameter was significantly different ($p \leq 0.5$) between treatments**.** Fire significantly reduced canopy diameter of woody species. No burn treatment had significantly more canopy diameter (2.5m) than other burn treatments ($p \leq 0.5$). Canopy diameter values were not significantly different under 1-year, 2-year, 3-year and 5-year burns. Canopy diameter values were relatively greater (1.3m) under 3-year burn and low (0.9m) under 5-year burn (Figure 6.15).

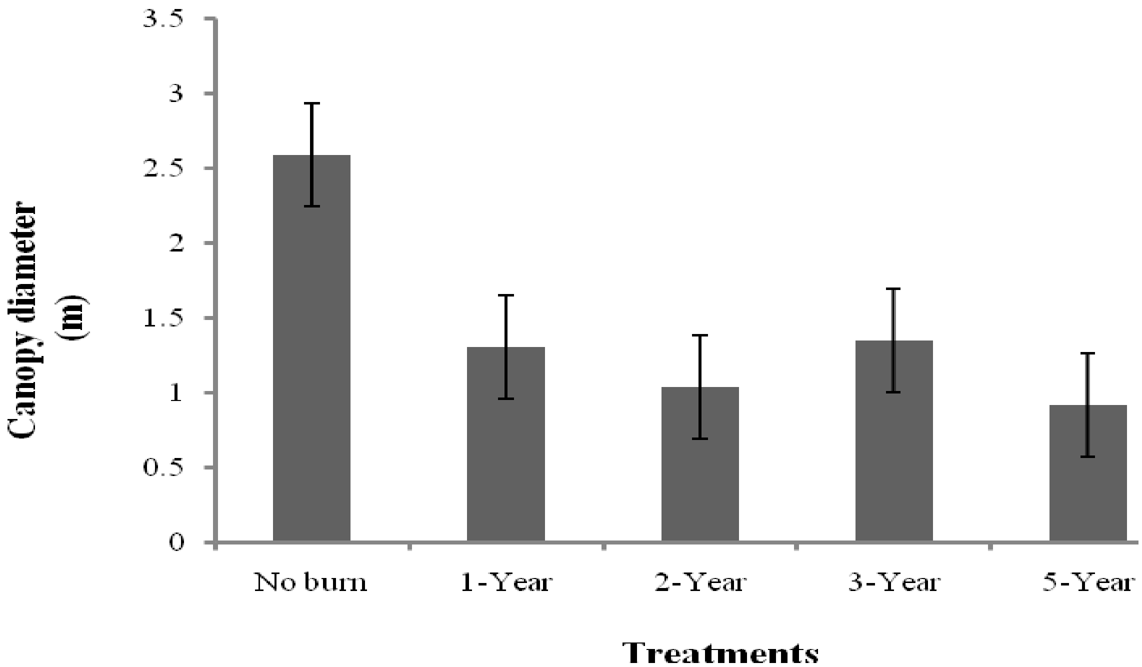


Figure 6.15: Canopy diameters for woody plants in each burn treatment (Matopos, Zimbabwe)

Fire significantly reduced the diameter of the main stems for woody species (Figure 6.16). Mean diameter value for main stems (5.3cm) under no burn was significantly higher ($p \leq 0.5$) than values recorded under other burnt treatments (from 1.7cm to 3.5cm). One-year burn had significantly higher mean diameter value for main stems than values obtained under 2-year, 3-year and 5 year burn treatments.

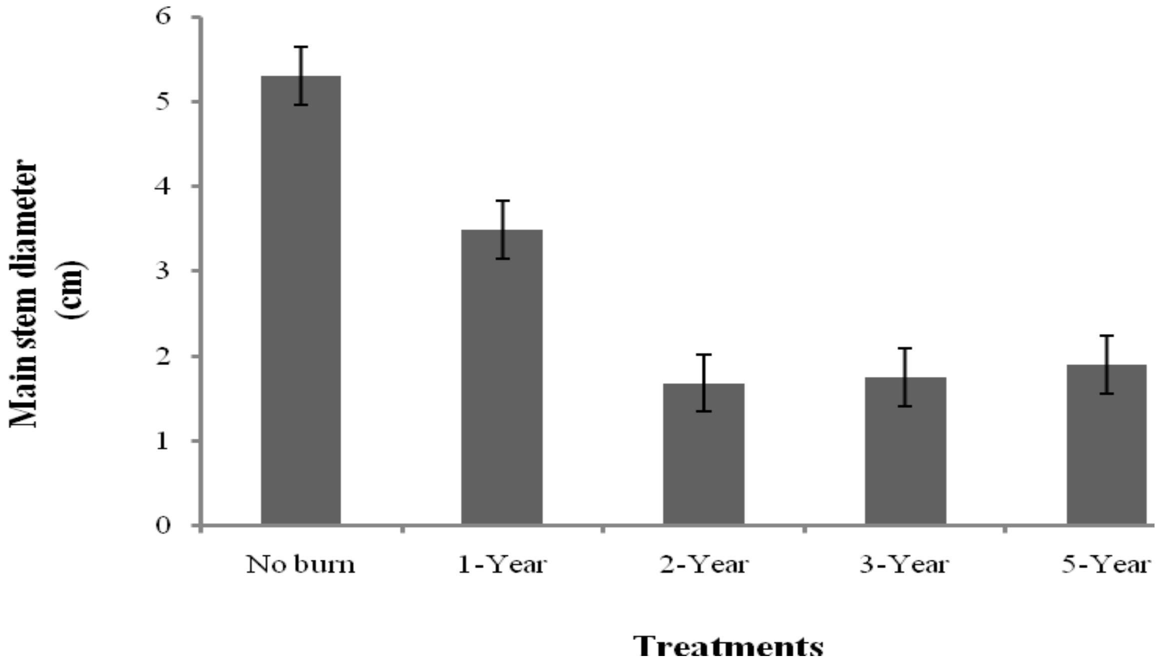


Figure 6.16: Main stem diameters for woody plants in each burn treatment (Matopos, Zimbabwe)

Vigour or vitality

Sprouting could be effectively used as an indicator of vigour in woody species. The diameter of sprouts was significantly different between treatments (p> 0.05). Significantly higher values for diameter of sprouts was under 1-year burn (1.9cm) and low (0.8cm) under 3-year burn. The sprout diameter values under 2-year, 3-year and 5-year burns were not significantly different (Figure 6.17).

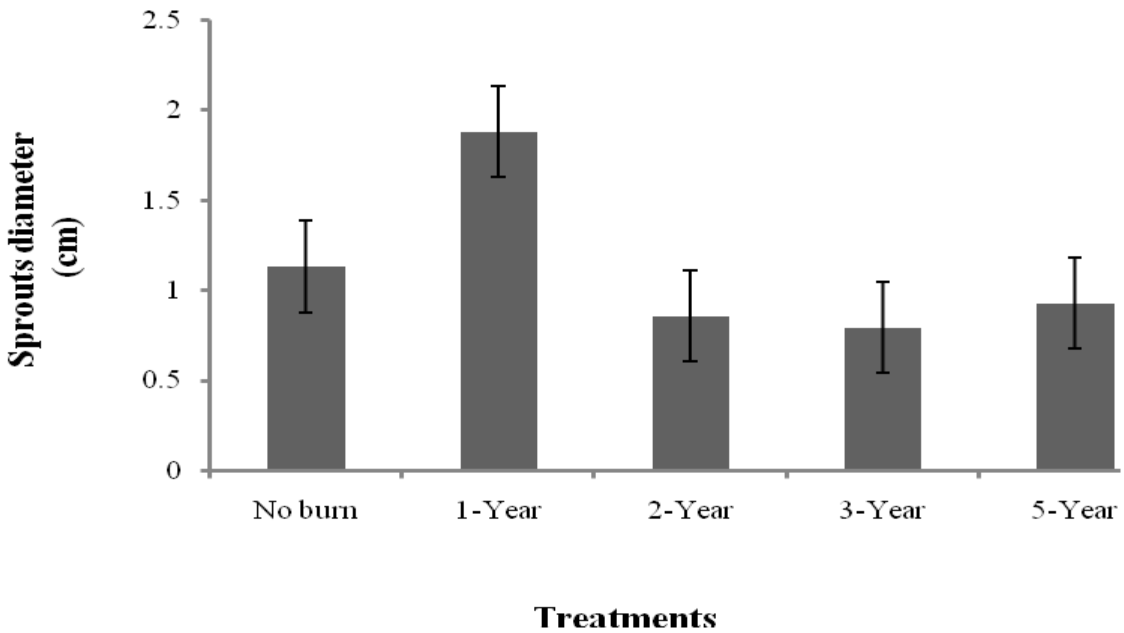


Figure 6.17: Sprouts diametes for woody plants in each burn treatment (Matopos, Zimbabwe)

Fire had significant different effects on number of sprouts produced by woody species under different treatments**.** Unburnt plots had fewer sprouts compared to burnt plots; however, the values recorded under unburnt plots did not differ significantly from values reported under 1-year and 2-year burn treatments. Significantly high ($p > 0.05$) number of sprouts (6) was under 3-year burn (Figure 6.18).

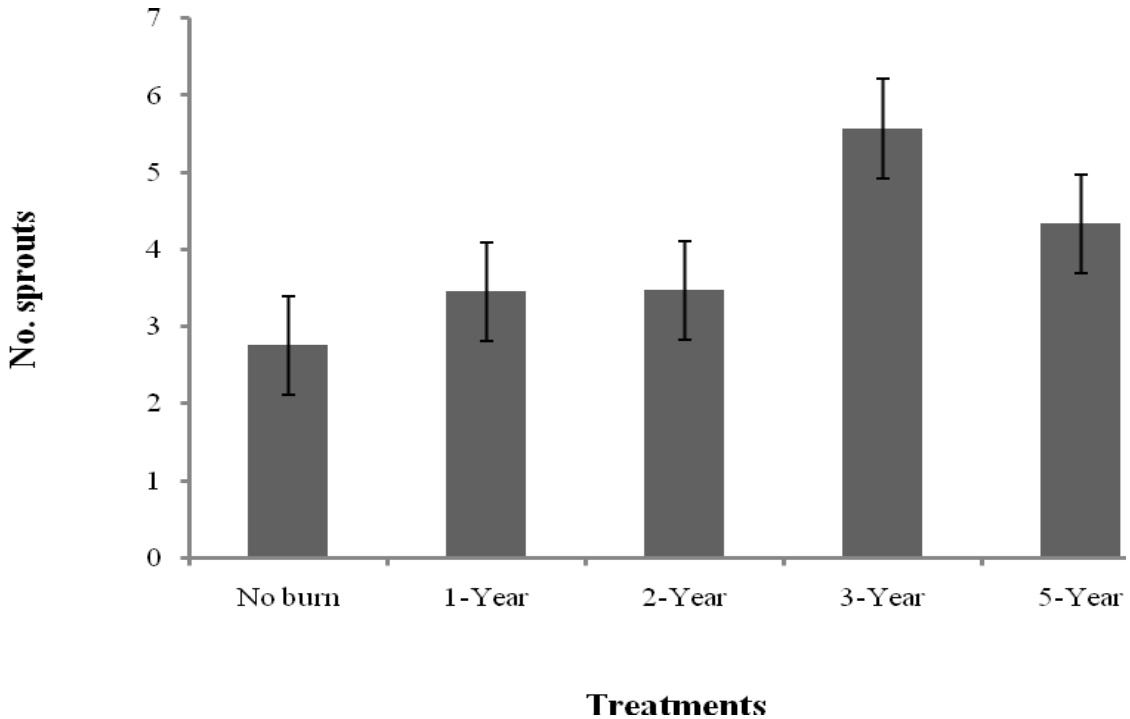


Figure 6.18: Number of sprouts for woody plants in each burn treatment (Matopos, Zimbabwe)

6.3.4 Correlations

In this study canopy distance was positively related ($p < 0.001$; $r = 0.279$) to stem to stem distance, negatively related ($p < 0.001$; $r = -0.158$) to canopy height and ($p < 0.001$; $r = -0.152$) to plant height. Canopy height was significantly related ($p < 0.001$; $r = 0.889$) to plant height and ($p < 0.001$; $r = 0.424$) to Canopy diameter. Plant height was positively related ($p < 0.001$; $r = 0.448$) to canopy diameter

6.4 Discussion

The long-term effects of fire, grazing and goats browsing on grazing potential, browse potential and woody plants vigour under savanna environment in the Eastern Cape, University of Fort Hare, South Africa and Two-Tree Kop, Matopos Research Institute, Zimbabwe was investigated. The discussion presented here is divided into three parts namely; (i) effects of burning frequencies (ii) effects of burning, grazing and browsing and (iii) effects of burning frequencies followed by ten-year period of fire exclusion grazing potential, browse potential and vigour. Two parts (i and ii), of the study were conducted in South Africa while the other part was conducted in Zimbabwe. In South Africa the burn frequency treatments that were studied had been under prescribed burning since 1980; the burning frequencies were 1-year burn, 2-year burn, 3-year burn, 4-year burn, 6-year burn and control/no burn. The second site of the experiment had been burnt (annually) grazed and browsed by goats since 1972. The experimental sites are fenced, hence; grazing by domestic stock and wildlife minimized.

Long-term fire trials in Zimbabwe had been burnt since 1954 until 1998 when the experiment was abandoned. In some cases during abandonment, some plots did experience some burning by wild fire; however information to explain which plots received burning and dates is not available. The fence around the fire plots was not well maintained when the study was undertaken; hence, plots were open to free ranging wildlife

6.4.1 Long-term effect of burning frequency on grazing and brows potential

Grass biomass was one of the attributes that were used in this study to estimate grazing potential of a site. More grass yield could be indicative of more forage material for livestock on a site. However, it is important to note that grass biomass yield is a function of many factor including rainfall (Smith & Hard 1999). Ability of a site to provide grazing is an important attribute of site productivity.

Highest grass biomass under plots that were protected from fire than under burnt ones was justifiable because constant removal of grass material by fire was bound to reduce grass yield under burn treatments. High grass yield on a site could sometimes be misleading if climatic conditions, season, species, species phenological stage, type and age of grazing animal and range condition are not taken into consideration. In this research study, it was discovered that litter material, standing dead grass biomass were found in relatively large quantities under plots protected from fire and 4-year burn; this was not the case under 6-year burn because it had received fire the previous year before data collection. Also in chapter four of the present research study (effects on biological community integrity), there was a considerable proportion (>8%) of species that are not acceptable to grazers, such as *M decumbense* and Karroo bushes under no burn than under other burn treatments, hence, the ability of such site to provide good graze for animals is reduced.

Palatable grass species such as *T triandra, P maxim* and *P stapfiana* were found in small quantities under plots protected from fire and less frequently burnt plot (4-year burn and 6-year burn). It was discovered in chapter four of the present research study that *T triandra*, an important and desirable species on a site for grazing animals decline in proportion with increasing burn interval.

Decreasers (usually palatable species) were relatively more under burnt plots compared to unburnt ones whereas, Increaser III and Increaser I (relatively less palatable species) were present in higher percentages under unburnt treatment compared to burnt ones. Therefore, the burnt plots had a relative gain of decreasers and loss of Increaser III and Increaser I giving an impression that abundance of decreasers could be sacrificed if fire is excluded as a management tool in grazing areas.

Even though grass yield was more under plots that were protected from fire compared to under burn treatments, it is only fair to infer that fire has potential to improve grazing potential on a site. In this study, the following undesirable condition for a healthy rangeland were recorded on plots that were protected from fire: (i) increased quantities of litter biomass, (ii) increased standing dead grass biomass, (iii) increased proportion of unacceptable or less palatable grass species to grazers and (iv) reduced proportions of palatable decreasers More grass yield under plots protected from fire does not really mean that the site has more potential for grazing than plots that were subjected to fire.

Physiognomic structure of woody species is an important factor when determining browse potential of a site. The physiognomic structure components of woody species discussed in this section are plant height, canopy height, canopy diameter, main stems diameter and sprouts diameter as well as number of sprouts. The long-term effect of fire on woody plants physiognomic structure was clearly demonstrated in this study, there were low measurements for plant height, canopy height, canopy diameter, main stems diameter and sprouts diameter, under burnt plots compared to under unburnt plots. The findings of this study are consistent with the expectations. Peter A *et al*. (2008) also reports more tree growth in height and canopy development on plots protected from fire than on burnt plots in thier study Savanna burning and the assessment of long-term fire experiments with particular reference to Zimbabwe. In support of the findings of this study, Hoffmann and Solbrig (2003) point out that once the apical meristerm of a tree or large shrub is destroyed by fire, it becomes increasingly susceptible to destruction in subsequent fires due to the reduction in size. Hoffmann and Solbrig (2003) indicat further that the degree to which damage is inflicted on burnt plants by fire could be governed by, fire behaviour (fire intensity and fire frequency), the timing of burns and species composition. Species resilience in varying conditions and herbivory are according to Hoffmann and Solbrig (2003) also very important determinants of the extent to which fire damage vegetation. Additionally, White (1983) supports the findings of this study by indicating that every time fire burns a plant, it damages tissues and this hampers uniform growth of the affected plants; repeated burning of plant is bound to inflict damage resulting in reduced growth. Higgins (1986) cautions that the long term effects of fire on woody species is dependent upon plant age, soil moisture at time of burn, intensity of fire, season of burn, health of the plants, and frequency of droughts.

The trend exhibited in this study is that damage by fire to woody plant increase with frequency of burn. The findings of this study show increased values for plant height, canopy height, canopy diameter, main stems diameter and sprouts diameter with decreased burn frequency. The findings further show less values for plant height, canopy height, canopy diameter, main stems diameter and sprouts diameter under 6-year burn compared to the 4-year burn. This could be ascribed to the reality that 6-year burn had been burnt a year before data collection date. Even though the 6-year burn plots had been burnt the previous year before data was collected, the recorded values for height, canopy height, canopy diameter, main stems diameter and sprouts diameter were still higher compared to under 1-year burn, 2-year burn and 3-year burn. This suggest that it is unlikely that a once off fire incident could drastically reduce the growth of woody plants as does repeated burning. In the case where fire is used to control bush encroachment to accommodate grazing, it is important to note that fire would be effective to keep woody plant at a grazeable height. Rebertus *et al.* (1993) reports that under frequent burning small individual woody plants fail to grow to larger size classes; they remain indefinitely in a reduced non-reproductive stage.

Characteristics of woody species could also be used to estimate browse potential of a site (plant height, canopy height, canopy diameter, main stem diameter, sprouts diameter and number of sprouts); tree height can be used to calculate total canopy volume on a site. The total canopy volume (TE/ha) was more under unburnt plots compared to burnt plots. More importantly, trees were beyond the reach of browsers (<1.5m) such as goats under no burn. Tree total canopy volume (TE/ha) increased constantly with increasing burn interval, however, it dropped under six year burn because the treatment received fire the previous year prior to data collection, this effect further confirms that fire could reduce canopy foliage hence browsing potential drastically; this pattern was in agreement with the findings of (Walker 1980). This suggests that frequent fire could be used to keep woody plants at browseable height (<1.5m), however, this is dependent on a number of both biotic and abiotic factors including type of burn, wind speed, moisture content of fuel material, fuel load, humidity and soil moisture. The canopy height and spread that was more under unburnt plots than under burnt ones was also reasonable because such plots never experienced defoliation of whatever magnitude since fire was not a factor in that circumstance. More canopy height and spread under no burn could mean that there is more browse material for browsers, but in view of the height of woody plants (above 1.5 browseable heights), the opposite is true.

Ability of plant species to resprout after disturbance is important because it is an index of vigour or vitality. This phenomenon perpetuates species where growth from seeds is not viable; browsers as well as grazers at times, need woody plants as food. If woody plants could be extinct on a site, this would mean a tragedy to animals that depend on them as a source of food. Vitality or vigour of plants is also an attribute of functioning ecosystem processes. Fire induced sprouting of woody species as expected. More sprouting under burn treatments could be a response of some woody plants to avoiding extinction following disturbance. However, Bond & Midgley (2001) argue that sprouting varies among species, among life history stages of species and among disturbances of differing severity. As expected, sprouting declined with increased burn interval.

More sprouting under burn treatments than under plots that were protected from fire was consistent with the findings reported by (Bock & Bock 1984, Furley *et al.* 2008 and Bond &

Midgley 2001). Under Savannah condition grazers e.g. cattle could consume leaves of woody species and some small twigs. Several small sized sprouts (>5 in number and<1cm in diameter) under burn treatments than under no burn could be additional food for animal. Even the main stems under burn treatments were not very thick (<3cm diameter) to avoid consumption by animals, however this could be dependent on species, species acceptability, species nutritive content, animal type and age and time of the year.

6.4.2 Long-term effect of burning, grazing and goats browsing on grazing and brows potential

Grass yield is an important indicator of a site ability to provide fodder for grazers (site productivity). Ability of a site to provide products and services is also an important attribute of functioning ecosystem processes. Higher and lower grass yield under goats plot and follow up burn respectively were expected. Goats are browsers and as such, they seldom eat grass when there is enough browse. On the contrary, fire (especially annual) could consume almost all above ground portion of grasses as well as litter material resulting in reduced grass yield. More tree height, canopy height as well as canopy diameter under grazing treatment than under control (treeless) could be blamed for the reportedly lower grass yields on grazed plots. Under this situation, grass layer could be shaded by the tree canopy resulting in failure to receive enough light for photosynthesis and ultimate growth.

Relatively small proportion of decreasers under grazing, goats browsing and control compared to under follow up burn could be due to over-utilization or underutilization of this resource. This was expected because decreasers dominate a site under good condition and decline in abundance when a site deteriorates in condition through over- or under-utilization. The findings suggest that grazing and control treatments were over-utilized while goats' browsing was underutilized. It is clear from this study that burning every year could sustain decreaser species better than injudicious grazing. This is an important revelation, because during experimentation, grazing capacities and stocking rates were determined before animals were set out to graze, it could be that grazing capacities were exceeded. To further prove a point that fire is required to sustain grazing areas in good condition than other treatments, increaser II species attained higher figures at the expense of decreasers under grazing, goats browsing and control. IncreaserII species tend to be abundant in overgrazed areas; these species replace decreaser species under such circumstances.

Browse potential of a site could be estimated by woody species characteristics. Burning, grazing and browsing effects on plant height, canopy height, canopy diameter, main stem diameter, sprouts stems diameter and number of sprouts reported are consistent with the expectation; fire and goats reduced the plant height, canopy height, and canopy diameter, sprouts diameter and sprouts diameter of woody species more than grazing. A chronic disturbance or removal of above ground parts of woody plants by intense fire and goats could lead to retarded plant growth. In some cases large number of domestic and wild animals feeding on tender growing tips of woody plant may kill or stunt such plants (Marañón 1988) thus, reducing their size in general. It therefore, suffices to conclude that more growth in woody plants in terms of plant height, canopy height, canopy diameter, stems diameter and sprouts diameter under grazing could be attributed to the fact that disturbance by grazing cattle is too lenient to hamper above ground growth of woody species because they are grazers. Still, animal activities may imply episodic disturbance when the climate is abnormally dry – because they may feed on woody plants when herbaceous cover is scarce (Gómez Sal *et al.* 1999). In the similar vein, Bailey *et al*. (1990) confirm that grazers have potential to reduce growth of woody plants hence, prevent the development of a forest. Growing season is also an important consideration when grazers feed on woody species; suckers defoliated by grazing late in the growing season could be eliminated whereas suckers defoliated earlier in the season could continue to regenerate (Bailey *et al*. 1990).

In the present study, more sprouts produced under follow-up burn than under grazing and goats browsing plots suggest that bush control using fire only cannot be a good option. Combination of different methods including goats browsing could cut down the sprouting potential of woody plants and thus bring some control. From this study it is clear that sprouting potential of woody plants could be two times higher under burning than under grazing and goats browsing. Nonetheless, species responses to disturbance are governed primarily by their life history and physiological traits and by the characteristics of the disturbance (Gómez Sal *et al.* 1999).

More total canopy volume (TE/ha) reported under grazing than under follow up burn and goats browsing could be explained by the fact that cattle are grazers, not browsers, they seldom consume woody species much when there is enough grazable material. Less total canopy volume (TE/ha) under goats browsing compared to under follow up burn indicates that goats can effectively lower canopy volume than fire. The results on tree height show that utilization of woody species by livestock could not be a problem under all treatments because it was within the browsers' reach (1.5m). The findings indicates that burning annually and browsing by goat are able reduce tree height to as low as below half a meter. Under follow up burn the reduced heights could be the results of top-kill of canopies by fire. More tree height values attained under - grazing treatment compared to other treatments could be attributed to the feeding behaviour of cattle. Cattle consume reachable leaves of woody species, down facing leaves and twigs as well as laterally growing parts; they also do not usually eat from the top of woody plant. Furthermore they could utilize woody plants leniently compared to burning and goats browsing which are able to reduce both upward and laterally growing parts of plants. Goats were also able to reduce the diameter of main stems and sprouts to as low as under half a meter. The potential of fire to weigh down both epical and lateral grow of woody plants could have induced more sprouting under follow up burn compared to under grazing and goats browsing.

6.4.3 Long-term effect of burning frequency followed by ten-year period of fire exclusion frequency on grazing and brows potential

High percentage of decreasers under plots that were protected from fire than under 1-year, 2-year and 3-year was logical. Decreaser often decline when range condition deteriorates due to underutilization; these species tend to die out where grazing is extremely lenient and fire is excluded (Camp and Hardy 1999). The findings suggest that judicious grazing and controlled fire perpetuates decreasers on a site; exclusion of fire on plots that were previously exposed to fire treatments renders decreasers liable to strong competition from increasers. Generally, decreasers exhibited consistent increase in proportion with increased burn interval whereas increaser II consistently decreased in proportion with increased burn interval on burnt plots. Much higher values for decreasers under 5-year burn than under no burn could not be easily explained. The effect could be the results of accidental fire. Still, occurrence of accidental fire in those plots at some stage before data was collected is probable. Besides, roaming grazers could also be blamed for that effect because the fence for the experimental plots was not well maintained. The results of this study suggests that sites that were previously subjected to long-term fire could sustain lower proportion of grass species with higher grazing value but higher proportion of grasses with average and lower grazing value.

The results demonstrated that burning effects on plant height, canopy height, canopy diameter, main stem diameter, sprouts stem diameter and number of stems of woody plant species could be long lasting (after ten years of fire exclusion). Generally, woody plants on burned plot recorded lower values for plant height, canopy height, canopy diameter and diameter of stems compared to no burn treatment. It is believed that more plant height, canopy height, canopy diameter and diameter of stems values obtained on no burn treatment over 1-year, 2-year, 3-year and 5-year burn treatments could be the result of disturbance and removal of above ground parts of the plants by fire over the years (before fire exclusion) on burnt plots. Sprouting is a form of persistence in a diversity of ecosystems; many woody plants can resprout and persist, *in situ*, following disturbance events. Sprouting favours self-replacement after stem death of woody plants where stem death is caused by disturbance rather than crowding or disease Bond &Midgley 2001.

Burning frequencies did not have clear contrasting effects on number of sprouts produced by woody plants after 10-year period of fire exclusion. In the present study, the results confirmed that burning effects on sprouting could be long lasting even though a significant difference could not be clearly established, there were relatively more sprouts produced in burnt plots than unburnt (no burn). After ten years of fire exclusion more sprouts could generally be associated to some extent with 3-year and 5-year burn treatments than 1-year and 2-year burn treatments. Significantly more sprouts under 3-year burn than under other burn treatments and control is hard to explain; Perceptible incidences of unprescribed fires could be attached to this effect. Burnt plots could become desirable areas for grazing because fire renders them green, tender and palatable. Because of this, there are chances that grazers could concentrate their efforts in such areas, which in this case could have been a 3-year burn.. In support of this, Zida *et al.* (2007) state that savanna species form sprouts following disturbances and these young sprouts are preferred by foraging animals because they are tender and nutritious. Though the findings of this study and Zida *et al.* (2007) are not without credibility, (Bond & Midgley 2001) advise that for sprouting to occur after sustaining an injury, a plant needs surviving meristems and stored reserves to support regrowth (Bond & Midgley 2001). On the same matter, Scholes *et al*. (2003) and van Wilgen *et al*. (2003) indicate that the degree to which fire influences savanna vegetation is to some extent still controversial.

More total canopy volume (TE/ha) reported under no burn than under burn treatments is not beneficial as forage material because the trees are very tall (3.5m) to be reached by foraging animals. One-year burn produced high total canopy volume than other burn treatments. Utilization of forage could also be fairly problematic for foraging animal. Trees however attained 1.6m height as opposed to 1.5m required browsing height for domestic animals.. From this study, evidence of fire could still be recognized ten years after fire was removed. The physiognomic structure for woody plants (plant height, can height, canopy diameter and main stem diameter) was reduced under burn treatments compared to under plots that did not receive fire. The findings demonstrate that fire effects on woody species could be long-lasting. After ten years of fire exclusion, burn treatments could still exhibit more sprouting ability than plots that were protected from fire. This suggests that burning could rejuvenate or sustain vitality of woody species.

Tree height declined with increasing burn interval. In this study higher value for tree height, tree density and tree equivalents were obtained under plots that did not receive fire compared to burnt ones. Surprisingly, tree height value under 1-year burn was above ideal height (1.5m) for grazing. Tree equivalents (TE/ha) for all burn treatments except 3-year burn could be a problem where grazing is an option and as such cutting of trees to size would be required to allow grazing. Relatively lower TE/ha under 5-year was strange; this further strengthens possible occurrence of accidental fire in 5-year burn plots reported earlier.

6.5 Conclusion

Findings of this study have demonstrated that fire effects on selected elements of grazing potential (total grass yield, grass ecological groups and grass grazing values), browse potential (total canopy volume and physiognomic structure) and sprouting, could ultimately have effects on productivity and vitality on a site. This effect could also have influence on functioning of ecological processes because site productivity and vitality are important attributes of ecological processes. In this study, burning reduced total grass yield but improved range condition by increasing proportions of decreasers and grasses with high grazing value (Grazing value refers to the quantity and quality of grazeable material).

Through its effects on physiognomic structure (plant height, canopy height, canopy diameter, diameter of main stems, sprouts stems diameter) and sprouting, fire had effect on the ability of a site to produce browse for animals (productivity) and ability of a site to regenerate (vigour). Burning reduced height of woody species to a browseable height (1.5m). Total canopy volume was decreased with frequency of burn. Canopy size (height and diameter) decreased with increased burn frequency. Diameter of main stems and sprouts were reduced to bellow 3cm and 2cm respectively. Burning induced sprouting of woody plant species. In this study, number of sprouts was more under 3-year burn than other burn treatments.

Burning, grazing and goats browsing had effects on site productivity and vitality through its influence on selected elements of grazing potential (total grass yield, grass ecological groups and grass grazing values), browse potential (total canopy volume and physiognomic structure) and sprouting. Burning (Follow up burn) reduced total grass yield but increased proportion of decreasers and other grasses with high grazing value). On the contrary, goats browsing increased percentage of increaser II species and grazing lowered percentage of decreasers. Grazing induced more plant height, canopy height, canopy diameter and main stem diameter but lowered sprouting of woody species. Goats browsing and burning reduced canopy height, plant height and diameter of sprouts alike. Goats browsing had significantly reduced canopy diameter, main stem diameter and number of sprouts than other treatments.

This study has demonstrated that long-term burning followed by ten-year period of fire exclusion could have effect on productivity and vitality of a site through its influence on selected aspects of grazing potential (total grass yield, grass ecological groups and grass grazing values), browse potential (total canopy volume and physiognomic structure) and sprouting. In this study, 1-year burn, 2-year burn and 3-year burn degraded the range condition by decreasing proportion of decreasers and grasses with high grazing value while increasing proportions of increaser I and II species. No burn and five year burn improved range condition by inducing more decreasers and high grazing value grasses; proportion of increasers was greatly reduced under these treatments.

Burning followed by ten-year period of fire exclusion resulted in reduced total canopy volume plant height, canopy height, canopy diameter and main stem diameter of woody plants. Three year burn had highest number of sprouts than other treatments. Plots protected from fire had more total canopy volume but their height exceeded the required browsing height (1.5m) for animals to utilize.

7 Long term effects of burning, grazing and goats browsing on hydrologic functioning and nutrient recycling

7.1 Introduction

Hydrologic functioning and nutrient recycling are important indicators of functioning ecological processes. Hydrologic functioning and nutrient recycling are influenced by abundance and distribution of dead plants residues on an ecosystem. Plant material and litter that covers the soil surface (standing, freshly fallen or slightly decomposed) promotes moisture retention and nutrient recycling. Plant material and litter are also important for water infiltration and percolation in the soil. They reduce soil erosion, reduce evaporative losses, reduce raindrop impact and they also act as physical barrier to heat and water flow on the soil surface (Adams *et al*.2003). In addition to hydrologic and nutrient cycling functions, plant material and litter are added to the soil and broken down by macro- and micro-organisms into organic matter. Organic matter is regarded as an important part of soil physical, chemical and biological fertility and acts as a nutrient pool (Evans & Young 1970). Soil organic matter is commonly estimated by measuring the amount of soil organic carbon in the soil. Decomposition of organic matter and nutrient cycling, which are essential in the maintenance of soil fertility are dependent on the functioning of the soil microbial community (Sparrow *et al* 1999).

Efficiency of nutrient uptake and growth by plants is considerably reduced when there is a microbial population of high sink strength for nutrients present (Michelsen *et al*. 1999). Storage, retention and slow release of water and conservation and recycling of nutrients are important consideration for stable ecosystem. It is thus important to estimate how long-term burning and herbivory could affect ecological processes such as hydrologic functioning and nutrient recycling in the rangeland ecosystem. Comprehensive knowledge of how ecological disturbances impact on a site is essential in order to manage and preserve fire-prone landscapes effectively. The main objective of this study was to investigate the potential long-term effects of burning, grazing and browsing on hydrologic function and nutrient cycling processes. Selected indices of hydrologic function and nutrient cycling presented in this section are Litter biomass, Soil organic Carbon (SOC), Microbial Biomass and Carbon (BMC)

The specific objectives were to:

(i) investigate if long term burning frequencies have effects on grass litter biomass, soil organic carbon, microbial biomass carbon and consequently hydrologic functioning and nutrient recycling on a site.

(ii) investigate if burning, grazing and browsing by goats have differential effects on grass litter biomass, soil organic carbon and microbial biomass carbon hence, hydrologic functioning and nutrient recycling

(iii) investigate if burning frequencies followed by ten-year period of fire affect grass litter biomass, soil organic carbon and microbial biomass carbon, hence, hydrologic functioning and nutrient recycling on a site

The study tested the following hypothesis:

(i) long-term burning frequencies have effects on grass litter biomass, soil organic carbon and microbial biomass carbon hence, hydrologic functioning and nutrient recycling on a site

(ii) long-term burning, grazing and browsing by goats have affects grass litter biomass, soil organic carbon and microbial biomass hence, hydrologic functioning and nutrient recycling of a site.

(iii) long-term burning followed by ten-year period of fire exclusion have effects on grass litter biomass, soil organic carbon and microbial biomass hence, hydrologic functioning and nutrient recycling on a site

7.2 Materials and methods

See chapter 3 for detailed description of materials and methods

7.3 Results

7.3.1 Long-term effects of burning frequencies on grass litter biomass, organic carbon and microbial biomass carbon

7.3.1.1 Litter biomass

There was a significant difference ($p \leq 0.05$) in biomass litter produced from different treatments. Burnt plots did not have significantly more litter biomass than unburnt plots ($p >0.05$) however, litter amounts were different between burn treatments ($p \leq 0.05$). Biomass litter was 73.9 g/m2 under no burn and ranged from 31g m2 to 100g/m2 under burnt plots. Highest litter biomass was under 6-year burn than under other burn treatments and control. Litter biomass was significantly low under 1-year and 3-year burns (Figure 7.1).

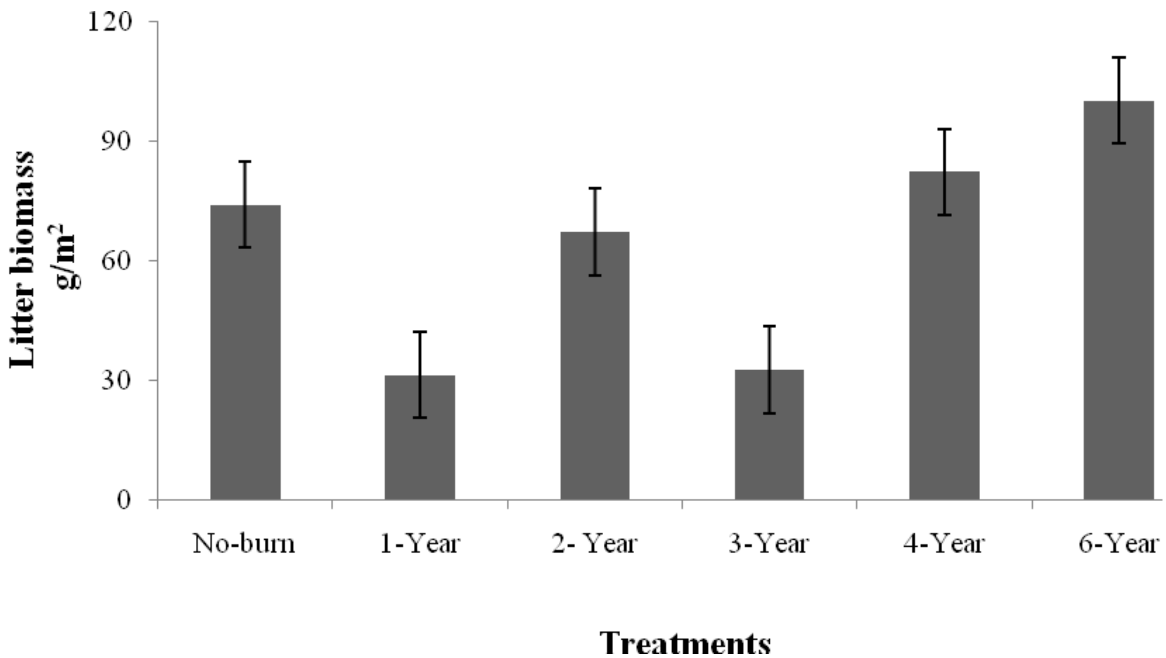


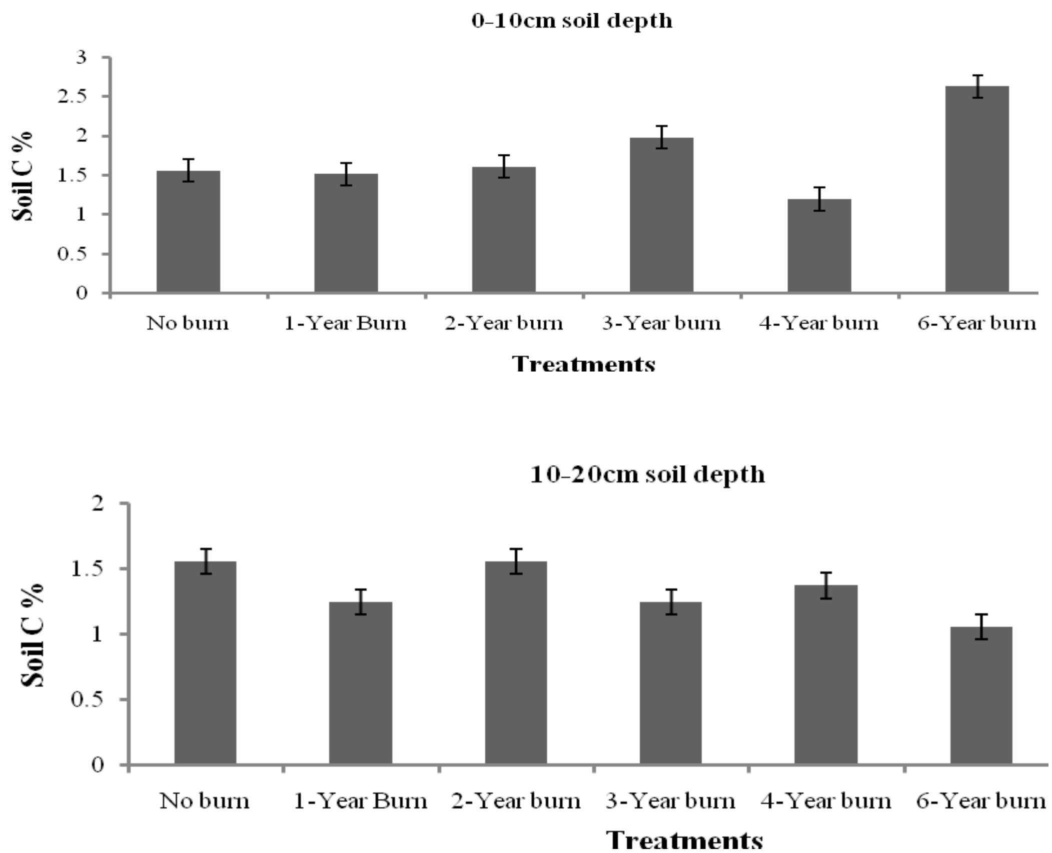
Figure 7.1: Grass litter biomass (kg/ha) in each burn treatments (UFH Farm)

Soil organic Carbon

Soil organic Carbon (SOC) results presented were determined at three soil depths (0-10cm, 10-20cm and 20-30cm). Soil organic carbon at 0-10cm (Figure 7.2a) and 20-30cm (Figure 7.2c) soil depths was significantly different ($p \leq 0.05$) between treatments. SOC quantity at 10-20cm soil depth (Figure 7.2 b) did not differ significantly between treatments ($p > 0.05$). There was significantly more soil organic Carbon under 6-year burn (2.6%) than under, 1-year, 2-year, 3-year, 4-year burns and control at 0-10cm soil depth. Lowest SOC value was under 4-year burn (1.1%) but this value was not significantly different from values obtained under 1-year, 2-year, and no burn (Figure 7.2a).

Percent soil organic Carbon was not different between treatments at 10-20cm soil depth (Figure 7.2b). At this depth, relatively more SOC was under no burn (1.6%) and lowest under 6-year burn (1%). Soil organic carbon was more ($p \leq 0.05$) under 2-year burn (1.4%) and lowest (0.9%) under 6-year burn at 20-30 cm soil depth (Figure 7.2c). SOC values under un-burnt plots and burnt ones did not show any statistical difference. Under no burn SOC was 1.2% and ranged from 0.9 to 1.4 under burn treatments.

(a)



(b)

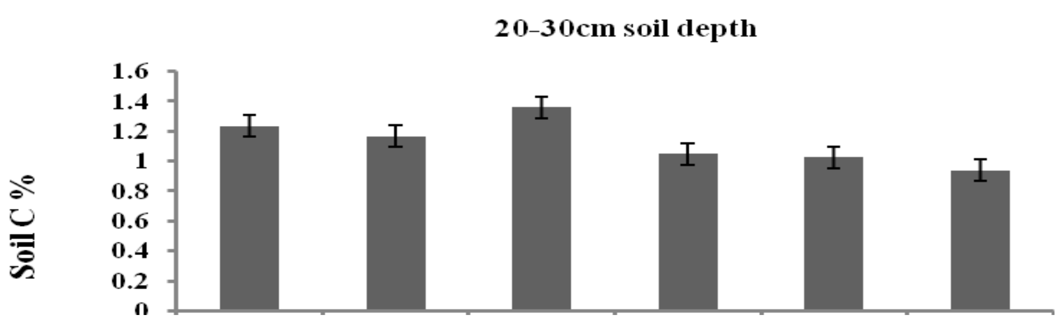


Figure 7.2: Soil organic carbon (%) under each burn treatments at UFH Farm for three soil depths (0-10cm, 10-20cm and 20-30cm)

7.3.1.2 Microbial Biomass Carbon (BMC)

Microbial Biomass Carbon (BMC) results reported here were determined at 0-10cm, 10-20cm and 20-30cm soil depths. Microbial Biomass Carbon (BMC) between burn treatments was significantly different ($p \leq 0.5$) at different soil depths**.** Significantly higher BMC at 0-10cm soil depth was under 3-year burn (1704µg/g) while lowest BMC (1337µg/g) was under 2-year burn (Figure 7.3a). Lowest BMC value under 2-year burn did not differ significantly from BMC values under 1-year, 4-year and 6-year burn treatments. BMC was 1503µg/g under no burn and ranged from and ranged from 1337 µg/g to 1704 µg/g under burn treatments.

At 10-20cm soil depth, BMC was highest (1358 µg/g) under 4-year burn and lowest (1141 µg/g) under no burn. BMC between burnt and unburnt plots did not differ significantly at this soil depth. It was 1141µg/g under no burn and ranged from 1229µg/g to 1358µg/g under burn treatments. Lowest BMC under no burn did not differ significantly from BMC under 1-year and 2-year burns (Figure 7.3b). BMC at 20-30cm soil depth was more (1314µg/g) under 2-year burn and low (1032µg/g) under 6-year burn (Figure 7.3.3c). Under burnt plots BMC ranged from 1032µg/g to 1314 BMC was 1066µg/g under plots protected from fire.

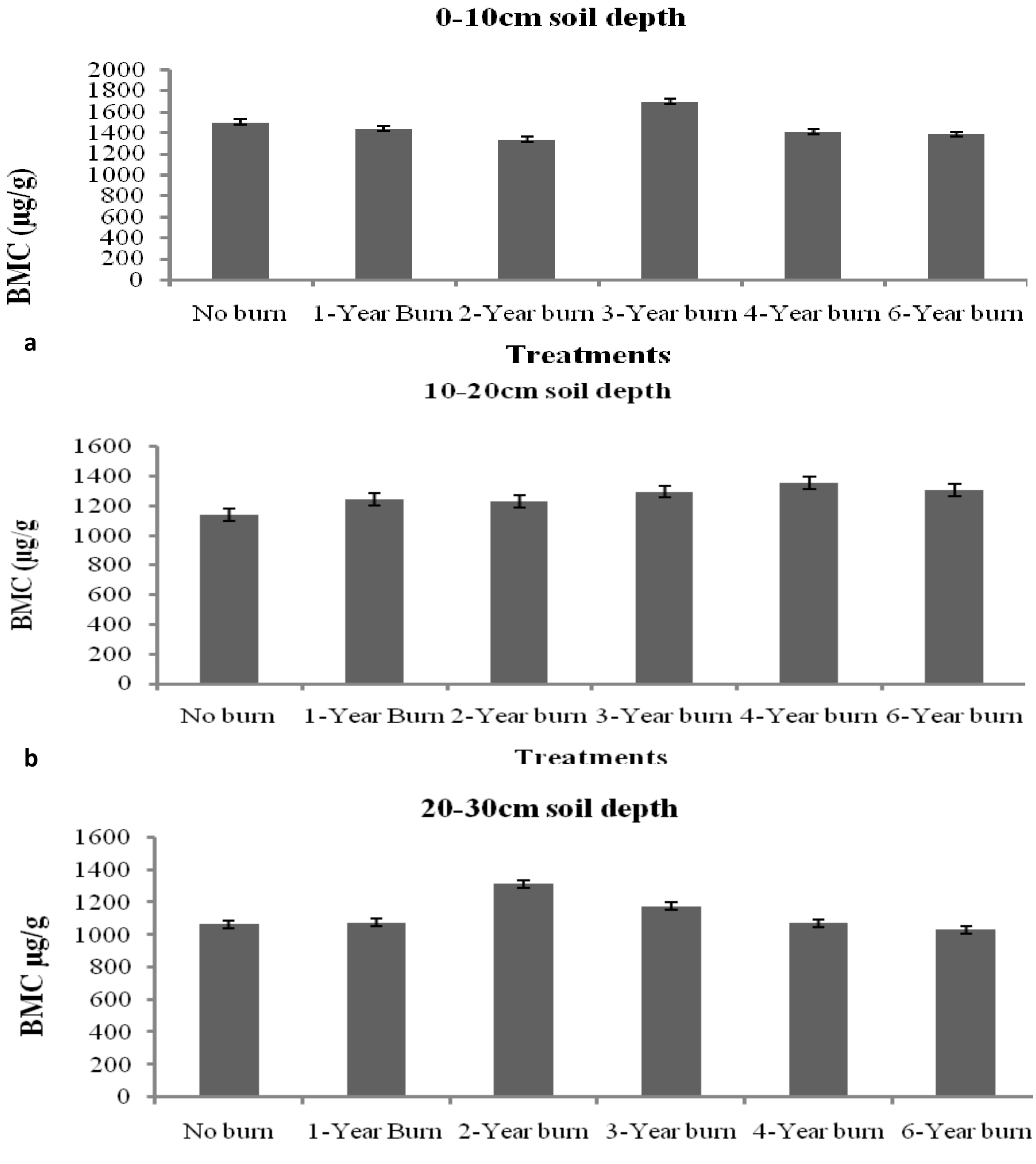


Figure 7.3: BMC (ug/g) under each burn treatments at three soil depths (0 - 10cm, 10 - 20cm and 20 - 30cm)

7.3.2 Long-term effects of burning grazing and goats browsing on grass litter biomass, soil organic carbon and microbial biomass carbon

7.3.2.1 Grass litter biomass

Treatments (Follow up burn, Goats browsing, grazing and Control) differed significantly in litter biomass production ($p \leq 0.05$). Follow up burn, Goats browsing and Control results on litter biomass production were not significantly different ($p > 0.05$). Litter biomass under grazing was lowest; however, the difference did not differ significantly from litter biomass values under follow up burn. Litter biomass was highest under goats browsing and lowest under grazing (Figure 7.4).

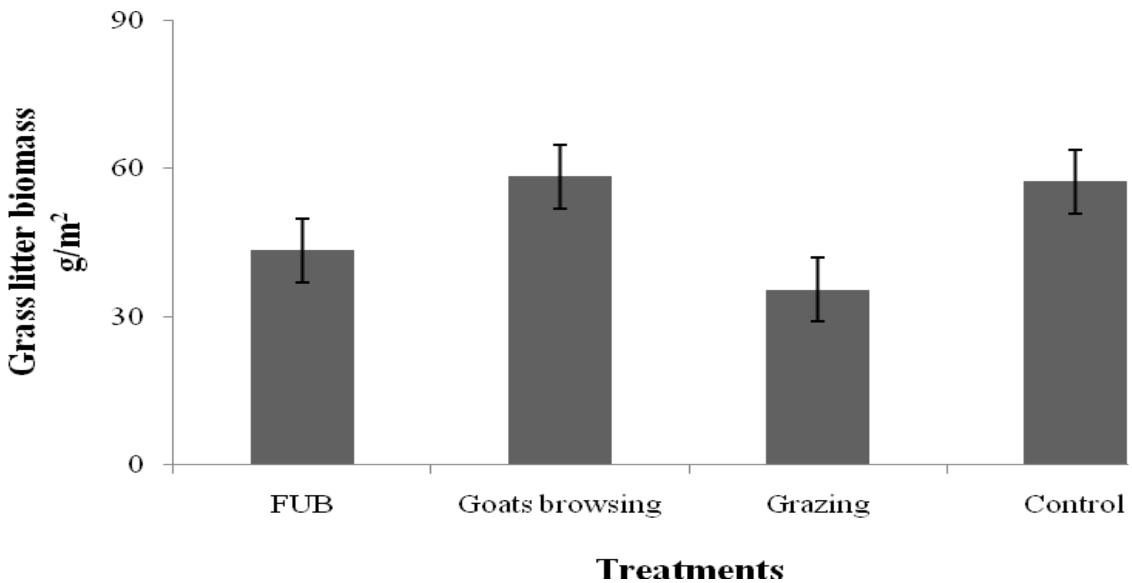


Figure 7.4: Litter biomass (g/m^2) under each treatment (UFH)

7.3.2.2 Soil organic carbon (SOC)

Soil organic carbon results reported here were determined at 0-10cm, 10-20cm and 20-30cm soil depths. Soil organic carbon was significantly different ($p \leq 0.05$) between treatments at different soil depths. Goats browsing had highest percentage of soil organic carbon under all treatments. Lowest SOC value (1.52) was under follow up burn, this value did not differ significantly from the SOC value (1.54) recorded under Control (Figure 7.5a). At 10-20cm soil depth, the lowest value for soil organic carbon was under grazing; this value did not differ significantly from soil organic carbon value under control (Figure 7.5b). Follow up burn and Goats browsing had soil organic carbon values higher than 2%.At 20-30cm soil depth, the lowest SOC value (1.4%) was under Control (Figure 7.5c).

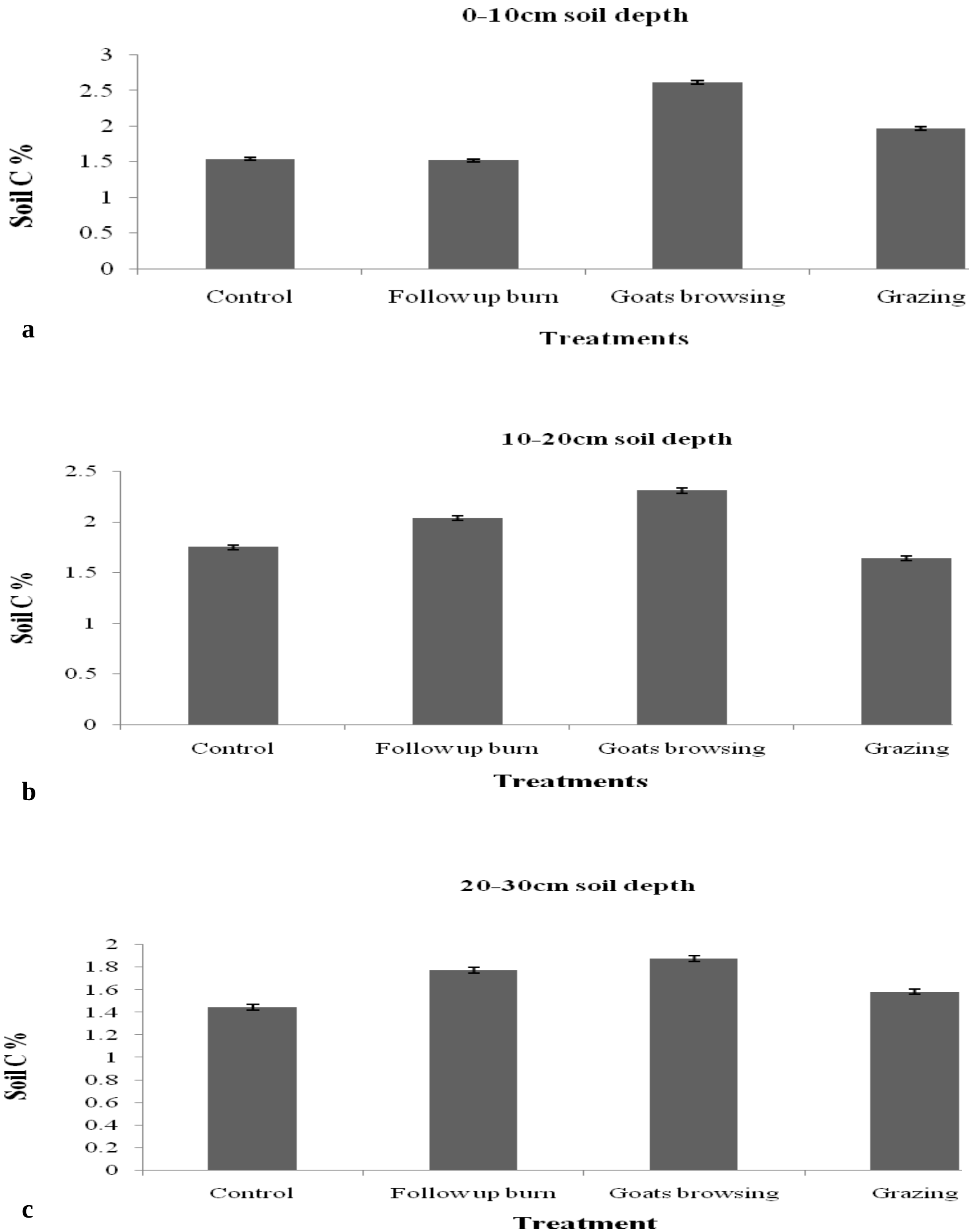
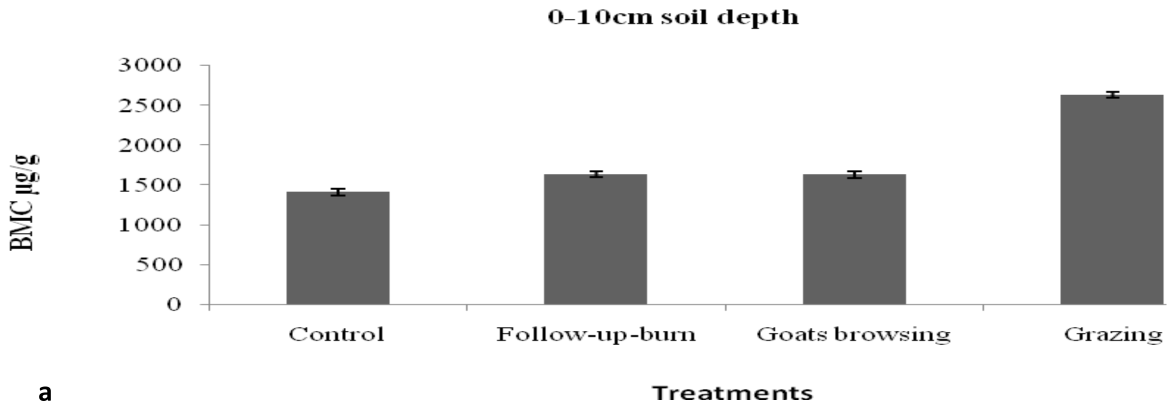


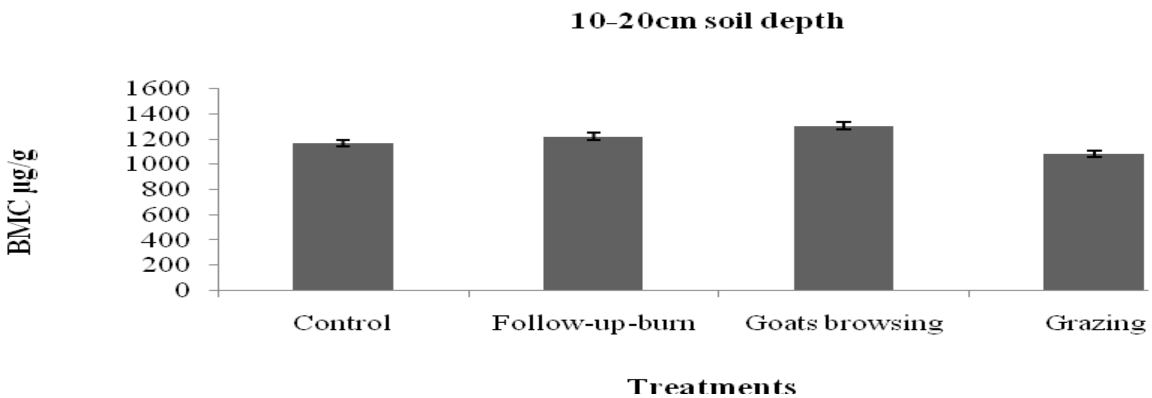
Figure 7.5: Soil organic carbon (%) under each treatment (UFH)

7.3.2.3 Microbial biomass carbon (BMC)

Microbial biomass carbon (BMC) results presented here were determined at three soil depths (0-10cm, 10-20cm and 20-30cm). BMC was significantly different between treatments at different soil depths ($p \leq 0.05$). At 0-10cm soil depth, BMC was highest (2636µg/g) under Grazing and lowest (1412 µg/g) under Control (Figure 7.3.6a). BMC values under Follow up burn and Goats browsing were not significantly different ($p > 0.05$). There was significantly more (1306µg/g) BMC under Goats browsing and significantly low (1082 µg/g) BMC under Grazing at 10-20cm soil depth (Figure 7.6b). BMC under Control was significantly high (1243µg/g) at 20-30cm soil depth. BMC was significantly low (1021µg/g) under follow up burn and goats browsing (Figure 7.6c).



a



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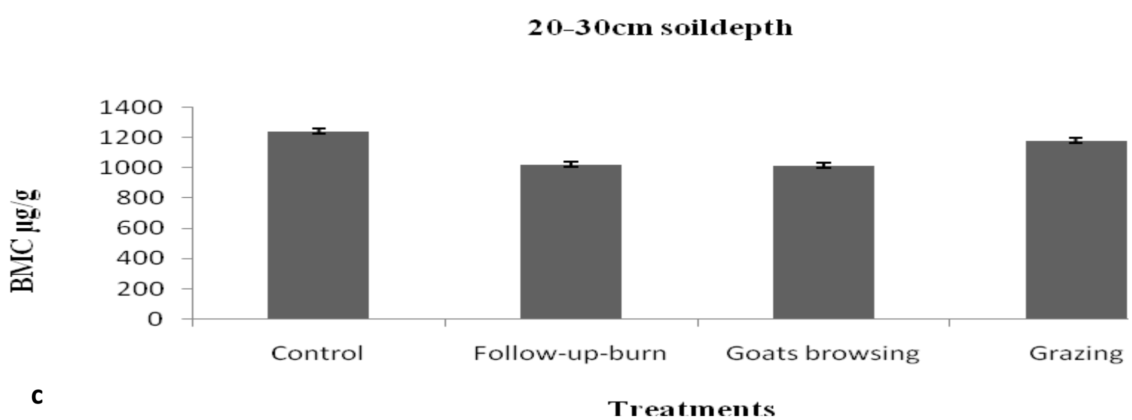

c

Figure 7.6: MBC (ug/g) under each burn treatment (UFH)

7.3.3 Long-term effects of burning followed by ten-year period of fire exclusion on organic matter

7.3.3.1 Grass litter

Grass litter (t/kg) was significantly different ($p \leq 0.05$) between burn treatments. Highest ($p \leq 0.05$) value for litter biomass was obtained under 5-year burn and lowest litter biomass was under 1-year burn. Grass litter biomass values under 1-year, 2-year and 3-year burn treatments were not significantly different.

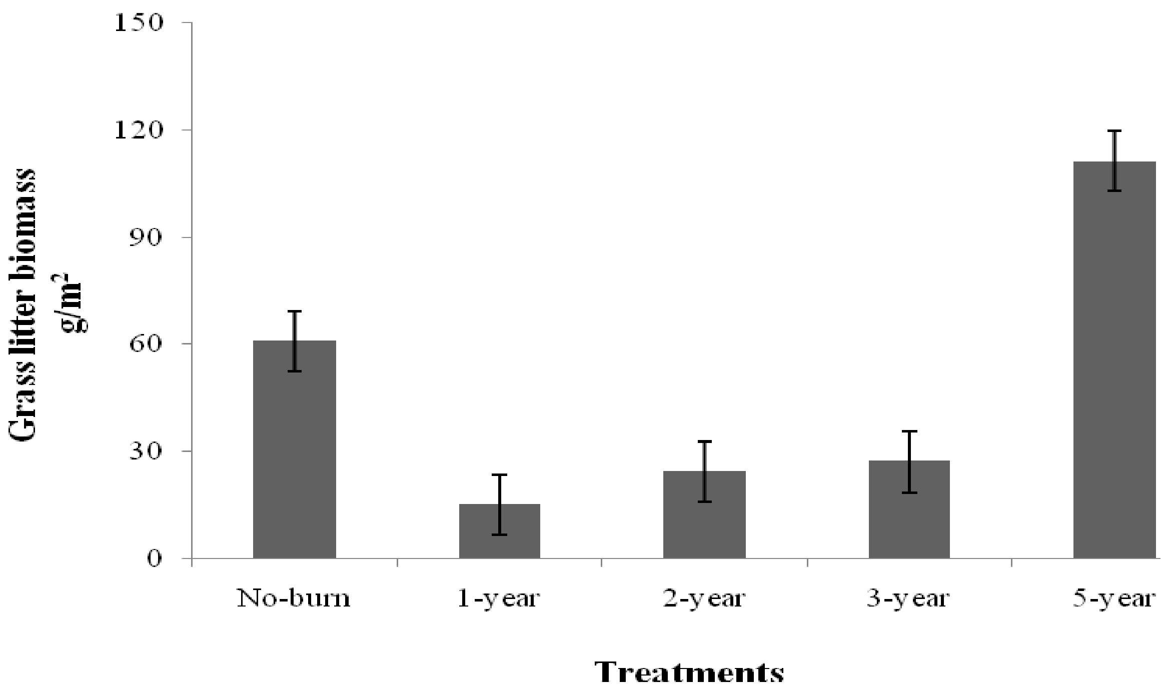

Figure 7.7: Grass litter biomass (g/m^2) under each treatment (Matopos, Zimbabwe)

7.3.3.2 Soil organic carbon

Soil organic carbon was significantly different ($p \leq 0.05$) between burn treatments. Highest (2.6%) organic carbon value at 0-10cm soil depth was under no burn.This this value was not significantly differently from SOC values (Figure 7.8a) obtained under 1-year and 5-year burns. At 10-20cm soil depth, SOC values were not significantly different between burn treatments (Figure 7.8b).

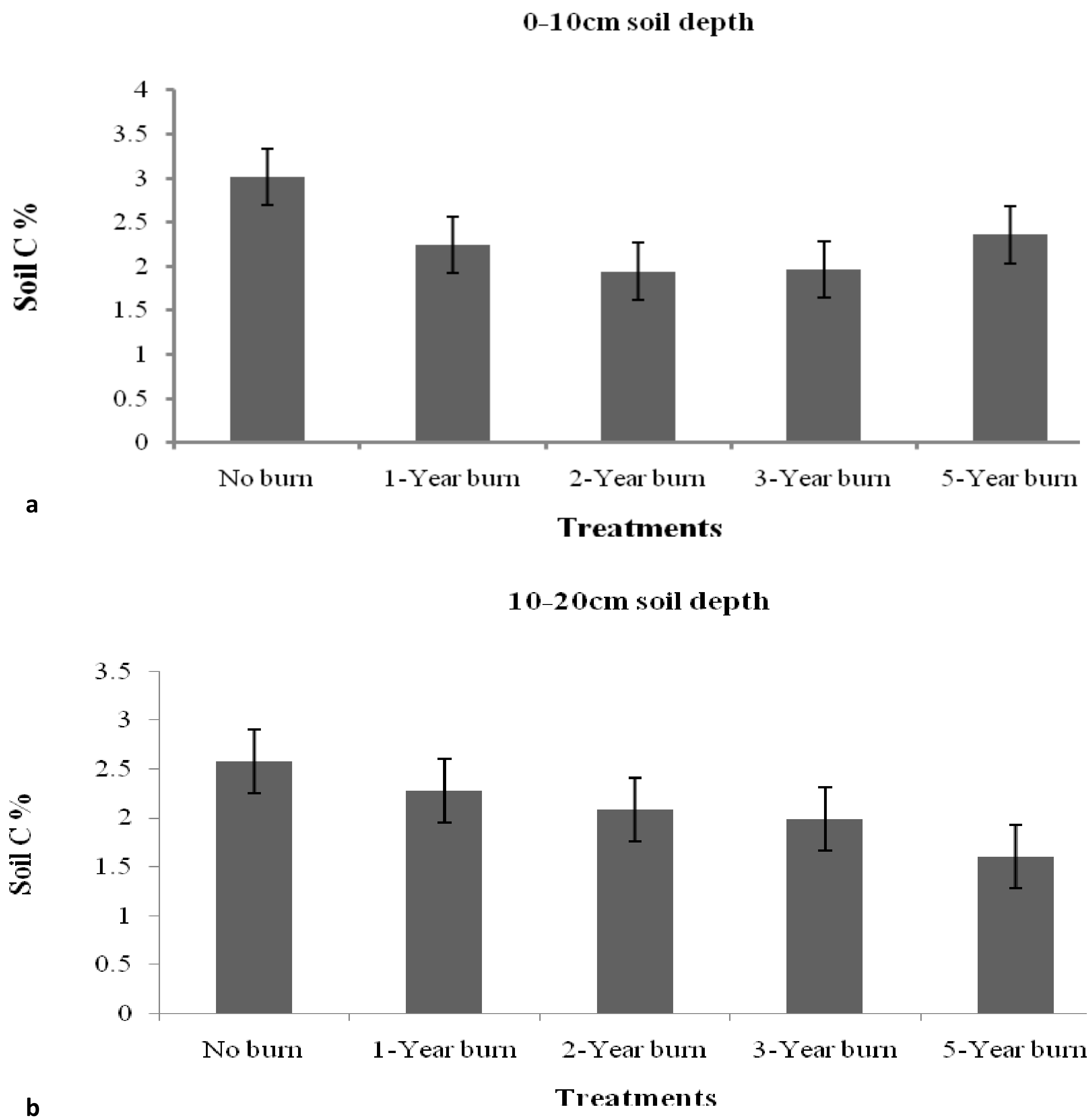

Figure 7.8: Soil organic carbon (%) under each burn treatment (Matopos, Zimbabwe)

7.3.3.3 Correlation

BMC was negatively related ($r = -0.235$, $p < 0.05$) to litter biomass. There was no correlation between soil organic carbon and litter biomass as well as between BMC and SOC.

7.4 Discussions

7.4.1 Long-term effects of burning frequency on organic matter

From this study, accumulation of litter biomass increased with increased interval of burning. This is understandable because every time burning occurs, almost all above ground grass debris is burnt. All the same, burning severity could depend on prevailing environmental factors and the moisture content of plants. The decreased litter under 3-year burn compared to under 2-year burn could be attributed to the fact that the 3-year burn plots had been burnt a year before (2007) data was collected in 2008.

The results of this study showed a general decline in soil organic carbon with an increased soil depth. This is logical because plant debris which is another source of soil organic carbon is found mostly on the surface of the soil. Thus far, soil organisms and dead roots of woody plant could also increase organic content of the soil. There was an increasing soil organic carbon with decreasing burn frequency from 1-year burn to 3-year burn treatments at 0-10cm soil depth. These findings are consistent with results reported by Herman *et al*. (2009). Findings of this study did not show any clear trend on the effect of burning frequency on microbial biomass carbon. So far, microbial biomass carbon seemed to decline with an increasing soil depth. The findings are not consistent with the results reported by Palese *et al*. (2004) and Mabuhay *et al* (2004) who found more microbial biomass carbon under unburned plots than burnt ones. It is important to note that numerous factors including litter chemistry soil moisture, temperature and management practices differently affect microbial biomass and their activities at a site (Kara *et al*. 2008).

7.4.2 Long-term effects of burning, grazing and browsing on organic matter

More litter biomass under goats browsing than under follow up burn and grazing is reasonable because goats seldom utilize grasses, hence, more grass leaves could increase litter on the ground. Surprisingly, more litter biomass was produced under follow up burn than under grazing. The findings are not consistent with expectations because fire consumes more plants biomass than grazing animals. More litter biomass under control than under grazing could be attributed to potential tree cover effects on grass yield as well as litter amounts. Trees were present on grazing and absent on control.

More soil organic carbon that decreased with soil depth under goats browsing and grazing treatments was consistent with the results reported by Shourkaie *et al.* (2007). Insignificant difference in soil organic carbon at 0-10cm and 10-20cm soil depths under control and follow up burn was surprising because fire consumes almost all above ground parts of plants leaving negligible organic materials while under control grass plants were not subjected to severe defoliation. Since grass is not the only source of soil organic carbon, other soil organisms and roots of woody plant could be responsible for the unexpectedly high organic carbon under follow up burn.

Microbial biomass carbon (BMC µg/g) under follow up burn and goats browsing seemed to decline with soil depth. This was anticipated because organic material commonly decreases with soil depth; however, contribution of plant roots and soil organisms to overall organic material is not underestimated. More BMC at 0-10cm soil depth under grazing compared to other treatments could be due to joint contribution of tree layer and grass layer to the soil organic material hence BMC. Under goats browsing most tree leaves were consumed hence, less contribution to organic material from woody plant. Even so, organic material from roots is also important. Under follow up burn most organic material is burned down hence less contribution to BMC is expected. Because trees are absent at control plot, only grass layer contributed organic material, and as such, it was not surprising that low values for BMC were recorded expected that BMC would be affected. It should be noted that soil organisms are also important contributors of soil organic material hence, BMC. Microbial biomass abundance and environmental conditions are important considerations in microbial biomass carbon studies (Mabuhay *et al*. 1994, Gallardo & Schlesinger 1995). In the present study microbial biomass abundance and environmental conditions were not given special consideration.

7.4.3 Long-term effects of burning followed by ten-year period of fire exclusion on organic matter

Even though significant difference could not be established between 1-year, 2-year and 3-year burns, litter biomass increased with an increasing interval of burning. More litter biomass under 5-year burn and control than under other burn treatments could be explained by the fact that continual consumption of grass litter material by fire hampered litter build up on the surface of the soil under burnt plots compared to unburnt ones. Soil organic carbon was considered at two soil depths (0-10cm and 10-20cm) in this part. More soil organic carbon under 5-year burn and no burn treatment than under other burn treatments were anticipated. Soil organic carbon did not decrease with soil depth as expected under 1-year burn, 2-year burn and 3-year burn at 0-10cm soil depth. An increase in organic carbon with increasing burn interval was observed from 2-year, 3-year, 3-year, 5-year and no burn treatments at 0-10cm soil depth. Conversely, soil organic carbon decreased with increased burn interval at 10-20cm soil depth; however, the difference between treatments was not significant. Little information exists on fire’s effect on sites that received long term burning and later protected from burning.

7.4.4 Correlations

This finding was not expected because under normal circumstances, BMC would increase with an increasing concentration of available organic matter from litter material. The reason for this effect could be that the litter material was less suitable as a microbial substrate. Physiological stress such as drought and rewetting could affect microbial biomass and the associated activities. On this matter Wagener and Schimel (1998) point out that dry condition make litter layer unsuitable habitat for a number of soil faunal groups. This limits microbial activities. More studies could be helpful to explore potential bases for the findings reported by this study.

7.5 Conclusion

The main objective of this study was to investigate the potential long-term effects of burning, grazing and browsing on selected components of organic matter such as grass litter biomass, soil organic carbon and microbial biomass carbon.

The study tested the following hypothesis:

(i) Long-term burning have effects on grass litter biomass, soil organic carbon and microbial biomass carbon hence, hydrologic functioning and nutrient recycling on a site

(ii) burning, grazing and browsing by goats have differential effects on grass litter biomass, soil organic carbon and microbial biomass hence hydrologic functioning and nutrient recycling of a site.

(iii) burning followed by ten-year period of fire exclusion have effects on grass litter biomass, soil organic carbon and microbial biomass carbon hence, hydrologic functioning and nutrient recycling on a site

This study has shown that long-term burn treatments have inconsistent effects on grass litter biomass, soil organic carbon as well as microbial biomass carbon. Burning, grazing and browsing by goats have differential effects on grass litter biomass, soil organic carbon and microbial biomass carbon. Burning followed by ten-year period of fire exclusion has effects on grass litter biomass, soil organic carbon and microbial biomass carbon.

Thorough their effect on grass litter biomass, soil organic carbon and microbial biomass carbon long-term burning frequency, burning, grazing and browsing as well as long-term burning followed by ten-year period of fire exclusion could affect hydrologic functioning and nutrient recycling on a site. A summary of conclusion is presented in Table 7.1.

Table 7.1: Summary of long-term burning, grazing and goats browsing and long-term burning followed by fire exclusion for ten years, effects on grass litter biomass, soil organic carbon (SOC) and Microbial biomass carbon (BMC)

Vegetation characteristics	Fire frequency effect	Burning, grazing, and goats browsing effects	Burning followed by fire exclusion for ten years
Grass litter biomass	Burn frequencies had inconsistent effects on litter biomass. Litter biomass more under less frequently burnt plots (6-year burn and 4-year burn) and no burn.	Grass litter biomass more reduced under grazing and follows up burn	5-year burn increased grass litter biomass. 1-year, 2-year and 3-year burns reduced biomass litter.
Soil organic carbon (SOC)	Inconsistent effect under different soil depths. Decreased with soil depth under. 6-year burn had highest SOC at 0-10cm soil depth and lowest SOC at both 10-20cm and 20-30cm soil depths.	More under goats browsing at all soil depths. Reduced under control and grazing at both 10-20cm and 20-30cm soil depth	Burning reduced SOC at all soil depths. SOC decreased with soil depth.
Microbial biomass carbon (BMC)	Inconsistent effect between treatments. BMC More under 3-year burn at 0-10cm soil depth. Lowest under no burn at 10-20cm soil depth.	BMC increased under grazing and was Lowest under control. More BMC under goats browsing at 10-20cm soil depth. B MC more reduced under follow up burn and goats browsing at 20-30cm soil depth.	No measured

8 General discussion and conclusion

8.1 Discussion

This chapter discusses findings of long-term effects of fire, grazing and goats browsing on characteristics of vegetation and organic matter. The study sought to establish if these biological and physical characteristics have potential to influence functionality of selected rangelands ecosystem ecological processes such as biological community integrity, site stability, productivity and plant vigour and hydrologic function and nutrient cycling.

8.1.1 Biological community integrity

In this study burning, grazing and goats browsing did not seem to have effects on grass species richness; burning frequencies did not produce deferential effects either. On the contrary, this trend was not maintained when fire was excluded for ten years from a site that received prolonged fire treatment. After ten-year period of fire exclusion fire reduced grass species richness. Even though the difference in species richness was not significant between burn treatments, the richness was relatively maximized under 3-year, 4-year and 6-year burn treatments compared to under short burning intervals (1-year and 2-year). The results suggest that short burning intervals could hamper species richness. These results approximate the findings reported by Peterson and Reich (2007) who found high species richness under intermediate burns (3-5 years). The results imply that biological community integrity could be maximized at intermediate burn frequencies.

Reduced richness of woody species by fire did not exhibit consistent trends in this study. This inconsistency was maintained even on sites that had fire treatment removed following prolonged subjection to burning. On both occasions species richness for woody species was relatively more under three year burn. The findings suggest that woody species richness could be maximized by burning a site after every 3 years. The findings of this study also suggest that fire effect on woody species richness could not be markedly reversed when fire is excluded from a site that received long-term burning. Through its effect on richness, burning has potential to influence biological community integrity. The study also suggests that burning, grazing and browsing do not have differential effects on woody species richness. It is important to consider that species response to disturbances is governed by a number of factors including their life history and physiological traits and by the characteristics of the disturbance (Gómez Sal *et al*. 1999).

Grasses as well as woody species respond differently from disturbances, in this study *D.eriatha*, *C.plurinodis*, *S.fimbriatus*, *P.stapfiana* and *T.triandra* botanical composition was maximized under different burn treatments, grazing and goats browsing. *Heteropogon contortus*, *S.incrassata* and *D.milanjiana* propotions were consistently maximized on a site that was previously exposed to long-term fire treatment. *Acacia karroo* botanical composition was maintained under different burning frequencies, burning and fire exclusion, grazing and goats browsing. These effects suggest that these species are resilient to disturbances by fire, grazing or goats browsing or disturbances were not extensive enough to retard existence of these species. The findings reaffirm that plant species respond differently to disturbances. In support of this, Gill (1975) reports that the effect of fire on a site vary depending on species composition, amount of herbage present, season of the year, frequency and intensity of burn, and post fire grazing management.

8.1.2 Site stability

Disturbances of sufficient magnitude on a site that affect vegetation could ultimately result in depletion of the plant cover, soil exposure to erosion, reduction of soil organic matter and nutrient content and the deterioration of soil structure Sánchez (2002). Burning, grazing and goats browsing as well as different fire frequencies did not have differential effects on vegetation characteristics such as basal cover, tuft to tuft distance, tufts diameter, canopy distance and stem to stem disturbances. In this study, high basal cover values were inclined towards frequently burnt plots (1 year, 2-year and 3-year burn) as opposed to intermediate burns (4-year and 6-year burns). These results are in agreement with the finding reported by O' Connor (1985). In addition, Canfield (1941) points out that basal cover is considered more important than canopy cover and foliar cover because it is more stable from year to year and changes less due to climatic fluctuation or utilization by grazing animals.. This could mean that lenient long-term burning; grazing and goats browsing have potential to sustain stability on a site. Burning had effect on standing dead grass biomass. Biomass of standing grass was more reduced under short interval burns. Also, on a site that was previously exposed to long-term fire treatment at different frequencies and fire exclusion for ten years, burning had more reduced standing dead grass biomass under frequently burnt plots. The implication of these findings is that short interval burns could have long-lasting effects on the built-up of grass biomass on a site hence, site stability.

8.1.3 Productivity and plant vigour

Healthy rangeland ecosystem is very efficient in utilizing available energy and water resources in the production of maximum biomass, forage production for livestock and wildlife and consumable products for all life forms (Adams *et al.* 2003). The general increase in decreaser species by fire is a testimony that burning is required to sustain grasses of high grazing value for livestock. This implies that burning (especially 2-year and 3-year burns) could improve site productivity by enhancing proportions of decreasers on a site. However, fire decreased percentage of decreaser species on a site that was previously burnt at different frequencies and ultimately fire treatment removed for ten years. The results reported here about decreasers are fair because in a situation where a site is protected from fire or grazing, decreaser species tend to decrease in proportion. This implies that defoliation of a site by either grazing or burning is needed to enhance quantity of grasses with high grazing value.

The findings of this study indicate that browsing by goats could surpass other treatments in reducing tree height as well as total canopy volume. Reduction of height of woody species by fire renders species reachable by animals and thus, browseable. According to the findings of this work plant height decreases with an increasing frequency of burn. Exposure of woody plants to different burning frequencies that resulted in noticeable reduction in sprouts diameter, canopy diameter, main stem diameter and canopy height under 1-year, 2-year and 3-year burns could be ascribed to interval of burning. Short burning intervals seem to be able to curtail the general physiognomic structure of woody species and render them available to animals. Components of physiognomic structure such as plant height, canopy height, canopy diameter and main stem diameter that were reduced by fire on a site that received long-term fire treatment and subsequent fire excluded confirm that fire effects could be long-lasting and uneasy to reverse. This study demonstrated that three year burn maximize sprouting than other burn frequencies. This pattern was also maintained on a site that was previously subjected to prolonged fire treatment and subsequently fire removed. All these could be attributed to frequency of burn. Under frequent burning small individual woody plants are often killed by fire or fail to grow to larger size. In support of the reported findings, Rebertus *et al.* (1993) advance that sprouts could remain indefinitely in a reduced non-reproductive stage by frequent burning. This could mean that 3-year burn maximize sprouting of woody species hence vitality.

8.1.4 Hydrologic function and nutrient cycling

Rangeland ecosystems store, retain and release water and make it available for plant growth and other organisms, they also conserve and recycle nutrients and render them available to plants. From this study, burning frequencies did not produce constant results on litter biomass; however biomass litter was highest under 6-year burn. The same pattern was exhibited on a site that was subjected to burning followed by ten-year period of fire exclusion. In this site litter biomass was more under 5-year burn than other burn treatments. This effect could be ascribed to the fact that grass leaves and tussocks were spared from burning for a longer period of time compared to under shorter burning intervals. According to findings of this study, burning after 4 year intervals allows litter accumulation and this could influence how water moves in the soil.

In majority of soils, C is held as soil organic carbon (SOC), soil organic carbon' refers to the C occurring in soil organic matter (SOM). Soil organic carbon is important for the functioning of the ecosystem and also has a major influence on the physical structure of the soil, the soil's ability to store water (water holding capacity), Loss of SOC can, therefore, lead to a reduction in soil fertility, land degradation and even desertification (Nelson & Sommers 1982). Even though burning had effects on SOC, the trends between different burn frequencies were not consistent, lack of inconsistency between burn treatments pertaining to SOC content at different soil depth on a site that was under prolonged fire treatments and fire exclusion for ten years was also portrayed in this study. These findings are not easy to explain because correctly interpreting depth of burn generally requires knowledge of pre-fire condition and post-fire management of a site. More reduced SOC at 0-10cm under 4-year burn could lead to reduction of microbial activities. According to Thurlow and Ruf (1999), a direct effect of poor SOC is reduced microbial biomass, activity, and nutrient mineralization due to a shortage of energy sources.

In this study, inconsistencies regarding effect of burning frequencies on Microbial Biomass Carbon (BMC) across soil depths could be attributed to a number of factors including depth of burn and soil organic carbon (SOC) quantities. Wade (1986) reports that depth of burn could be influenced by the moisture and porosity (compactness) of the floor. In addition to this, Wade (1986) state that moisture in the floor has to be evaporated before the layers can be heated to ignition temperature. Therefore, the moister the floor is and the more compressed the litter is, the poorer the floor will burn (Wade 1986). Soil organic carbon quantity was among the highest under 3-year burn in this study. Soil organic carbon is the main source of energy for soil microorganisms. This implies that under 3-year burn, there was supply of substrate for microbial population hence BMC. The finding lead us to infer that fires can affect biological and physical characteristics on a site by transferring heat into soil and indirectly by changing vegetation and the dynamics of nutrients and organic matter. Though, high soil temperatures can kill soil microbes, destroy soil organic matter and alter soil nutrient and water status. Alexander (1982) reveals that the degree of soil heating during fire depends on a variety of factors, including fuel characteristics, fire intensity and residence time, and properties of the soil and litter layer.

8.2 Conclusion

The objective of the study was to investigate long-term effects of perturbations of a site by fire, grazing and browsing on characteristics of the vegetation and organic matter and determine whether such effects could influence selected rangelands ecosystem ecological processes. The study has demonstrated that long-term perturbation of rangelands by burning, grazing and browsing have effects on vegetation characteristics and organic matter. The study has shown that through their effect on vegetation characteristics and organic matter, burning, grazing and goats browsing could have subsequent effects on selected ecological processes of the rangeland ecosystem such as biological community integrity, site stability, productivity and plant vigour and hydrologic function and nutrient cycling. From this study, it is clear that burning effects on a site could be long-lasting and sometimes irreversible. Long-term burning frequencies, burning, grazing and goats browsing as well as long term burning followed by fire exclusion for ten years effects on vegetation characteristics and organic matter are summarized in Table 8.1 under biological community integrity, productivity and plant vigour, site stability, hydrologic function and nutrient cycling (selected rangeland ecological processes). Through its effect on grass and woody species richness, botanical composition and species diversity, burning, grazing and goats browsing as well as long burning followed by fire exclusion for ten years could have consequent effect on biological community integrity which is an important ecological process of the rangeland ecosystem.

Table 8.1: Long-term burning frequencies, burning, grazing and goats browsing as well as long term burning followed by fire exclusion for ten years: effects on vegetation characteristics and organic matter

Treatments	Effects Increase effect	Decreasing effect	No differential effect/inconsistent effects
	1. Fire frequency effect		
• **Biological community integrity**	Increased species composition percentage for *S.fimbriatus*, *D. eriatha*, *C. plurinodis*, *T.triandra*, *A.Congesta*, *P.stapfiana T.triandra* , *R.lucida*, A.karroo and *E.rigida* species composition percentage increased with frequency of burn.	*E. curvula*, *E.obtusa*, *M.decumbens S.africanus*, *G.occidentalis M.heterophylla* and *M.decumbens* species composition percentage decreased with frequency of burn	No differential effect on grass richness as well as grass and woody plant diversity. No differential effect on species composition for *D.eriatha*, *C.plurinodis*, *S.fimbriatus*, *A.karro* and *E.rigida*.
• **Productivity and plant vigour**	Increased decreasers and increaser II species proportions Burning reduced grass yield, total canopy volume, tree height, canopy height main stem diameter and sprouts diameter.		Inconsistent effects on sprouting of woody species
• **Site stability**	Standing dead grass biomass more under 6-year burn		No differential effect on basal cover, tuft to tuft distance, tufts diameter, canopy distance, stem to stem distance
• **Hydrologic function and nutrient cycling**	Litter biomass more under 6-year burn		Inconsistent effects on litter biomass, SOC and BMC

2. Burning, grazing, and goats browsing effects

Biological community integrity	Grazing increase woody species diversity	Increased percent species composition for *C.rudis, G.occidentalis, R.lucida, S.myrtina* and *X.rudis*	No differential effect on both grass and woody species richness as well as grass species diversity. No differential effects on species composition percentage for *C. plorinodis, D.erientha, forbs, P stapfiana, S.fimbriatus, T.triandra A. karroo* and *E.rigida*
Productivity and plant vigour	Follow up burn increased proportion of decreasers and few decreaser II species Follow up burn induced sprouting	Goats browsing and burning reduced canopy height, canopy diameter and main stem diameter. Goats browsing reduced total canopy volume and sprouting than other treatments. Goats browsing and burning reduced plant height than grazing and control	
Site stability			No differential effect basal cover, standing dead grass, tuft to tuft distance, tufts diameter, canopy distance and stem to stem distance
Hydrologic function and nutrient cycling	goats browsing increased SOC at all soil depths grazing increased BMC at 0-10cm soil depth than other treatments	grazing and follows up burn reduced grass litter biomass than control and goats browsing	No consistent effect on SOC and BMC between treatments at different soil depths

3. Burning followed by fire exclusion for ten years

Biological community integrity	Increased species composition percentage for A.karroo	Reduced grass richness Reduced /excluded *T.sericea, C.adenogonium, C.glabrum, F.indica, B.discolor, S.birrea* and *gardeniifolia* (were present on plots protected from burning only). Decreased both grass and woody species diversity	Inconsistent effect on woody species richness No differential effects on species composition for *A.karroo, S.incrassata, H.contortu and D.milanjiana*
Productivity and plant vigour	Increased number of sprouts under 3-year and 5-year burns Increased percentage of decreasers under no burn and 5-year burn	Decreased proportion of decreaser species under 1-year, 2-year and 3-year Reduced total canopy volume, plant height, canopy height, canopy diameter and main stem diameter Decreased percentage of increaser II species under no burn and 5-year burn	Inconsistent effects on diameter of sprouts
Site stability	Increased tuft to tuft distance	Decreased quantity of standing dead grass biomass	No differential effects on tufts diameter, canopy distance, stem to stem distance

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