EFFECT OF *ACACIA KAROO* ENCROACHMENT ON GRASS PRODUCTION IN THE SEMI-ARID SAVANNAS OF THE EASTERN CAPE, SOUTH AFRICA.

BY

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A Dessertation Submitted in Partial Fulfilment of the requirements for the

Degree of Masters Agriculture (Pasture Science)

Department of Livestock and Pasture science

Faculty of Science and Agriculture

At the University of Fort Hare

2016

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DECLARATION

I declare that "**Effect of *Acacia karoo* encroachment on rangeland productivity in the semi-arid savannas of the Eastern Cape, South Africa**" is my original work conducted under the supervision of Prof S.T. Beyene and it has not been submitted to any university. All the references cited in this dissertation have been properly cited.

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Prof. S. T Beyene (Supervisor)

January 2016

ABSTRACT

The objectives of this study were (1) to investigate the influence of individual *A. karroo* on soil and grasss layer. (2) to investigate the effect of *Acacia karroo* encroachment levels (open, moderate and severe) on the grass layer in semi-arid communal grazing lands. The first study was conducted at the University of Fort Hare farm located in Alice in the Eastern Cape Province, South Africa. A total of thirty *A. karro* plants were selected randomly, of which ten trees each having sizes of (>1.5m – 2m, >2 – 2.5m or > 2.5m). Two transects radiating out of the tree trunk to open grassland were marked at each woody stand in the north and south directions. Each transect was divided into two sub-transects to represent the under canopy and outside canopy zone. In each sub-transect, two 0.5 x 0.5 m quadrat was laid to record all vegetation and soil data. The tuft diameter of *C. plurinodis* was significantly ($p<0.05$) smaller on the open habitats of >1.5m – 2m trees. Tuft diameter of *Sporobolus africanus* was significantly ($p<0.05$) smaller under canopies of >2m – 2.5m trees in winter. Tuft diameter of *Themeda triandra* was significantly lower in the open habitats of >1.5 m – 2m trees in summer. The grass biomass production was significantly ($p<0.05$) lower under the canopies and open habitats of >1.5m – 2m stands in winter than summer. Soil organic carbon content was significantly ($p<0.05$) lower under canopy and open habitats of >1.5m – 2m trees. The second study was conducted at Melani communal village which is located approximately 12 km North of Alice Town. Three encroachment sites were selected namely severe (3650 trees/ha), moderate (2521 trees/ha) and open (250 trees/ha). A total of 16 grass species were identified of which 15 were perennials. Grass biomass production was affected ($P<0.05$) by encroachment being lowest at open sites. T. *triandra* dominated the moderate and severe encroached sites whereas *Digitaria eriantha* dominated the low encroached site. Overall decreaser grass species increased with the increase in encroachment levels. On the other hand, the increaser II grass species such as *S. africanus* and

Microchloa caffra dominated the open site showing that their abundance decreased with the increase in tree density. In terms of height, grass species at the open site were shorter ($P<0.05$) than the moderate and severe encroached sites. Basal cover improved with the increased encroachment levels. Grass biomass production was affected ($P<0.05$) by encroachment being lowest at open sites. *A. karroo* improves grass production. Grass layer improves under tree canopies with the increase in *A. karroo* up to a point where *A. karroo* suppresses grass growth. The more palatable grass species occurred under canopies than open habitats. *T. triandra* was dominant under tree canopies than open habitats. The grass biomass production and basal cover improved under canopies than open habitats.

Key words: Grass species, overgrazing, soil nutrients, basal cover, dry matter

DEDICATION

This dissertation is dedicated to my parents, father (Roy Rooi Magandana), mother (Nofezile Magandana), my grandmother (MaDlomo) and my son (Bulumko).

ACKNOWLEDGEMENTS

I would like to thank National Research Foundation (NRF) and Research Niche Area (RNA) for funding the first year of this research. I would like to thank Prof Beyene for his supervision. I am grateful to Prof Muchenje and Dr Mopipi for their support throughout the research project. I am thankful to the technicians of the Department of Livestock and Pasture Science Mr Monwabisi Wellington Sibanga and Mr Mweli Nyanga for their assistance during data collection. Many thanks go to the community of Melani Village for allowing me to conduct my research on their rangelands. I would also like to extend my heartfelt thanks to my colleagues Thando Ntutha; Sinethemba Matshawule; Sive Tokozwayo; Siphamandla Huza; Sanele Mpongwana; Odwa Ngcofe; Sibusiso Nxele; Yonela Maziko; Ntomboxolo Mamayo;Akhona Ndandani who were always there to assist me during data collection. I would like to thank my family for supporting me throughout this journey especially my parents. Above all I give a special thanks to the one above "God" who made this possible.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
EDTA	Ethylenediaminetetraacetic acid
DM	Dry matter
ICP	Inductively Coupled Plasma
SAS	Statistical Analysis System
KCl	Potasium chloride
GLM	General Linear Model
S.E	Standard Error
TE	Tree Equivalents
OC	Organic Carbon
N	Nitrogen
P	Phosphorous
K	Potassium
Mg	Magnesium
Ca	Calcium
Na	Sodium
Zn	Zinc
Cu	Copper
Mn	Manganese
Fe	Iron

CHAPTER 1. INTRODUCTION

1.1 Background

Vegetation assessment indicates that woody plants encroachment which is often referred to as bush encroachment) has been widespread on many semi-arid grasslands and savannas of Southern Africa resulting in a decline of rangeland productivity and ecosystem services (Hudak and Wessman, 2001; Tefera *et al.*,2008; Wigley *et al.,* 2009). Bush encroachment can be defined as the increase in density, cover and biomass of indigenous woody or shrubby plants (Van Auken, 2009). The causes of such encroachment have been debated for many years, and are still a subject of controversy. Researchers report that anthropogenic activities including high cattle densities are the primary cause of bush encroachment (Moleele, 2005). The increase in the woody cover coincides with the introduction of grazers in Southern Africa (Moleele, 2005).

The areas which are being overgrazed tend to be dominated by the shrub-tree element (Low and Rebelo, 1996). Others argued that bush encroachment is a natural phenomenon which is prompted by irregular exceptional events, such as periods of high rainfall which leads to high shrub density (Belay and Moe, 2012). The reason why the root niche separation is not accepted by some researchers is because the seedlings of trees and the grasses use the very same subsurface layer of soil and water while the trees are in their sensitive stages of growth (Moleele, 2005). The cattle density is directly involved in the increase of tree density through seed dissemination (Drewer *et al*.,2002).

Semi-arid rangelands in Eastern Cape province of South Africa cover vast area and have huge potential to produce livestock and other indigenous natural products (food, feed and ornamental plants), but this is limited by the heavy encroachment of *Acacia karoo* on large part of the grazing lands. *Acacia karoo*, a multi-stemmed woody plant, has been observed encroaching

grazing lands subjected to heavy grazing pressures and abandoned crop lands (Solomon and Mlambo, 2010). Some communal farmers in the Eastern Cape perceived that this species causes land degradation, and has generally impacted their livelihood (Libala, 2015).

Many researchers and ecologists viewed that woody plant invasion is an indication of range degradation, loss of land productivity, economic returns and livelihoods, while others still maintain the view that there are some ecological advantages associated to it. The former (e.g. Van Auken, 2009) argued that woody plant proliferation may reduce grass formation, cover and production. Invasion also reduces plant and animal's diversity to the risk of extinction (Gaertner *et al*., 2009), alters ecosystems functions and services (Belay and Moe, 2010). Indeed, the effect of this encroaching species on the rangeland ecosystems services and functions has remained debatable.

Therefore, any intervention to sustainably use the rangeland resources and optimise goods and services requires understandings of the impact of the encroaching species on the rangeland ecosystem components including the grass layer and the soil. Four major sites that represent heavy, moderate, light encroachment and open grasslands were selected. Data on herbaceous species composition, diversity, forage production, and soil characteristics were collected under the tree canopies and open habitats.

1.2 Problem statement

Communal farmers depend on the natural veld for year round grazing of their animals. However, the encroachment of the grazing lands by woody plants may limit the availability of forages and grazing lands for the animals. *Acacia karoo* is one of the dominant encroaching species in the Eastern Cape communal lands. In this leguminous tree, under canopy and sub-canopy habitats may provide less favorable environments for the growth of grasses than in open grassland and the effect may also depend on the density of the woody plants. However there is no adequate studies that have investigated the effect of individual *A. karroo* and its density on grass production.

1.3 Justification

This study examined the nutrient composition of the soil occurring under these trees. Therefore, there is a need to study the effect of *A. karroo* on the quantity and quality of forages, species abundance and on life stage of the herbaceous vegetation that grow under these trees. Studies to investigate the effects of these woody plants on the physical and chemical soil properties are also needed. There is also a need to investigate the threshold density of the woody plants beyond which they will have a negative impact on the rangeland ecology and livestock production.

The study provided information on the optimum density of *Acacia karroo* that can be maintained to the benefit the ecosystem services and functions including ecology sustainability and livestock production. The study examined how individual woody plant influence the vegetation diversity and structure as well as the soil organic carbon, and other soil nutrients that are important for plant growth. This study provided information about the positive and negative impact of *Acacia karroo* density on soil and grass layer.

1.4 Objectives of the study

1.4.1 The general objective of this study was to investigate the ecological and agricultural impacts of woody plant encroachment on semi-arid rangelands of South Africa.

1.4.2 Specific objectives

- To investigate the effect of individual *A. karroo* on the grass layer and soil nutrient content.
- To investigate the influence of *A. karroo* density on grass and soil layer in communal rangelands.

1.5 Research question

- What are effects of individual *Acacia karroo* trees and their density on grass layer biomass production and soil chemical properties?

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CHAPTER 2. LITERATURE REVIEW

2.1. Introduction

The phenomenon whereby the woody plant density and cover increases in abundance is referred to as bush encroachment (O'Connor and Crow, 1999). Bush encroachment is mainly associated with savanna biomes as it involves woody species such as *Acacia karroo* that occur in their natural environment (Smit, 2004). The term Savanna was once restricted to describe grasslands in Spanish but is accepted as a description of vegetation with the herbaceous layer that is dominated by grasses with an upper layer of woody species which might vary in densities (Edwards, 1983; Rutherford and Westfall, 1994). According to Rutherford and Westfall (1994) savanna biome of southern Africa extends from north of 22^0S into the northern Namibia, Mozambique, Botswana and South Africa. Savanna ecosystems are home to all livestock and most ungulates.

Where there is limited moisture available, bush encroachment can be considered as a major factor leading to low occurrence or absence of herbaceous plants (Smit et al., 1999). The grazing capacity of the rangelands can also be affected by the increase in bush density, to such an extent that many previously economic livestock properties are now no longer economically feasible (Smit, 2004). The removal of some or all the trees can normally lead to an increase in grass production and cover and thus increase the carrying capacity of the veld (Teague and Smit, 1992). However, the removal of the trees may give different results depending on the type of the vegetation and these may have negative or positive responses (Teague and Smit, 1992). Studies conducted in the semi-arid savanna of east Africa show an increase in grass production and soil fertility under tree canopies than in open areas (Ludwig et al., 2004).

Grazing livestock depend on the maintenance of high quality and abundant grass in the system, therefore there should be more grass than the trees. The mechanisms underlying the maintenance

of the tree-grass savanna are still poorly understood. In this study we outlined the positive and negative effects of *A. karroo* encroachment on our rangelands.

Increased tree sizes in terms of heights and diameters can reduce the biomass of the grass layer in the savanna rangelands which leads to decreased livestock production (Archer et al. 1995: Kraaij and Ward 2005; Bond 2008; Wigley *et al*. 2009; Burkinshaw and Bork 2009). For the management of the savannas to be effective, the causes of the woody encroachment must be understood. Some of the factors that contribute to woody encroachment are rainfall, herbivory, nutrients and fire and are basic variables of tree and grass balance in the savanna rangeland (Sankaran et al. 2004; Ward 2005; Wiegand et al. 2006). According to Mbatha and Ward (2006), herbivores may have a direct negative impact on woody plants through trampling and the grazing and are the most common factors associated with bush encroachment. Herbivores that are grazers may reduce the ability of the grass to compete with trees (Kraaij and Ward 2006; Riginos 2009; Goheen et al. 2010).

2.2 Causes of bush encroachment

It is argued that bush encroachment results from the increase in the biomass of the already established woody plants and/or from the increase in the number of woody plants through the germination of new seedlings (Smit, 2004). The causes of bush encroachment in the semi-arid rangelands of Africa are diverse and complex. These include overgrazing, soil related factors climate change and fire suppression. These drivers may either be primary (climate and soil) or secondary (fire and the effect of herbivores). Fire and the impact of herbivores are of special interest although they are also affected by the constraints caused by climate and soil they can be modified directly by the management (Smit, 2004). The absence of occasional hot fires, the use of domestic livestock at high stocking rates instead of indigenous grazers and browsers, poor

grazing management practices, the restricted movement of herbivores by fences and the use of manmade watering points (Smit et al., 1999).

2.2.1. Overgrazing

The general understanding that bush encroachment occurs after the removal of grasses through overgrazing is simplistic and may not be regarded as the general explanation of the increase in bush density (Ward, 2005). The manner in which the rangeland is managed may have an impact that may unintentionally lead to bush encroachment (Mampholo, 2006). The removal of game animals and replacement by domestic livestock which are largely grazers at high stocking densities, poor grazing management of grazing livestock and the use of man-made watering points led to increased woody plant densities (Smit *et al.*,1999). Africa was previously dominated by ungulates which were largely herbivory in nature and these were capable of modifying the woody structure of the rangelands (Owen-Smith, 1989). The replacement of browsing game ungulates by domestic animals might have contributed to the problem and increased bush density in the savannas of Africa (Smit, 2004).

Poor grazing management is severe during dry seasons and this puts stress on grass growth than on tree growth during periods of water stress (Smit, 2004). It is believed that high grazing pressure reduces the rate at which the individual plants grow and also affects their reproductive potential and in so doing the competitive relationship among the different species is influenced (Smit, 2004). However, in part of East and southern Africa short grazing lawns occur and they maintain high productivity under heavy grazing pressure (Bond. 2003). Prolonged overgrazing can indirectly influence the occurrence of fire due to reduced fuel load (Smit, 2004). Woody plants exploit water and soil nutrients when the land is overgrazed due to the removal of the grass by the grazers (Smit, 2004). Overgrazing is the major cause of bush encroachment in the

eastern areas of Botswana and South Africa (Smit, 2004). Long-term or heavy grazing is the requirement for establishment of higher densities of woody plants (Smit, 2004). Before the introduction of high number of domestic animals savannas of Africa were previously dominated by high levels of ungulates which are browsers and grazers and these are capable of modifying the composition and woody structure of the plants (Owen-Smith, 1989). Amongst the causes of bush encroachment is the removal browsing ungulates (Smit, 2004). In a study that was conducted in north-east of Swaziland it was suggested that bush encroachment was promoted by the high grazing pressures through their effect on fire frequency (Roques et al. 2001). The woody cover is also affected by whether the woody plants are palatable or not and this will determine the browsing pressure as the animals will also control the level of bush encroachment through browsing. In a study that was conducted in the semi-arid grasslands of the southwestern USA increased grazing pressure lead to more woody cover (van Auken 2000).

2.2.2 Fire

Literature has considered fire as one of the determinants of increased woody plant density (Higginns *et al.,* 2000 and Bond *et al*., 2003). The structure of the woody layer may be modified using veld fires as the veld fires are found to be useful (Smit, 2004). The total exclusion of fire in most cases leads to increased density of woody plants (Smit et al.,1999). In a number of semi-arid and arid ecosystems fire promotes the occurrence of invasive species (Pyke & Knick, 2003). Lack of managed veld fires for a very long period of time or their prevention and the lack of periodic, hot, brush-killing fires contribute to increased woody plants density (Barac, 2003).

Fire has been described as the important disturber that limits the growth of seedlings into mature and taller trees (Higgins *et al*., 2000). Some evergreen macrophyllus thickets have been changed into savannas through the use of fire as a tool to control bush encroachment (Hoffmann et al.,

2003; Nangelo *et al.*,2006; Gignoux *et al*., 2009). The use of fire keeps the height of the trees in a level where the browsing herbivores can easily browse. However, fire suppression can result in taller trees with bigger girths hence escaping the effects of fire and browsing (Midgley and Bond, 2001). Where climate permits, trees owe their existence and growth to drivers such as fire and browsers (Sannkaran *et al*.,2005). In many researches that have been conducted in wet savannas fire suppression is followed by bush encroachment (Russell-Smith *et al.*,2003). Regional shifts in fire frequency and grazing pressure may lead to increase in woody cover of grasslands (Vick 2011). In central USA grasslands fire frequency has caused an increase in the abundance of woody species (Vick 2011) while in Africa the opposite is true with a fire frequency interval of less than 10.5 years may lead to woody cover increase (Sankaran et al. 2005).

2.2.3 Climate change

The climate of the earth was cooler two million years ago than it is today (Martin, 1999).The interglacial which started about 12,500 years ago also played a role and is expected to last longer than the previous interglacials (Berger and Loutre, 2002). Plant communities around the world changed their distributions as the temperatures warmed the glaciers (van Auken, 2009). Plants migrated in the past with the warming up of the climate without the interference of man or animals (van Auken, 2009). The interglacial is expected to continue for another 50,000 years if the current warming trend continues (Berger and Loutre, 2002). The interacting factors and short period have made it difficult to link the vegetation changes to climatic changes over the past 160 years (van Auken, 2009). As the climate continues to get warmer, droughts are also expected to increase (van Auken, 2009). The type of biomass and the type of species that would be present in given area are determined by the management that is employed in a particular area (van Auken 2009).

The increase in atmospheric CO_2 has also contributed in the increase of bush density because the elevated levels of CO2 favour the growth of woody plants (O'Connor et al., 2014). The atmospheric CO_2 has been increasing exponentially since 1950s where it reached 12% above pre-industrial levels (O'Connor et al., 2014). The increase in atmospheric CO_2 levels is expected to cause more bush encroachment. The growth of C_3 versus C_4 plants serves as evidence that the increased levels of atmospheric CO_2 plays a role in bush encroachment (Bond and Migley 2012; O'Connor et al. 2014). The increased levels of atmospheric CO_2 lead to higher biomass of the roots which will cause a rapid regrowth of woody plants after the above-ground biomass was disturbed by factors such as fire (O'Connor et al. 2014).

There is evidence available to show that some C_3 taxa plants were replaced by a number of C_4 taxa plants during the past glacial periods while it was reversed during subsequent interglacials (Ehleringer, 2005). The increased levels of carbon dioxide favour the growth of C_3 plants which are mostly woody plants and the C_4 plants which are mostly grasses and are being replaced by these C_3 plants (van Auken, 2009). However, some grasses have C_3 photosynthetic pathway and the elevated levels of CO_2 in the atmosphere favours them and is present in the cool season grasses (Ehleringer, 2005). The long term elevated levels of carbon dioxide are probably dependent on the precipitation, temperature and disturbances (especially herbivory) and may have complex outcomes (Shaw *et al*., 2005).

2.2.4. Soil related factors

Soil clay content is negatively correlated with woody cover (Sankaran *et al*., 2005). Sandy soils with low clay content are likely to be affected by bush encroachment (Kgosikoma et al., 2012). High levels of nitrogen in the soil reduce the occurrence of bush encroachment, this is revealed on a broad-scale analysis of woody cover in African savannas (Sankaran et al., 2008).

Phosphorus levels in the soil have no linear relationship on the density of woody cover (Sankaren et al., 2008). However, contrary to what is mentioned above other researchers argue that the soil type has no significant effect on the shrub densities in African savannas (Roques et al., 2001). The ability of leguminous trees to fix nitrogen helps them to survive in poor environments (Kraaij and Ward, 2006). The seedlings depend on the cotyledons for their nutrient requirements during their first weeks of establishment (Kraaij and Ward, 2006). Grasses require the nitrogen for fast growth than the trees (Kraaij and Ward, 2006). It is predicted that the high levels of nitrogen in the soil enhances the growth of herbaceous plants which will then suppress the establishment and the growth of tree seedlings of leguminous trees (Moshe et al., 2000). Some woody species such as *Acacia mellifera* may grow on any soil type ranging from sandy soils to clay soils (Hagos and Smit, 2005). The soil depth also contributes to the extent of bush encroachment due to certain types of trees being more adaptable to the types of the conditions (Hugos and Smit, 2005).

2.3 Effects of bush encroachment

Several studies have shown that the trees have the competitive effect on grasses and vice versa (Sankaran et al., 2004 and Ward, 2006). Some species such as *Acacia karoo* naturally establish on disturbed soils (Boyes et al., 2010). The availability of nutrients for plant growth on the understory is facilitated by the trees (Ludwig *et al*., 2004). Some grass species grow under trees while other grass species prefer open grasslands in the savannas of South Africa (Ludwig *et al*.,2004). It is not easy to determine what exactly determines the grass productivity and species changes because trees affect water, nutrient and light availability on the understory vegetation (Scholes and Archer,1997). In a wide range of savannas soil has been reported to be more fertile under tree canopies (Ludwig *et al.*,2004). However, it is not clear how these islands under these canopies occur. Some researchers suggested that the trees through their roots take up water and

nutrients from the deeper layers of the soil to the top soil where they will be accessible to herbaceous plants with shorter roots (Ludwig *et al.,* 2004).

2.3.1 Effects of bush encroachment on species composition

The positive effects on the grass growth may be attributed to the fact that the soils under the canopies of the trees are enriched with the nutrients such as nitrates and phosphorus (Smit 2004). In a study that was conducted by Stuart-Hill et al. (1987) in the false thornveld of the Eastern Cape province of South Africa, it was concluded that the there was a consistent pattern of grass production under the canopies of *A. karroo* trees. In another study in South Africa it was concluded that where leguminous plants occur, the occurrence of palatable and potentially productive species such as *Panicum maximum* increase with an increase in the density of the trees up to a point where the density of the trees suppresses the grass through competition from trees (Smit 2004). Many studies have documented the occurrence of *P. maximum* in areas that are encroached by *A. karroo* (Schmidt et al. 1995; Durr and Rangel 2000). According to Kinyamario et al. (1995), *P. maximum* has less water requirements due to lower stomatal conductance and higher water use efficiency than grasses such as *Themeda triandra*, which grow in open land than under trees. This implies that where the woody plants are totally removed, the *P. maximum* will be affected in a negative way in its long term persistence (Schmidt et al. 1995). Some good and nutritious grasses e.g *Themeda triandra* prefer to grow on canopied sub-habitats and would be lost in the absence of these tree canopies (Smit 2004).

2.3.2 Effects of bush encroachment on biomass production

Biomass refers to the amount of above ground dry matter herbaceous material that is available for animal consumption and is expressed in kilograms per hectare ($kg.ha^{-1}$) (Abule *et al* . 2007). The amount of forage that will be available for animal consumption is measured using the

biomass of the forage and this helps in determining the carrying capacity of the veld and its condition (Abule *et al.,* 2007). The quality and the biomass production of the rangeland may describe the forage yield (Peden, 2005). Factors such as nutrients, moisture percentage, fibre content, and chemical substances found and all these vary with species (Lesoli 2008). A well-managed rangeland can be identified by the presence of more palatable than the less palatable species and the palatable species decrease with an increase in overgrazing (Morris and Kotze, 2006). The available moisture and nutrients influence the biomass production of the rangeland (Noellemeyer *et al.* 2006). Biomass production is higher in soils with high organic content and these are soils that are silt and clay dominated while the sand dominated soils have low organic matter (O'Farrel *et al.* 2007). The continuous removal of the leaves of the grass leads to the loss of grass vigour through the draining of the nutrient reserves (Malan and Van Niekerk, 2005). The biomass of herbaceous plants is removed by defoliation and it changes the light regime in a plant stand (Tomlinson and O'Connor 2005).

The plant will fail to produce new leaves when it is unable to replenish the stored resources, when this happens it will fail to produce new leaves and this will lead to reduction of photosynthetic power (Morris and Kotze, 2006). The competitive ability of the grasses is reduced when the number of grass roots in the upper layer of the soil is decreased due to death of desirable plant parts (Sisay and Baars, 2002).

The interactions between grasses and the trees in the savannas can be negative or positive (Lortie et al. 2004, Dickie et al 2005). The response whether positive or negative depend on numerous factors such as abiotic conditions, life stage, herbivory and the species involved (Robello et al. 2002; Riginos et al. 2005). In savannas herbivores are the major drivers of the dynamics of the vegetation (Riginos 2000). The herbivores can have contrasting effects on savanna rangelands

by reducing the abundance of trees, grass and forb species that they eat (Riginos, 2000). They can also modify the competitive interactions between the grass and trees by reducing the dominance of one or the other (Scholes and Archer 1997, Riginos 2000).

Some of the positive interactions between the trees and the grasses can be expressed in the presence of the herbivores where one species protect the other from herbivory (Riginos 2000, Rebollo et al. 2002). According to van Vegten (1984) and Robello et al. (2002), heavy grazing in the savannas of Africa is associated with bush encroachment, while the areas that are dominated by the wild ungulates such as elephants the opposite can be true (Dublin et al 1990, Western and maitumo 2004). *Acacia karroo* encroachment can have a negative effect on grass species and rangeland productivity (Schole and Archer 1997, dean et al 1999, Tobler et al. 2003). Woody encroachment is believed to be as a result of both direct and indirect mechanisms (Riginos 2000). Trees benefit from the reduction in browsing pressure when the browsers such as goats and wild ungulates are replaced by primary grazers such as cattle (Riginos 2000). The high tree density may have a negative impact in the protection of small herbivores such as goats from the predators (Riginos 2000). According to Riginos (2000), high density of trees reduces the amount of forage that would be available to animals for grazing while low tree density leads to higher forage production.

Wilson (1988), argued that the determinant of the botanical composition and the productivity of any of mature stand of vegetation is the competition. The primary competition which is said to be the determinant of production between woody plants and the herbaceous layer is soil water, and it has been reported globally (Smit and Rethman 1999; 2000; Richter et al. 2001; Smit 2004). The roots of the plants are a very important part of the plant that plays a role in the extraction of water and nutrients from the soil. The spatial distribution of water and nutrient

uptake is determined by the roots and can lead to the increase or decrease in the availability of resources (Wu et al. 1985; Smit 2004). In savannas, the roots can extend beyond the canopy radius (Wu et al. 1985). Rutherford (1980) argued that the lateral roots of some *Acacia* species can extend up to seven times the size of the canopy of the tree itself. The large proportion of the roots of the woody plants is largely concentrated on the top layer of the soil and that is where they compete with the herbaceous species (Smith and Rethman 1998).

2.3.3 Effects of bush encroachment on soil chemical properties

According to Smit (2004), nutrients such as nitrates, various trace elements, a series of anions and cations and phosphorus are very important for plant growth and their variations may affect vegetation composition, structure and productivity. Although base-richness of the parent material is of importance in the determination of soil fertility, biological activities are also important in the creation and maintenance of localized areas of enhanced soil fertility, mostly on base-poor substrates (Scholes 1991 and Smit 2004). Many researchers agree that tree canopies may create islands of soils that show differences from outside canopy areas in terms of soil chemical and physical properties. Significantly higher total nitrogen, organic carbon, Ca, K, Mg, and Na under the canopy compared to open areas were reported by (Smit 2004). In a study that was conducted in Zimbabwe it was found that *Colophospermum mopane* had positive effects on soil fertility (Mlambo et al., 2005). The mechanism and the source of soil enrichment that occur under the tree canopies remain unclear and require more investigation. One of the causes of soil enrichment that has been mentioned as the possible source is the leaf litter from leaf fall (Smit 2004).

2.4 Acacia karroo

Acacia karroo tree is a leguminous woody plant that is small to medium sized and it grows to a height of 12m where there is good water supply (O'Connor, 1995). It has a red bark on young branches and they darken with age. Its leaves have a fine texture and are dark green in colour. *A. karroo* grows very well in deep soils which allow roots to spread. It has a life span of 30 to 40 years and it is able to establish itself without shade or protection from grass fires(O'Connor, 1995). *Acacia karroo* species is widespread in southern Africa and has increased its density and has historically expanded its distribution within its original range (O'Connor, 1995). It displays a range of leaf and growth forms across its distribution range (Archibald and Bond, 2003). The increased density normally results in decreased biomass production in grasslands. The invasion of grazing lands by woody plants is a widespread incidence (Van Auken, 1993). However, one of the encroaching woody plants species in the Eastern Cape Province of South Africa is *A. karroo*. Successful dispersal, germination and seedling establishment is a pre-requisite for the rangeland to be encroached with the woody plant species (Van Auken, 1990). The rangeland is said to be encroached when the bush density is above 2400 trees/ha (Abate *et al*., 2010).

Apart from competition between *A. karroo* and grasses facilitation also occurs (Moustakas *et al*. 2013). However, many researchers have focused on the negative effects than positive effects. These trees improve grass production by facilitating the grass growth underneath their canopies (Moustakas *et al*. 2013). *Acacia karroo* has a capacity to fix N_2 because it is a leguminous tree especially at seedling stage, and it may contribute to their proliferation in the southern African savannas (Cramer *et al*. 2010). When the trees are at their seedling stage the competition between *A. karroo* trees and grasses may lead to suppression of the tree growth (Knoop and Walker 1985). In their study, Cramer et al. (2007) were not able to find the difference between

the competition on the above ground and the below ground parts of the *A. karroo* tree and therefore could not be able to determine the causes of grass-induced seedling growth reduction. According to Vitousek & Howarth (1991) and Sprent (1999), the competition for soil nitrogen between the tree seedlings and the grasses leads to suppression of the growth of the tree seedlings and increases dependence on carbon hungry nodulation. In the savanna vegetation, the leguminous trees are very important (Midgley and bond 2001). According to Cramer et al. (2007), the large proportion of tree flora fixes N_2 and it improves grass growth than the trees that are non-nodulating which then improves the tree-grass competition. The grasses that compete most with the trees are C_4 grasses (Le Roux et al 1995), and are able to maintain high photosynthetic rate which makes them powerful competitors in savanna rangelands.

2.5 Conclusion

Bush encroachment is mainly associated with savanna biomes as it involves woody species such as *Acacia karroo* that occur in their natural environment. The causes of bush encroachment in the semi-arid rangelands of Africa are diverse and complex. These include overgrazing, soil related factors climate change and fire suppression. These drivers may either be primary (climate and soil) or secondary (fire and the effect of herbivores). *Acacia karroo* may have positive effects, negative effects or on effects on rangeland grass production. This study examined the effect of individual *A. karroo* and its density on grass and soil layer.

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CHAPTER 3

THE EFFECT OF INDIVIDUAL *ACACIA KARROO* TREES ON GRASS AND SOIL LAYER IN THE SEMI-ARID SAVANNAS OF THE EASTERN CAPE, SOUTH AFRICA.

Abstract

The objective of this study was to investigate the influence of individual *A. karroo* on soil and herbaceous layer. The study was conducted at the University of Fort Hare farm located in Alice in the Eastern Cape Province, South Africa. A total of thirty *A. karro* plants were selected randomly, of which ten trees each having sizes of (>1.5 – 2m, >2 – 2.5m or > 2.5m). Two transects radiating out of the tree trunk to open grassland were marked at each woody stand in the north and south directions. Each transect was divided into two sub-transects to represent the under canopy and outside canopy zone. In each sub-transect, a 0.5 x 0.5 m quadrat was laid to record grass and soil data. The occurrence of *C. plurinodis* was significantly ($p<0.05$) higher (59.83%) under the canopy zones that are > 2m – 2.5m than trees that are > 2.5m (28.81%) and those that are >1.5 m– 2m (28.99%). The tuft diameters of *Cymbopogon plurinodis* were significantly ($p<0.05$) smaller on the open habitats of >1.5m – 2m trees. The tuft diameters of *Sporobolus africanus* were significantly ($p<0.05$) smaller under canopies of >2m – 2.5m trees in winter. The tuft diameters of *Themeda triandra* were significantly lower on the open habitats of >1.5 m – 2m trees in summer. Although the occurrence was higher under tree canopies it was lower under >2.5m trees than open habitats in both seasons. The grass biomass production was significantly ($p<0.05$) lower under the canopies and open habitats of >1.5m – 2m *A. karroo* trees in winter than summer. The >2 – 2.5m canopies had the highest biomass production than the >1.5 – 2m and > 2.5m trees. The carbon contents were significantly ($p<0.05$) lower under canopy (1.46%) and open habitats of >1.5 – 2m trees. Calcium content was significantly ($p<0.05$) lower (3.92 cmol(+)/kg) on the open canopies of >2.5m trees. The *A. karroo* trees had positive effects

on soil and herbaceous layer. The more palatable grasses were under canopies of *A. karroo* than open habitats. *Themida triandra* contributed to higher dry matter production under canopies. The canopies improved biomass and basal cover because of improved soil fertility.

Key words: Soil fertility, biomass, tree height, species composition, desirability ecological status.

3.1 Introduction

The contrasting life forms of grasses and woody plants that coexist together have been of greatest interest to ecologists for many years (Ward 2005). Many studies that look at the effect of trees on grass layer and vice versa have been conducted (Sankaran et al. 2004). Savannas are characterized by a grass layer that is continuous and a tree layer that is discontinuous. The savannas cover more than 20% of total earth surface and support a large proportion of wild herbivores and livestock (Sankaran et al. 2008). Woody plant cover in savanna ecosystem varies depending on various environmental factors such as rainfall and soil properties which are considered as the major drivers at large scale which in turn affect the plant to plant interactions at local scale (Sankaran et al. 2008).

The structure of the savanna rangelands is determined by the competition between grasses and trees (Sankaran et al. 2004). Woody plants and grasses compete for various resources such as light, water and nutrients. Several studies have demonstrated that grass yield decreases as tree density increases. In the studies that have been conducted the grass biomass has been found to be higher in habitats that occur under tree canopies than in open land (Durr & Range 2002). In certain savannas it has been reported that no differences in terms of biomass production and species composition have been found between grasses that grow under tree canopies and those that grow in tree interspaces (Ludwig et al. 2001). Currently the reasons for these responses are unclear.

Trees of the savannas can facilitate grass growth by altering the availability of resources and microclimatic conditions, and providing refuges from grazing. Trees create shade and they affect water redistribution in the landscape (Weltzin & McPherson 1997), and draw water that is inaccessible to plants through hydraulic lift (Belsky 1994 & Ludwig et al. 2001). The main

limiting resource in the semi-arid savannas is water (Sankaran et al. 2005). The biomass can increase under tree canopies due to hydraulic lift and increased nutrient contents below tree canopies (Treydte et al. 2008).

This study looked at the effects of individual *Acacia karroo* trees on soil and grass layer. Specifically, we looked at how the tree size and the distance from the base affected the grass production, species composition and soil nutrient composition. In the semi-arid savannas of the Eastern Cape we expected higher biomass production under the canopies of *A. karroo* than the open habitats.

3.2 Materials and methods

3.2.1 Site description

This study was conducted at the University of Fort Hare farm located in the Eastern Cape Province of South Africa. The study site was located at coordinates of $32^0$47´S and $26^0$52´E and an altitude of 550 m above sea level. The mean annual rainfall is 500 mm of which 70% falls between October and March. The mean minimum and maximum in summer and winter seasons are 17 ^{0}C and 28^0C, and 8^0C and 20 ^{0}C respectively. According to Mucina and Rutherford (2006) the vegetation is the Bisho Thornveld savanna characterized by the dominance of grasses and woody plants such as *A. karroo.* The study was conducted over two seasons (winter and summer) 2014 and 2015 respectively.

3.2.2 Study lay out and data collection

A total of thirty *A. karroo* plants were selected randomly in one of the camps that had been slightly grazed over extended period of years. Three tree height classes (> 1.5 – 2m, >2 – 2.5m and >2.5m) were selected each with ten individual plants. Two transects radiating out of the tree trunk to open grassland were established under each woody plant. The two transects represented

two directions (S-N). Each transect was divided into two sub-transects to represent the under canopy (0 – 2m) and outside canopy (> 2 – 4m). Two 0.5 m x 0.5 m (0.25m^2) quadrats were laid under each canopy and open zone to record vegetation and soil data.

3.2.3 Grass layer Data collection

Grass species were counted within each quadrat to determine grass species composition. Tuft diameter and height of individual grass plants were measured using a 30 cm ruler. After these measurements were done, plants within the quadrats were harvested and separated into grasses and non-grasses as well as at species level within grasses. Harvested samples were oven dried at 70 ^{0}C for 48 hours. Soil samples up to 20cm were taken using an auger within each quadrat at the time of plant data collection. The soil samples were placed in paper bags pending chemical analysis.

3.2.4 Soil chemical analysis

The soil was analysed at the Western Cape Department of Agriculture for pH (KCl), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), percentage carbon (C), calcium (Ca), magnesium (Mg), total nitrogen (N), potassium (K) and phosphorus (P). Total soil N was analysed using the standard Kjeldahl method using a block digester (Bremner and Breitenbeck, 1983). Soil P, Ca, Mg and K was determined using Inductively Coupled Plasma (ICP) analysis of extracts of soil with 1% citric acid (ALASA, 1998). Soil Zn, Cu, Fe and Mn were determined using ICP in 0.02 M Di-ammonium Ethylenediaminetetraacetic acid (EDTA) soil extracts (ALASA, 1998). Soil pH was determined using 1 M potatasium chloride (KCl) 2.5 KCl: 1 soil (ALASA, 1998).

3.2.5 Grass identification and classification

Grasses were identified in the field. Grasses were classified into desirability groups following the procedures of Tainton *et al.* (1980) and Vorster (1982). Accordingly, the species were grouped into (1) desirable grass species: those which occur in rangeland in good condition and increase when they are under grazed (Increaser I) (2) desirable grass species: those which occur in rangeland in good condition and increase when they are moderately overgrazed (Increaser II) (3) less desirable grass species: those which occur in rangeland in good condition and increase with severe overgrazing (increaser III) and (4) highly desirable species: those which occur in rangelands in good condition and decrease with overgrazing (decreasers). Grass species were also grouped according to their life forms, grazing value and their abundance. The data were collected during the winter season of 2014 and summer season of 2015. Only habitats were considered for species composition.

3.2.6 Statistical analysis

Mean differences were considered significant at $p< 0.05$. Both vegetation and soil data were subjected to analysed to analysis of variance by using the General Linear Model (GLM) of SAS (1999). Treatment means were separated using PDIFF option of the least squares means statement of the GLM procedure of SAS (1999). Mean differences were considered significant ap $P< 0.05$. Habitats (canopied or open zones) and seasons corresponded to independent variables whereas (DM yield, tuft height, tuft diameter, and soil nutrients corresponded to the dependent variables. No transformations were required to meet parametric assumptions for ANOVA.

3.3 Results

3.3.1 Species composition.

A total of 13 grass species were identified within canopy and open areas. All the grass species were perennial grass species. Of the identified species, six were decreasers, two were increaser III, one was increaser I and four were increaser II grass species. Seven of 13 grass species identified had high grazing value, five had low grazing value and one had the moderate grazing value.

Table 3.1 Life forms, ecological status, grazing values and % abundance of grasses in the study sites.

Species	Life Form	Ecological Status	Desirability	% Abundance
Aristida junciformis	Perennial	Increaser III	Low	0.1
Cymbopogon plurinodis	Perennial	Increaser I	Low	28.5
Cynodon dactylon	Perennial	Increaser II	High	2.0
Digitaria eriantha	Perennial	Decreaser	High	4.1
Eragrostis chloromelus	Perennial	Increaser II	Average	0.3
Eustachys paspaloides	Perennial	Decreaser	High	0.1
Microchloa caffra	Perennial	Increaser II	Low	0.2
Panicum maximum	Perennial	Decreaser	High	0.2
Setaria neglecta	Perennial	Decreaser	High	0.2
Sporobolus africanus	Perennial	Increaser III	Low	5.4
Sporobolus fimbriatus	Perennial	Decreaser	High	1.8
Sporobolus nitens	Perennial	Increaser II	Low	0.1
Themeda triandra	Perennial	Decreaser	High	57.6

3.3.2 Effects of habitat on abundance of common grass species.

The abundance of all the five common grass species that were above 2% are presented in table 3.2. No significant interaction effect was found between habitat and tree size and season for the variables measured. There was no significant difference in the abundance of *C.plurinodis* between the canopy zone and the open areas both in winter and summer seasons in all tree height classes. Similar results were found for *S. africanus* with its abundance under canopy and open areas showing significant difference. Season and height interact significantly, to influence the occurrence of *S. africanus* under the canopy habitats (Table 3.2). Although the statistical analysis showed the absence of significant difference in the occurrence of *C. dactylon* between the two habitats, this does not does not seem agreeable when mean values were assessed visually.

Accordingly, it appears that there was a great significance in abundance of *C. dactylon* between two habitat zones, and this was indeed influenced by both tree size and season. Accordingly, in summer, the abundance of *C. dactylon* was higher beneath the canopy habitat than outside for tree height classes of >1.5 – 2 m and > 2.5 m. In winter no *C. dactylon* was recorded in the open areas. In both seasons, under canopy habitat had highest abundance of *T. triandra* at young plants (> 1.5 – 2 m), but this changed when the plant matures (> 2.5m), where the under canopy habitat had the lowest abundance. The occurrence of *D. eriantha* in the open areas was higher

compared to beneath the canopy in young plants (> 1.5 – 2 m). This species was not recorded in the mature plants (> 2 m) in both habitats during winter. Only habitat was tested here.

Table 3.2 Effect of individual *Acacia karroo* on frequency occurrence (%)of common grass species.

		Summer		Winter	
Species	Tree size	Canopy	Open	Canopy	Open
C. plurinodis	>1.5–2m	29.0 ± 9.9[a]	33.0 ± 10.2[a]	39.0 ± 9.9[a]	43.1 ± 9.0[a]
	>2–2.5m	60.0 ± 10.5[a]	35.2 ± 11.3[a]	35.2 ± 9.9[a]	33.1 ± 9.9[a]
	>2.5m	29.0 ± 9.9[a]	27.4 ± 10.5[a]	26.2 ± 9.9[a]	12.5 ± 9.4[a]
C. dactylon	>1.5–2m	11.7 ± 3.8[a]	-	0.5 ± 3.8[b]	2.2 ± 3.4[a]
	>2–2.5m	0.01 ± 4.0[a]	0.60 ± 4.3[a]	0.8 ± 3.8[a]	-
	>2.5m	6.5 ± 3.8[a]	1.52 ± 4.0[a]	-	-
D. eriantha	>1.5–2m	2.2 ± 3.7[b]	13.4 ± 3.9[a]	1.6 ± 3.7[b]	3.2 ± 3.4[ab]
	>2–2.5m	9.5 ± 3.9[a]	5.0 ± 4.2[a]	-	-
	>2.5m	1.7 ± 3.7[a]	11.84 ± 3.93[a]	-	-

S. africanus	>1.5–2m	-	1.6 ± 4.7^{b}	16.3 ± 4.5^{a}	15.0 ± 4.0^{a}
	>2–2.5m	5.1 ± 4.7^{a}	3.1 ± 5.0^{a}	-	-
	>2.5m	6.1 ± 4.5^{a}	14.4 ± 4.7^{a}	3.1 ± 4.5^{ab}	0.5 ± 4.2^{b}
T. triandra	>1.5–2m	74.1 ± 8.5^{a}	57.8 ± 9.0^{ab}	36.8 ± 8.5^{bc}	19.5 ± 7.7^{c}
	>2–2.5m	60.3 ± 9.0^{a}	70.5 ± 7.0^{a}	71.0 ± 8.5^{a}	67.2 ± 8.5^{a}
	>2.5m	56.3 ± 8.5^{b}	77.4 ± 9.0^{ab}	66.3 ± 8.5^{b}	93.2 ± 8.1^{a}

Small letter values within the same row having different superscripts were significantly different ($P<0.05$).

3.3.3 Effects of season, habitat and tree size on grass tuft diameter.

Change in the canopy habitat did not have a significant effect on the tuft diameter of *C. plurinodis.* The tuft diameter of *D. eriantha* was not significantly affected by canopy habitat, but beneath a canopy zone, it seemed to change with the size of the woody plant in both seasons (Table 3.3). Tuft diametr of *T. triandra* changed significantly ($P<0.01$) with tree size but in most cases this change was not significantly influenced by the effect of habitats and seasons. Tuft diameter of *C. dactylon* was not influenced by habitat, tree size and season (Table 3.3).

Table 3.3 Effect of individual *Acacia karroo* on grass tuft diameter (cm) of common grass species.

		Summer		Winter	
Species	Tree size	Canopy	Open	Canopy	Open
C. plurinodis	>1.5–2m	7.4 ± 1.1^{Aa}	4.9 ± 1.0^{Bb}	8.4 ± 1.2^{Aa}	10.5 ± 1.4^{Aa}
	>2–2.5m	10.6 ± 1.3^{Aa}	8.6 ± 1.8^{ABa}	7.1 ± 1.2^{Aa}	8.0 ± 1.3^{Aa}
	>2.5m	8.5 ± 1.4^{Aa}	9.5 ± 1.4^{ABa}	9.6 ± 1.0^{Aa}	7.3 ± 1.2^{Aa}
C.dactylon	>1.5–2m	7.2 ± 0.9^{Aa}	6.3 ± 1.1^{Ba}	7.4 ± 0.9^{Aa}	8.9 ± 1.1^{Aa}
	>2–2.5m	8.3 ± 0.8^{Aa}	9.2 ± 0.7^{Aa}	6.0 ± 0.8^{Aa}	7.2 ± 0.9^{Aa}

	>2.5m	9.5 ± 0.9^{Aa}	7.8 ± 0.8^{ABa}	6.6 ± 1.2^{Aa}	8.3 ± 0.7^{Aa}
D.eriantha	>1.5–2m	6.1 ± 0.6^{Ba}	6.3 ± 0.6^{Ba}	7.1 ± 0.6^{Aa}	8.9 ± 0.7^{Aa}
	>2–2.5m	8.2 ± 0.5^{Aa}	7.6 ± 0.5^{ABa}	6.4 ± 0.5^{Aa}	7.0 ± 0.6^{Ba}
	>2.5m	8.8 ± 0.6^{Aa}	8.9 ± 0.5^{Aa}	7.9 ± 0.6^{Aa}	7.0 ± 0.5^{Ba}
S.africanus	>1.5–2m	6.4 ± 2.2^{Ba}	7.4 ± 1.9^{Aa}	10.8 ± 2.5^{Aa}	5.6 ± 1.7^{Ab}
	>2–2.5m	20.0 ± 5.0^{Aa}	11.0 ± 2.9^{Ab}	6.3 ± 3.5^{Ab}	-
	>2.5m	6.5 ± 3.5^{Ba}	13.0 ± 5.0^{Aa}	5.4 ± 1.9^{Aa}	10.3 ± 2.9^{Aa}
T.triandra	>1.5–2m	10.0 ± 1.2^{a}	3.3 ± 0.7^{Bb}	-	7.3 ± 0.7^{Aa}
	>2.5m	-	11.5 ± 1.2^{Aa}	8.0 ± 1.2^{a}	11.0 ± 1.2^{Aa}

Capital letter values within the same column with different superscripts were significantly different ($P < 0.05$).

Small letter values within the same row with different superscripts were significantly different ($P<0.05$).

3.3.4 Effects of season, habitat and tree size on grass tuft height.

Results showed that plant height of *D. eriantha* were significantly affected by habitats in both seasons being higher under the canopy than the open areas, but only in mature plants (>2 – 2.5 m) (Table 3.4). Although the statistical analysis did not show significant difference, there seemed to be great variations of in the height of *D. eriantha* growing under the canopy of the three height classes. The height of *C. plurinodis* was significantly affected by habitats. Plant heights of *S.*

africanus did not seem to change in response to habitats except in few cases where this species was not recorded in open areas. Similarly, tuft height of *T. triandra* and *C. dactylon* were not significantly (P>0.05) affected by habitat. Tree height and season had a significant (P <0.05) effect on the tuft height of *C. dactylon.*

Table 3.4 Effect of individual *Acacia karroo* on grass tuft heights (cm) of common grass species.

		Summer		Winter	
Species	Tree size	Canopy	Open	Canopy	Open

C. plurinodis	>1.5–2m	20.7 ± 1.8^{Aa}	18.1 ± 1.8^{Aa}	9.8 ± 2.7^{Ab}	11.7 ± 2.2^{Ab}
	>2–2.5m	13.4 ± 2.6^{Ba}	14.9 ± 2.6^{Aa}	12.4 ± 2.3^{Aa}	14.8 ± 2.3^{Aa}
	>2.5m	12.5 ± 2.1^{Ba}	14.4 ± 2.7^{Aa}	13.5 ± 1.9^{Aa}	12.3 ± 2.3^{Aa}
C. dactylon	>1.5–2m	18.0 ± 1.4^{Aa}	19.6 ± 1.8^{Aa}	10.7 ± 1.6^{Aa}	10.6 ± 2.1^{Aa}
	>2–2.5m	14.2 ± 1.3^{Ba}	12.7 ± 1.1^{Ba}	13.9 ± 1.2^{Aa}	14.7 ± 1.4^{Aa}
	>2.5m	12.6 ± 1.5^{Ba}	10.3 ± 1.1^{Ba}	11.9 ± 2.1^{Aa}	14.4 ± 1.1^{Aa}
D.eriantha	>1.5–2m	20.3 ± 1.1^{Aa}	19.9 ± 1.3^{Aa}	10.2 ± 1.3^{Aa}	12.63 ± 1.17^{Aa}
	>2–2.5m	14.7 ± 1.2^{Aa}	12.2 ± 1.0^{Aa}	16.1 ± 1.2^{Aa}	14.8 ± 2.3^{Ab}
	>2.5m	13.82 ± 1.2^{Aa}	14.4 ± 1.1^{Aa}	15.9 ± 1.4^{Aa}	13.5 ± 1.0^{Aa}
S.africanus	>1.5–2m	15.6 ± 2.4^{Aa}	21.4 ± 2.1^{a}	8.5 ± 3.3^{Ba}	7.3 ± 1.9^{Aa}
	>2–2.5m	16.0 ± 4.7^{Aa}	-	8.8 ± 3.3^{Ba}	10.0 ± 2.8^{Aa}
	>2.5m	10.9 ± 2.1^{Ab}	-	16.9 ± 1.7^{Aa}	10.0 ± 2.7^{Aa}
T.triandra	>1.5–2m	18.5 ± 1.8^{Aa}	10.0 ± 2.6^{Aa}	-	6.5 ± 1.8^{Ab}
	>2.5m	-	14.6 ± 2.6^{Aa}	30.0 ± 2.6^{a}	19.0 ± 2.6^{Aa}

Capital letter values within the same column for each grass species with different superscripts were significantly different ($P < 0.05$).

Small letter values within the same row with different superscripts were significantly different ($P<0.05$).

3.3.5 Effects of tree height and habitat on dry matter (DM) production.

Results showed that grass DM was not significantly (P>0.05) affected by habitat, but the results in the table showed a higher DM beneath canopy value than open area in summer and for the mature tree classes (>2 – 2.5 m), and the opposite was true in winter for the height class >2.5 m (Table 3.4). Although there was no significant difference (P>0.05), DM seemed to be higher in open areas than canopied habitats of > 1.5 – 2m. The DM appeared to be higher only on the open areas of > 2 – 2.5 m and > 2.5m tree class in winter.

Table 3.5. Total dry matter production of grass (mean ± SE ($kg.ha^{-1}$))

	Summer		Winter	
Tree size	Canopy	Open	Canopy	Open
>1.5-2 m	2662.3 ± 263.6^{Ba}	2762.8 ± 325.2^{Aa}	925.2 ± 325.2^{Aa}	834.2 ± 296.9^{Aa}
>2-2 .5m	3099.7 ± 342.8^{Aa}	1981.9 ± 342.8^{Ab}	1085.4 ± 342.8^{Aa}	1118.04 ± 325.2^{Aa}
>2.5m	2107.9 ± 325.2^{Ba}	1928.1 ± 310.1^{Aa}	768.6 ± 325.2^{Ab}	1054.00 ± 325.2^{Aa}

Capital letter values within the same column with different superscripts were significantly different ($P < 0.05$).

Small letter values within the same row with different superscripts were significantly different ($P<0.05$).

3.3.6 Soil pH, macro and micro nutrients.

Tree habitat had no significant ($p>0.05$) effect on all soil nutrients (Table 3.6). However, tree size affected most soil nutrients except Ca, K and Zn levels. Organic C ($P<0.01$), P($P<0.0001$), Mg ($P<0.001$) and N ($P<0.001$) levels showed significantly the lowest values beneath the canopy habitats of young plants (>1.5 – 2 m) compared to the mature plants. These results are the same for the open areas. In contrast, highest soil P was recorded under the canopy and open habitats of the young trees followed by the mature plants (> 2 – 2.5 m). Of the soil micro nutrients, Cu ($P<0.0001$) and Mn ($P<0.01$) had the highest levels beneath the canopy and open habitats of young plants, where Fe level was lowest. Soil pH was significantly high beneath the canopy habitats compared to the open areas.

Table 3.6 Mean (± SE) macro soil nutrients under different tree sizes and habitats.

Element	Tree size	Canopy	Open
C (%)	>1.5 - 2m	1.5 ± 0.1^{Ba}	1.4 ± 0.1^{Ba}
	>2- 2.5m	1.8 ± 0.1^{Aa}	1.7 ± 0.1^{Aa}
	> 2.5m	1.7 ± 0.1^{Aa}	1.6 ± 0.1^{Aa}
Ca (cmol(+)/kg	>1.5 - 2m	4.4 ± 0.2^{Aa}	4.3 ± 0.2^{Aa}
	>2- 2.5m	4.5 ± 0.2^{Aa}	4.4 ± 0.2^{Aa}
	> 2.5m	4.6 ± 0.2^{Aa}	4.0 ± 0.2^{Ab}
K (mg/kg)	>1.5 - 2m	134.4 ± 50.0^{Aa}	245.0 ± 50.0^{Aa}
	>2- 2.5m	215.1 ± 50.0^{Aa}	221.4 ± 50.0^{Aa}
	> 2.5m	186.6 ± 50.0^{Aa}	234.9 ± 50.0^{Aa}
Mg (cmol(+)/kg)	>1.5 - 2m	1.5 ± 0.11^{Ba}	1.5 ± 0.1^{Ba}
	>2- 2.5m	1.9 ± 0.11^{Aa}	1.8 ± 0.1^{ABa}
	> 2.5m	2.1 ± 0.11^{Aa}	1.9 ± 0.1^{Aa}
N (%)	>1.5 - 2m	0.1 ± 0.01^{Ba}	0.1 ± 0.01^{Ba}
	>2- 2.5m	0.12 ± 0.01^{Aa}	0.14 ± 0.01^{Aa}
	> 2.5m	0.12 ± 0.01^{Aa}	0.11 ± 0.01^{Aa}
P (mg/kg)	>1.5 - 2m	37.7 ± 2.8^{Aa}	38.7 ± 2.8^{Aa}

	>2- 2.5m	28.7± 2.8^{Ba}	29.4 ± 2.8^{Ba}
	> 2.5m	16.1 ± 2.8^{Ca}	14.6 ± 2.8^{Ca}

Capital letter values within the same column for each nutrient with different superscripts were significantly different ($P < 0.05$). Small letter values within the same row for each nutrient with different superscripts were significantly different ($P<0.05$).

Table 3.7 Mean (± SE) soil pH (KCl) and macro nutrients under different tree sizes and habitats.

Element	Tree size	Canopy	Open
Cu (mg/kg)	>1.5 – 2m	3.00 ± 0.3^{Ba}	3.0 ± 0.3^{Ba}
	>2- 2.5m	4.6 ± 0.3^{Aa}	4.6 ± 0.3^{Aa}
	> 2.5m	4.0 ± 0.3^{Aa}	3.51 ± 0.3^{Aa}
Fe (mg/kg)	>1.5 – 2m	284.5 ± 14.1^{Aa}	278.6 ± 14.1^{Aa}
	>2- 2.5m	257.0 ± 14.1^{Aa}	238.7 ± 14.1^{Ba}
	> 2.5m	207.5 ± 14.1^{Ba}	203.3 ± 14.1^{Ba}
Mn (mg/kg)	>1.5 – 2m	288.9 ± 47.9^{Ba}	262.5 ± 47.9^{Ba}
	>2- 2.5m	442.9 ± 47.9^{Aa}	430.4 ± 47.9^{Aa}
	> 2.5m	395.8 ± 47.9^{ABa}	416.0 ± 47.9^{Aa}
Zn (mg/kg)	>1.5 – 2m	1.0 ± 0.1^{Aa}	1.06 ± 0.1^{Aa}
	>2- 2.5m	1.2 ± 0.1^{Aa}	1.1 ± 0.1^{Aa}

	> 2.5m	1.0 ± 0.1^{Aa}	0.9 ± 0.1^{Aa}
pH(KCl)	>1.5 – 2m	7.7 ± 0.3^{Aa}	4.0 ± 0.3^{Ab}
	>2- 2.5m	7.8 ± 0.3 ^{Aa}	4.1 ± 0.3^{Ab}
	>2.5m	7.6 ± 0.3^{Aa}	3.9 ± 0.3^{Ab}

Capital letter values within the same column for each nutrient with different superscripts were significantly different ($P < 0.05$). Small letter values within the same row for each nutrient with different superscripts were significantly different ($P<0.05$).

3.4 Discussion

3.4.1 Effect of individual *Acacia karroo* trees on grass species composition.

Positive and negative effects of savanna trees on their understory grass layer have received much attention (Riginos and Young, 2007; Abdallah et al., 2012). However, the reasons for differences that occur through the mechanisms that interact to bring about positive or negative net effects on the herbaceous layer and soil are not clearly understood. One of the main objectives of this study was to determine whether the individual *Acacia karroo* height and distance from the tree affects the herbaceous layer and soil nutrient status. The results showed that the tree heights and the distance from the tree do affect the herbaceous layer and the soil nutrient status. The species that occurred under the canopies were the same with those that occurred on the open habitats however the frequency of occurrence was not the same because some were higher under the canopies and vice versa.

Cymbopogon plurinodis was not significantly affected by the habitat (canopy and open) but it was affected by the tree size. *C. plurinodis* was significantly ($p<0.05$) higher under the canopies of >2m – 2.5m trees. Habitat did not affect all the grass species while others were significantly affected by the habitat. It is clear that the individual *A. karroo* trees and habitats had an effect on grass species composition in the semi-arid savanna of the Eastern Cape. Change in species composition under the canopies of different individual tree sizes and open habitats have been reported in several studies but the causes still remain unclear (Scholes and Archer 1997; Ludwig *et al*., 2004). These results agree with those of Ludwig et al. (2004) who suggested that species composition was similar under canopy and outside canopy habitats. The occurrence of *S. africanus* was higher in winter than summer. This could be attributed to the fact that the *S. africanus* is an increaser grass species which increases with the decrease in more palatable grass species. The occurrence of *S. africanus* was not linear with the tree heights and habitats. The strong root system, dissemination ability and drought tolerance (Scheffer-Baso *et al*.,2012) of *S. africanus* gave it advantage to compete with *A. karroo.* The hydraulic shift through *A. karroo* deep roots may have benefited the growth of *S. africanus* in winter (Smit, 2004). The *Coynodon dactylon* which is an increaser II grass species known for its high palatability occurred more under canopies than open areas. These results agree with those that were reported by Abdallah *et al*.,(2012) in southern Tunisia who confirmed the positive effect of *Acacia tortilis* on grass cover.

The occurrence of *T. triandra* was higher under the canopies of >1.5m – 2m and >2m – 2.m while it was low under the canopies of >2.5m trees. *T. triandra* is a highly palatable grass species which is commonly found in undisturbed fertile soils of grasslands and bushlands (Van Oudtshoorn, 2012). *T. triandra* is the key indicator of a rangeland in good health and it one of the major species in southern Africa (Solomon *et al*., 2007). Therefore we can say that the *A. karroo*

favoured the growth of *T. triandra* grass species as it was the case with the *Acacia tortilis* (Solomon et al., 2007).

Another common species that was dominant at the University of Fort Hare farm was *Digitaria eriantha.* It is a highly palatable grass species and it grows very well in fertile and damp soils (Van Oudtshoorn, 2012). The *D. eriantha* did not grow well under the canopies of *A. karroo,* it preferred open habitats. It can be said that *D. eriantha* is intolerant (Ludwick *et al.,* 2004) to shade because its occurrence was higher in open habitats than canopies. The understory herbaceous layer can change because of the shade effect (Ludwig et al., 2004). This might have been the case with the *D. eriantha* because it preferred open habitats than the open habitats. Another limiting factor for some grass species might be moisture availability under *Acacia* tree species (Ludwig, 2001).

3.4.2 Effects of individual *Acacia karroo* trees on grass biomass production

Acacia karroo trees had an effect on the biomass production of grasses as the grass biomass was higher under the canopy than open habitats. These results agree with those of Solomon and Mlambo (2010) who reported that isolated trees of *A. brevispica* and *A. drepanolobium* improved grass productivity under canopies than open habitats. The higher biomass production under the canopies of *A. karroo* can be attributed to the higher occurrence of *T. triandra* which is a high yielding grass species (Solomon and Mlambo, 2010). This suggests that *A. karroo* supports the grass and livestock production up to a certain height after which the trees suppress grass production.

The increased grass production under tree canopies is often associated with leguminous trees especially *Acacia* (Teague, 1984). A study that was conducted by Helman *et al.* (2014) showed that savanna trees facilitate the grass growth under tree canopies. In dry semi-arid savannas trees facilitate grass growth while they suppress the grass growth in wetter areas (Moustakas *et al*., 2013). The net facilitation is probably due to the reduced evapotranspiration under the shade of the *A. karroo* trees and the hydraulic lift (Dohn *et al.,* 2013). In this study the grass production was higher under the canopies than open habitats of *A. karroo* trees in summer than winter. This can be attributed to higher rainfall in summer than winter (Dohn *et al*.,2013). These tree-grass competitive and facilitative interactions depend on certain factors such as grazing intensity, species specific interactions, tree size and rainfall seasonality (Callaway, 2007). The biomass production was higher under the canopies of >2m – 2.5m than > 1.5m – 2m and >2.5m trees. These results agree with those of Stuart-Hill and Tainton (1989) who reported that taller *A. karroo* tree had a competitive effect which suppressed the grass growth under these trees than the shorter trees in South African savannas.

However, Moustakas *et al.* (2013) found no relationship between tree heights and the distance from the canopy. Other studies have reported higher biomass production under the canopies of larger trees than smaller trees (Ludwig *et al*.,2004 and Mlambo *et al*., 2005). The older trees have also been reported to facilitate grass growth under the canopies than younger trees and this was attributed the deep roots that the older trees have while the competitive younger trees have lateral roots (Callaway *et al*.,1991). The tree height may have positive effects on sub-canopy grass biomass production where light is the limiting factor (Moustakas et al,2013).

Apart from abiotic factors grass biomass production under canopies of larger trees can also be affected by biotic factors such as grazing. The grass biomass can decrease under taller trees than shorter trees due to easy access by the grazing animals (Moustakas et al.,2013). The insignificant differences on biomass production under tree canopies in winter can be attributed to low rainfall. Results show that facilitation is more predominant in summer where the rainfall is higher than winter because the grass is taller in summer than in winter leading to higher biomass production in summer than in winter. While the grass biomass production was higher under the tree canopies than open habitats it varied between tree sizes. The taller trees probably have higher water uptake than shorter trees which made them to be more competitive to grasses (Ludwig *et al*., 2004). The grass biomass production under the tree canopies is assumed to be related to the crown and root morphologies of woody plants (Solomon and Mlambo.,2010).

3.4.3 Effects of individual *Acacia karroo* trees on grass tuft heights and basal cover.

The tree heights affected the tuft heights of the grasses. The grass heights differed from species to species. The *D. eriantha*, *C. plurinodis, C. dactylon, S. africanus*, and *T. triandra* grass species were taller under tree canopies than the open habitats. The grass heights were not linear with the tree height. It appeared that the grass heights were more affected by the habitat than the tree size. The taller grass species under canopies can be attributed to the fact that these habitats are more nutritious than the open habitats (Moustakas *et al*.,2013). Furthermore the grass heights might have been affected by the moisture availability that might have been brought up through

hydraulic lift by the *A. karroo* trees (Moustakas *et al.*, 2013). We can say that the trees facilitated the grass growth under tree canopies rather than competition. The effect of rainfall seasonality also played a role on the grass heights as the grass was taller in summer than in winter both under canopy and open habitats. *D. eriantha* grows very well in habitats with fertile soils and high moisture content (van Oudtshoorn, 2012) therefore we can say that the canopies had high soil nutrient content than the open habitats and that is why it was taller under tree canopies than the open habitats.

The tuft diameters of the grass affects the soil basal cover. The basal cover appeared to be higher under the tree canopies than open habitats. The basal cover was also affected by the seasonal rainfall as the diameters were wider in summer than in winter. The basal cover was also affected by the tree sizes. Different grass species such as *S. africanus, D. eriantha, C. plurinodis, T. triandra* and *C. dactylon* differed in terms of their response to habitat, season and tree heights. These grasses provide cover for soil under these canopies against negative impacts of water runoff and direct sunlight to the soil that would compromise the soil moisture. The trees might have facilitated (Moustaskas *et al*., 2013) the grass cover by minimizing the raindrops intensity and ensuring high infiltration rate under tree canopies. The canopies also provided refuge for grasses from water stress and grazing.

3.4.4 Effects of *Acacia karroo* on soil macro nutrients

Macro nutrients such as nitrogen, phosphorus, trace elements and a series of cations and anions are very important for plant growth (Hagos and Smit, 2005). These elements determine the grass species composition and rangeland productivity. The parent material is the primary determinant that is important in soil fertility and the biological activities that create the localized areas of improved soil fertility (Hagos and Smit, 2005). The trees may act as biological agents that create islets that are different to the open habitats. In this study the habitat had no significant effect on

the organic carbon although the values were higher under tree canopies. The tree heights had a significant effect on the soil organic C content as the soil under taller trees (i.e >2m – 2.5m and >2.5m) had higher OC percentage content under these trees. The season had no significant (P>0.05) effect on the soil OC content although summer season had a little bit higher OC percentage than winter. This can be attributed to high biomass production under taller trees than shorter trees which led to high OC (Smit, 2004). Other theories such as droppings from mammals and birds, accumulation of nutrients from areas outside the tree crown through lateral roots have been mentioned as causes of high OC content under trees (Smit, 2004).

Soil Ca^{2+} content was lower on the open habitats of >2.5m trees than under the canopies. These results agree with those of Hagos and Smit (2005) who found high soil Ca^{2+} contents close to tree stem. There was no significant difference on the soil N, P, K^{+} and Mg^{2+}, contents between habitats and tree sizes. However, the levels were a bit higher under the tree canopies as opposed to open habitats. The soil N and Mg^{2+} content were significantly affected by tree size rather than habitat. The shorter trees had significant low values of N and Mg^{2+} than taller trees. These results concur with those of Ludwig et al. (2004) who found high soil nutrient values under taller than shorter trees.

3.4.5 Effects of *Acacia karroo* on soil pH and micro nutrients.

The growth of plants depends on a variety of nutrients for many processes that are responsible for photosynthesis. This makes it essential for studies such as this one to be conducted in order to know the nutrient composition of the soil. The micro nutrients such as Cu, Fe, Mn and Zn are essential for plant growth (Tiedemann and Lopez, 2004). The habitat had no significant effect on the micro nutrients values although the values were a little bit higher under tree canopies than open habitats. The micro nutrient composition was not linear with the tree sizes as some nutrients such as Cu and Mg contents were lower under shorter trees, Fe content was higher

under short and medium trees while the tree sizes had no significant effect on the soil Zn content. Although the Zn content did not differ significantly, they were within the required levels. The levels are considered to be within the required range for plant growth as they are within the range of 0.15 and 6.56 mg/kg as illustrated by Tyrer *et al.*,(2007).

These results concur with those that were reported by Smit,(2004) who suggested that trees improve soil fertility. However, the low biomass production on the open habitats shows that the nutrient composition in those habitats is lower than under tree canopies. Although the biomass production was higher under tree canopies it deteriorated with the tree heights. This may imply that the taller trees compete with herbaceous layer rather than facilitating growth. The soil appeared to be more fertile under tree canopies but the grass production was lower and this could mean that the trees use the high nutrient content and light for their own benefit.

The soil pH (KCl) was alkaline under tree canopies while it was acidic on the open habitats. The soil pH was not affected by the tree size but by the habitat. These results are in agreement with those of Abule *et al.,(*2005) who reported higher pH under tree canopies than open habitats. A higher pH under tree canopies may be attributed to higher contents of exchangeable cations in these sub-habitats (Smit, 2002).

3.5 Conclusion

Results show that the *A. karroo* influences the grass layer. The more palatable grasses were under canopies of *A. karroo* than open habitats. *Themida triandra* contributed to higher dry matter production under canopies. The canopies improved biomass and basal cover. *Acacia karroo* facilitates grass growth up to a certain height after which it decreases The grass was shorter under > 1.5m – 2m trees, taller under >2m – 2.5m trees and it was shorter under > 2.5m

trees. The grass was taller under canopies than open habitats. The trees also improve soil fertility as the soil was more fertile under canopies. The tree canopies enhance species composition under canopies. Therefore it can be said that *A. karroo* promotes grass production in its understory vegetation through abiotic environment such as water and nutrient resources.

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CHAPTER 4

EFFECT OF *ACACIA KARROO* ENCROACHMENT LEVELS ON GRASS LAYER AND SOIL IN COMMUNAL RANGELANDS.

Abstract

The study investigated the effect of *Acacia karroo* encroachment levels (open, moderate and severe) on the herbaceous and soil layer in semi-arid communal grazing lands of Alice in the Eastern Cape. A total of 16 grass species were identified of which 15 were perennials. *Themida triandra* dominated the moderate and severe encroached sites (39% and 43% respectively) whereas *Digitaria eriantha* dominated the open site (28%). Overall, decreaser grass species increased with the increase in encroachment levels (open - 49%, Moderate – 70% and severe –

66%). On the other hand, the increaser II grass species such as *Sporobolus africanus* and *Microchloa caffra* dominated the open site showing that their abundance decreased with the increase in *A. karoo* density. In terms of height, grass species at the open site were shorter ($P<0.05$) than the moderate and severe encroached sites. Basal cover improved with the increased encroachment levels (open - 1.26cm, moderate – 1.13cm and severe – 0.86cm). Grass biomass was affected ($P<0.05$) by encroachment being lowest at the open sites. The study showed that *A. karroo* has a positive effect on grass production to a certain level. The encroached sites were dominated by highly palatable grass species than the open site. The grass biomass production was highest in encroached sites than the open site.

Key words: Biomass, basal cover, species composition, Melani, village.

4.1 Introduction

Encroachment by woody plants may have positive, negative or no effects on soil and herbaceous layer depending on the tree density and/or cover (Abule *et al*., 2005). Positive effect is when the savanna trees improve the soil quality and facilitate growth of herbaceous layer while the negative effect is when they supersede the herbaceous layer (Moustakas *et al*., 2013). A study by Xu *et al*., (2011) in China concluded that bush encroachment improves grass production because of higher biomass yield under the canopy compared to open areas.

Similarly, the research by Solomon and Mlambo (2010) indicated that *Acacia* species are associated with the increases in sub-canopy grass production. Abdallah *et al*. (2012) conducted a

study on the influence of *Acacia tortilis* on the understory vegetation in Tunisia and found that the woody species allowed establishment of new grass species as opposed to open grasslands. *Acacia* was also reported to improve the soil nutrients, in particular N (Boyes et al. 2010). In contrast to the above findings, Durr and Rangel (2002) concluded that less grass dry matter was found in *Acacia* encroached areas than the open grasslands in Australia.

Different from these two findings, the study by Ludwig *et al.* (2001) found no differences in the dry matter production in grasses that grew under tree canopies and in open spaces suggesting that bush encroachment will not have any significant impact on the grass yield. Indeed many researchers agree that trees compete for resources such as light, nutrients and moisture (Knoop and Walker, 1985; Riginos , 2009; Moustakas *et al* 2013).

This study therefore examined the grass layer and soil nutrients in relation to different levels densities of *A. karroo.* The study provided more knowledge on how the *A. karroo* can be maintained to benefit the ecosystem services and functions including ecology sustainability and livestock production. The study examined how *A. karroo* density influence the vegetation diversity and structure as well as the soil organic carbon and other soil nutrients that are important for plant growth. Three major sites that were selected for this study were severely encroached (3650 trees/ha), moderately encroached (2521 trees/ha) and open (350 trees/ha) grazing land sites.

4.2 Materials and methods

4.2.1 Site description

The study was conducted in a communal village, Melani, in the Eastern Cape Province, South Africa. The village is located at the coordinates of 32^0 44,602´S and 26^0 53,302´E and at an average altitude of 660 m above sea level. The mean annual rainfall is 500 mm of which 70%

falls between October and March. The summer season is dominated by hot sunny weather and thunderstorms with average temperature ranges of 17 ^{0}C to 28^{0}C. The winter season is characterized by moderate cold weather with an average temperature ranges of 8^{0}C and 20 ^{0}C. The vegetation is the Bisho Thornveld Savanna comprising of open savanna characterized by a mixture of grasses and small trees of *Acacia* species (Mucina and Rutherford, 2006). The soils are heterogeneous but are predominantly sedimentary with some variations of red soils occurring in some areas because of igneous rocks.

4.2.2 Site selection and experimental layout.

The sites were dominated by *A. karroo* species with an insignificant number of other woody species. Sites with *A. karroo* encroachment levels namely; severe encroachment (3650 trees/ha, 6770.7 TE/ha), moderate encroachment (2521 trees/ha, 5103.11 TE/ha) and open site (350 trees/ha, 319.5 TE/ha) were selected (Table 4.1). In each site three 50 x 100 m plots were established giving a total of nine plots on the north facing slope. The longer side of the plot was laid 100m along the slope gradient. In each plot, a total of four 100 m transects were established evenly at 12.5m distance intervals. Transects were laid in such a way that could accommodate open, sub-canopy and canopy habitats.

4.2.3 Data collection

4.2.3.1 Woody plants

Acacia karroo trees were counted and recorded on each plot and converted into number of trees per hectare. The plots were placed evenly along the length of each main site and were used to record density, canopy diameter and height of *A. karroo* plants were recorded in each plot. Plants with a height of > 3 m were considered mature trees. All the plants that fall within ≥ 2 – 3 m height were considered as shrubs. Woody plant data were standardised to tree equivalent (TE)

per hectare (1 TE = 1 tree, 1,5 m high) (Teague *et al*., 1981). The canopy diameter of *A. karroo* was measured along two axes (length, L, and with, W) perpendicular to each other. Canopy cover was calculated using the formula canopy cover = $(n\pi r^2)/(3)$, where *n* is the number of *A. karroo* plants and r^2 is equivalent to $LW/4$, where L is the length of the canopy and W is the width of the canopy. Where overlap exists between the canopies of adjacent *A. karroo,* the length of the overlap was subtracted from the length or width of either of the plants.

4.2.3.2 Species composition and dry matter production

Composition of the grass layer was estimated from each plot using the step-point method (Hardy *et al*., 1999). The nearest plant and basal strikes were recorded from 400 point observations per plot. Basal cover was estimated as the percentage of basal strikes out of the total number of points taken. This sample size is adequate for detailed scientific studies in semi-arid savanna (Hardy *et al*., 1999). When the distance of nearest plant was further than 40 cm from the marked step-point, it was recorded as bare area. Point observations were spaced at approximately 2 m intervals along straight parallel lines approximately 1 m apart over the length of the plot.

Grasses were identified according to species, whereas other herbaceous plants were identified as sedges, forbs and ecological status. The grasses were classified according to life form, grazing value and ecological status. The data were collected during the winter season of 2014 and summer season of 2015. Four 0.5 m x 0.5 m quadrats were randomly laid per transect in a zigag sampling style to record grasses as well as to collect soil samples. Quadrates were laid to include canopy, sub-canopy and open habitats. In each quadrat, Individual grass tuft height, tuft diameter and distance between tufts were measured using 30 cm ruler. After recording, plants were harvested and separated by species for biomass production determination. Harvested samples

were oven dried for 48 hours at a temperature of 70 ^{0}C. Grass data were collected during the winter season of 2014 and summer season of 2015.

4.2.3.3 Soil sampling and chemical analysis

Soil samples up to 20cm were taken using an auger within each quadrat at the time of plant data collection. The soil samples were placed in paper bags pending chemical analysis. The soil was analysed at the Western Cape Department of Agriculture for pH (KCl), copper (Cu), iron (Fe), manganese (Mn), zinc (Zn), percentage carbon (C), calcium (Ca), magnesium (Mg), total nitrogen (N), potassium (K) and phosphorus (P). Total soil N was analysed using the standard Kjeldahl method using a block digester (Bremner and Breitenbeck, 1983). Soil P, Ca, Mg and K was determined using Inductively Coupled Plasma (ICP) analysis of extracts of soil with 1% citric acid (ALASA, 1998). Soil Zn, Cu, Fe and Mn were determined using ICP in 0.02 M Di-ammonium Ethylenediaminetetraacetic acid (EDTA) soil extracts (ALASA, 1998). Soil pH was determined using 1 M potatasium chloride (KCl) 2.5 KCl: 1 soil (ALASA, 1998). The elements were analysed according to macro and micro elements.

4.2.4 Statistical analysis

All the quantitative data obtained from the soil and vegetation properties were analysed by SAS software (SAS, 1999). The effects of season and bush encroachment status plus the interaction of the main effects were subjected to ANOVA using the GLM procedure of SAS (1999). The post hoc analysis were conducted using the Fishers' least significance difference (LSD) method for mean comparison of species composition, basal cover, species composition, biomass production and soil properties. All the means were considered significant when $P<0.05$. The following model was used:

$$Y_{ijk} = \mu + \alpha_{i} + \beta_{j} + (\alpha\beta)_{ij} + e_{ijk}$$

Where Yıjk= Response variables (species composition, biomass production, basal cover).

μ= overall mean

α_ι = effect of the ι^{th} bush encroachment (open grassland, moderately encroached and severely encroached)

β_j = the j^{th} effect on season

$(\alpha\beta)_{ij=}$ interaction between the effect of season and bush encroachment

e_{ijk} = the random error.

4.3 Results

4.3.1 Species composition

Table 4.1 presents species composition of grasses identified in different encroachment levels. In total, 16 grass species were identified. Of these, 5 were highly desirable, 5 were moderately desirable 6 less desirable. The most dominant species was *D. eriantha* as it dominated in all the sites. *T. triandra* was dominant in the severely encroached and moderately encroached sites while it was less common in the open site. *Sporobolus africanus* was common in the severely encroached and moderately encroached sites while it was less common in the open site. Although *M. caffra* was rare in the severe encroached and moderate encroached sites, it showed dominance in the open site. *Cynodon dactylon* showed consistency as it was less common in all three sites. *Eustachys paspeloides* also showed consistency in all the sites although it was rare in all the sites. *Eragrostis curvula* appeared only in the severely encroached site while it was absent

in the moderately encroached and open grassland sites. Karroo was present in the severe and moderate encroached sites but its occurrence increased in the open site.

Table 4.1 Grazing values, ecological status and life forms of grasses identified in the study areas

Species	Grazing value	Life form	Ecological status	Severe encroachment	Moderate encroachment	Open site
Aristida congesta	Low	P	Increaser II	+	-	+
Cymbopogon plurinodis	Low	P	Increaser I	R	R	+
Cynodon dactylon	High	P	Increaser II	LC	LC	LC
Digitaria eriantha	High	P	Decreaser	D	D	D
Eragrostis capensis	Average	P	Increaser II	R	LC	LC
Eragrostis chloromelas	Average	P	Increaser II	+	R	R
Eragrostis curvula	Low	P	Increaser II	+	-	-
Eragrostis obtusa	Average	A	Increaser II	+	-	R
Eragrostis plana	Low	P	Increaser II	R	R	+
Eustachys paspaloides	High	P	Decreaser	R	R	R
Hyparrhenia hirta	Average	P	Increaser I	+	-	-
Microchloa caffra	Low	P	Increaser II	R	R	D

Panicum stapfianum	Average	P	Decreaser	-	+	-
Sporobolus africanus	Low	P	Increaser II	C	C	LC
Sporobolus fimbriatus	High	P	Decreaser	R	R	LC
Themeda triandra	High	P	Decreaser	D	D	LC
Forb	-	-	-	R	R	LC
Karroo	-	-	-	+	+	LC
Sedge	-	-	-	-	+	-

[a] A = annual, P = perennial; AGV = average grazing value, HGV = high grazing value, LGV = low grazing value.

[b] + = present (<1%), R = rare (1-5%), LC = less common (5-10%), C = common (10-15%), D=dominant (> 15%), - = absent (0%).

4.3.2 Common grass species.

Table 4.2 shows the common grass species that appeared more than 5% in the three encroachment levels. The presence of *D. eriantha* was significantly ($P< 0.05$) higher in the open site followed by severely encroached site ($P<0.05$). *Microchloa caffra* occurred more abundantly in the open site than moderately and severely encroached sites.

The occurrence of the *Sporobolus africanus* was not affected by the sites as there was no significant effect ($P>0.05$) between all the sites. The occurrence of *Themeda triandra* increased with an increase *in A. karroo* encroachment where it was significantly ($P<0.05$) lower in open site. The *A. karroo* encroachment had no significant effect ($P> 0.05$) on the occurrence of *C. dactylon*.

Table 4.2 Species composition (%) of common occurring species in response to encroachment.

Species	Open	Moderate	Severe	S.E
Cynodon dactylon	6^{a}	5^{a}	6^{a}	1.58
Digitaria eriantha	28^{a}	16^{b}	19^{ab}	3.11
Microchloa caffra	17^{a}	4^{b}	2^{b}	2.24
Sporobolus africanus	9^{a}	10^{a}	14^{a}	2.20
Themeda triandra	13^{b}	39^{a}	43^{a}	4.67

Small letter superscripts along the rows for each grass species, show significant difference between levels of encroachment.

4.3.3 Effect of encroachment on ecological groups.

The frequency of decreaser species was significantly lower ($P < 0.05$) in the open grassland site than the moderately and severely encroached sites (Table 4.3). Increaser I grass species were significantly higher ($P < 0.05$) on the severe encroached site than the moderate encroached site and open site. The occurrence of increaser II and III species were significantly highest ($P < 0.05$) on the open site and severe encroached site respectively. The frequency of non-grass species was much greater in the open sites than moderate and severe encroached sites.

Table 4.3. Ecological status (%) on three different encroachment levels.

Ecological status	Open %	Moderate %	Severe %
Increaser I	1 ± 0.75^{b}	1 ± 0.75^{b}	5 ± 0.75^{a}

Increaser II	40±3.47[a]	16±2.47[b]	16±2.47[b]
Increaser III	2±0.94[b]	7±1.54[b]	15±1.54[a]
Decreaser	49±4.21[b]	70±4.21[a]	66±4.21[a]
Non-grass	16±0.32[a]	2±0.32[b]	1±0.32[b]

[a,b] Superscripts along the rows for each ecological status, show significant difference between levels of encroachment.

4.3.4 Effect of *Acacia karroo* encroachment on grass tuft diameter.

Mean values of tuft diameters of the common occurring species are presented in table 4.4. *Digitarias eriantha* had the highest diameter in the moderate and severe encroached areas, whereas *T. triandra* had the highest tuft diameter in the open and severe encroached sites. *Sporobolus africanus* had the highest diameter in the severe encroached than the moderate encroached and open sites. The mean diameter of *C. dactylon* was highest in the open site than the severe and moderate encroached sites. *Microchloa caffra* diameter was significantly highest in the severe encroached than the moderate encroached and open sites.

Table 4.4. Mean (±S.E) cm tuft diameters (cm) of five common grass species on three sites in two different seasons.

Species	Open	Moderate	Severe
Cynodon dactylon	8.8±1.6[A]	2.2±1.8[B]	6.4 ± 1.4[A]
Digitaria eriantha	4±0.31[C]	5±0.32[B]	6±0.32[A]
Microchloa caffra	4±0.74[B]	5±0.73[B]	7±0.56[A]
Sporobolas africanus	4±0.44[B]	5±0.45[B]	7±0.48[A]
Themeda triandra	5±0.69[A]	3±0.90[B]	5±0.97[A]

[AB] Along the rows for each grass species tuft diameter, show the difference between levels of encroachment.

4.3.5 Tuft heights (cm) of five common grass species on three sites in two different seasons.

Mean plant height of frequently occurring species in table 4.5. The results showed that height of *T. triandra* was greater ($P < 0.05$) in the moderate and severe encroached sites than the open sites. *Digitaria eriantha* had the greatest height in the moderate encroached site. The mean height of *M. caffra* was highest in the moderate encroached site than the severe encroached and open sites. *Sporobolus africanus* mean tuft height was lowest in the severe encroached site. The mean tuft height of *C. dactylon* was highest in the moderate encroached site.

Table 4.5. Mean (±S.E) cm tuft heights (cm) of five common grass species on three sites in two different seasons.

Species	Open	Moderate	Severe
Cynodon dactylon	2.1 ± 0.5^{B}	2.6 ± 0.5^{A}	2.0 ± 0.5^{B}
Digitaria eriantha	5 ± 0.1^{B}	8 ± 0.29^{A}	5 ± 0.25^{B}
Microchloa caffra	3 ± 0.4^{C}	10 ± 0.9^{A}	5 ± 4.4^{B}
Sporobolus africanus	16 ± 3.3^{A}	17 ± 0.8^{A}	12 ± 0.8^{B}
Themeda triandra	4 ± 0.4^{B}	8 ± 0.15^{A}	7 ± 0.21^{A}

[ABC] Along the rows for each grass species tuft height, show the difference between levels of encroachment.

4.3.6 Basal cover and biomass production

Results show that basal cover decrease significantly with increased levels of woody plant density (Figure 4.1). Table 4.6 presents biomass production in the three different levels of encroachment in two different seasons. The overall biomass production on the study sites was low in both seasons. Summer showed higher biomass production than winter. In winter the biomass production in the moderate encroached site was significantly the highest, but in summer this was highest in severe encroached site followed by moderate encroached site.

Table 4.6 Effect of *Acacia karroo* encroachment on biomass production (kg/ha).

Site	Winter	Summer
Open	118 ± 20.1^{Bb}	202 ± 20.1^{Ca}
Moderate encroachment	297 ± 20.1^{Ab}	328 ± 20.1^{Aa}
Severe encroachment	273 ± 20.1^{Ba}	484 ± 20.1^{Aa}

Capital letter values within the same row with different superscripts were significantly different ($P < .05$).

Small letter values within the same column with different superscripts were significantly different.

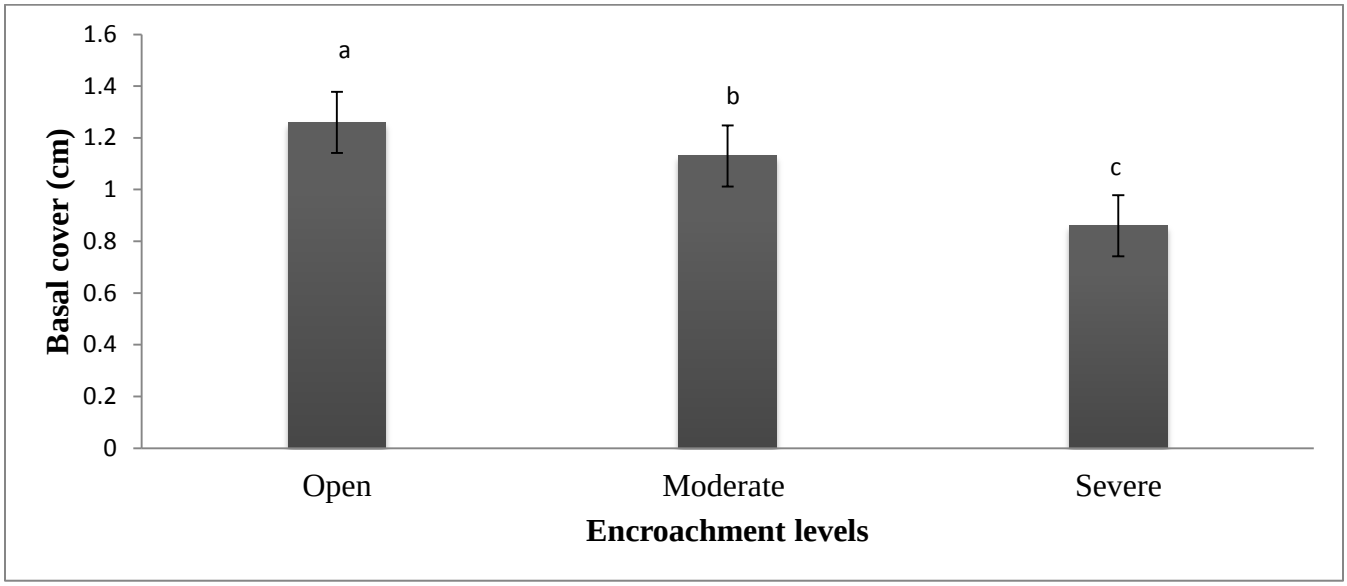

Figure 4.1 Mean basal cover (cm) in open, moderate encroached and severe encroached sites at Melani village.

[abc] Superscripts indicate differences ($p<0.05$) on the mean basal cover of three vegetation sites.

4.3.7 Different *Acacia karroo* densities and tree equivalents at Melani communal rangeland.

The *Acacia karroo* densities were significantly different ($P<0.05$) in all the sites. The tree equivalents were significantly higher in the moderate and severe while the open site had a significant low tree equivalent (Table 4.7). The diameters were significantly higher on the severe encroached site.

Table 4.7 *Acacia karroo* densities, canopy diameters and tree equivalents.

	Open	Moderate	Severe
Density (trees/ha)	349.83±128.66 [c]	2520.83 ±128.66 [b]	3650 ± 128.66 [a]
Tree equivalents (TE/ha)	319.45 ± 870.38 [b]	5103.11 ± 870.38[a]	6770.67 ±870.38 [a]
Canopy diameters (m)	1.4 ± 0.2[b]	1.4 ± 0.1[b]	1.8 ± 0.1[a]

Small letter values within the same row with different superscripts were significantly different ($P<0.05$).

4.3.8 Soil macro and micro nutrients

Table 4.8 presents the macro element concentrations of soil collected from the three encroachment sites. The results showed that soil organic C, Ca, and K did not show significant differences between the encroachment levels. However, soil Mg and P levels were highest ($P< 0.0001$) in the open site, whereas the moderate and severe encroached sites had lowest and similar values. Soil N content was significantly ($P<0.05$) higher in severe encroached site than other sites. Table 4.9 presents the soil micro nutrient concentrations of soil collected from the three encroachment levels. The results showed that Cu and Mn were highest ($P<0.05$) in the moderate and severe encroached sites. Fe was highest ($P<0.05$) in the open and moderate encroached sites. Soil Zn content was highest in the open and severe encroached sites. The soil pH was significantly higher in the open site than severe and moderate encroached sites.

Table 4.8 Mean macro nutrients in different *A. karroo* levels.

Soil nutrient	Open	Moderate	Severe	SEM
C (%)	2.02[a]	2.04[a]	2.04[a]	0.06
Ca (cmol(+)/kg)	2.51[a]	2.64[a]	2.46[a]	0.11
K (mg/kg)	203.75[a]	159.67[a]	207.67[a]	16.96
Mg (mg/kg)	1.02[a]	0.89[b]	0.87[b]	0.03

P (mg/kg)	22.75[a]	7.08[b]	9.58[b]	0.92
N %	0.11[b]	0.12[ab]	0.13[a]	0.003

Small letter values within the same row for each nutrient with different superscripts were significantly different (P<0.05).

Table 4.9 Mean micro nutrients and pH in different *A. karroo* levels at Melani communal village.

Soil nutrient	Open	Moderate	Severe	SEM
Cu (mg/kg)	1.61[b]	2.28[a]	2.58[a]	0.13
Fe (mg/kg)	89.25[a]	81.59[ab]	75.82[b]	4.45
Mn (cmol(+)/kg)	211.28[b]	239.28[ab]	301.17[a]	22.84
Zn (mg/kg)	1.22[a]	0.69[b]	0.83[a]	0.08
pH (KCl)	8.88[a]	5.03[a]	5.06[a]	2.32

Small letter values within the same row for each nutrient with different superscripts were significantly different (P<0.05).

4.4 DISCUSSION

4.4.1 Effect of *Acacia karroo* encroachment on biomass production.

Results in this study show that dry matter production is affected by season and level of encroachment (Table 4.6). Summer had higher biomass production although overall dry matter production for both seasons was low. The higher biomass production in summer can be attributed to higher rainfall and temperatures (Sherry *et al.,* 2009). It is speculated that higher rainfall in summer contributes to the increased leaf production and leaf area of the grasses thereby promoting production per plant (Ward *et al*., 2004). The higher dry matter production in

summer might have also contributed to higher moisture content. In a study that was conducted in the region of central western Spain it was observed that the rainfall increases the herbaceous yield in areas that are encroached by woody plants (Cubera and Moreno, 2007; Rivest *et al*., 2011) and our results correspond with those results.

Biomass production was significantly affected by the encroachment level where moderate and severe encroached sites had the higher biomass production than the open site. This may be associated with the higher soil fertility and moisture in the former than the latter sites. Our results agree with the study of Abdallah *et al*. (2008) who concluded that there is a linear relation between woody cover and the grass production. Trees provide better protection for the herbaceous plants growing under those canopies and this explains the improved biomass production in encroached areas (Abdallah *et al.*, 2008). A high number of plants in an area promote high fixation of soil particles which has a good impact on the soil fertility and water holding capacity. The higher biomass production on moderate and severe encroached sites might have been promoted by the higher N in the soil. Acacia *karroo* is a leguminous plant therefore it increases the supply rate of nitrogen to the grasses that grow nearer to it. The positive effects of increased woody plant density on grass biomass was also similarly reported by Abule *et al*. (2005) who indicated that the bush encroachment had a positive effect on herbaceous layer.

4.4.2 Effect on grass species composition.

The occurrence of *T. triandra* increased with the increase in *A. karroo* encroachment. These results correspond with those of Solomon and Mlambo (2010) who reported that the *T. triandra* is adapted to sub-habitats under the *Acacia brevispica*. However, although Solomon and Mlambo (2010) did their study on the effect of individual trees it can be said that the increase in the occurrence of *T. triandra* was as a result of increase in *A. karroo* encroachment. *Acacia karroo*

had a positive effect on the occurrence of *T. triandra* due to the increased soil N content (Fridel, 1987). Although *T. triandra* grows in most soils it prefers fertile soils (van Oudtshoorn, 2012), therefore we can say that the more encroached sites are more fertile than the open site. *Themeda triandra* is a good indicator of a veld in good and healthy condition (van Outshoorn, 2012). The open site had the lowest occurrence of *T. triandra* although according to van Oudtshoorn (2012) this grass species prefers open grassland. The occurrence of overgrazing was visually observed as the grass was too short. The overgrazing might have played a role in reducing the occurrence of *T. triandra* in the open areas.

Unlike *T. triandra* the occurrence of *D. eriantha* was highest in the open site than the moderate and severe encroached sites (Table 4.3). The occurrence of *D. eriantha* was highest in the open site than the moderate and severe encroached sites. *Digitaria eriantha* is a perennial tufted grass with stolons (van Oudtshoorn, 2012). The stolons that the *D. eriantha* have make it possible for this grass to escape grazing. The animals that were grazing on the open site were cattle, sheep and donkeys while the moderate and severe encroached sites were grazed by cattle and goats. Goats are more browsers than grazers therefore we can say that their pattern might have also contributed on the change in species composition in these different sites. The continuous grazing was considered as the common factor in all three sites which might have played a role in the *A. karroo* difference in encroachment levels (Angasa, 2012). The high levels of phosphorus might have also played a role in the occurrence of *D. eriantha.*

The encroachment levels of *A. karroo* showed no significant difference on the occurrence of *Cynodon dactylon* (Table 4.3) unlike the study of Mndela (2013) and Angasa (2012) who concluded that the bush encroachment had a positive effect on the occurrence of *C. dactylon.* The *C. dactylon* is a stoloniferous grass and this makes it easier for it to escape grazing (van

Oudtshoorn, 2012). In summer, moderate and severe encroached sites were dominated by highly palatable species (except *D. eriantha*) whereas the opposite was true for the less palatable species which are increaser II species. *Microchloa caffra* was the most dominant increaser species in the open site. *Microchloa caffra* has a low grazing value, grows in shallow soils and in veld that is overgrazed (van Oudtshoorn, 2012). This clearly indicates that the open site was overgrazed as it was dominated by *M. caffra*.

4.4.3 Grass tuft diameter, tuft height and basal cover.

Except for *T. triandra*, all the common grass species had wider tuft diameters in the severely encroached site. It can be suggested that the *A. karroo* encroachment accelerated grass production up to a certain level (Moustakas *et al.*, 2013). Wider tuft diameters would suggest better basal cover of the soil. There was no constant trend between the sites as diameters of some grass species were wider on the open than severe encroached and vice versa.

On the other hand the tuft heights of all grasses were generally shorter in all the sites with the exception of *S. africanus* (Table 4.6). Except for *S. africanus*, all the common grass species had low plant height in the open site compared to moderate and severe encroached sites. This could be due to the fact that *S. africanus* is an increaser III grass species. *Sporobolus Africanus* has strong leaves which are difficult to break and low forage yield which makes it not to be attractive to grazing animals (van Oudtshoorn, 2012). It is not easily uprooted by the animals. These might have all contributed to the height of *S. africanus* as it is less grazed because of the aforementioned reasons. This can also be attributed to facilitation effect by *A. karroo* in these two sites (Moustakas *et al*., 2013). The summer season had a positive effect on the height of the grass as the grass was taller in summer than in winter. These results agree with those of Moustakas *et al*. (2013) who suggested that rain plays a role in the nature of tree-grass

interactions. Basal cover was lower in open areas compared to encroached sites. Better basal cover improves water absorption for plants and leads to less evapotranspiration (Moustakas *et al*., 2013).

4.4.4 Effects of *Acacia karroo* encroachment on soil minerals.

Nutrients such as macro and micro minerals are very important to the plant nutrition and can also act as the determining factors of vegetation productivity, structure and composition (Smit, 2004). Trees may act as biological agents leading to more fertile soils occurring in areas that are dominated by trees than open areas. The results of this study showed that the *A. karroo* encroachment levels had no significant effect on organic C, Ca and K values. These results correspond with those of Solomon et al. (2007), who indicated that the soil organic C did not differ with the difference in encroachment levels. Moreover, it has been reported that woody plants improve soil carbon through their leaves and seed droppings (Solomon *et al*., 2007) but this was not the case with our study as there was no significant difference in all the sites. The low organic content in the sites can be attributed to the absence of moribund due to overgrazing (Abule *et al*., 2005).

The sites had no significant effects on the of Ca and K contents. These results are in contrast with those of Abdallaht *et al*.,(2012), who recorded higher Ca content under canopied sites than uncanopied sites. However, Abdallah *et al*., (2012) conducted their study in Tunisia. Hagos and Smit (2005) also recorded highest Ca values under *A. karroo* trees. Calcium is a major nutrient for normal plant growth and is essential for reducing soil acidity (Ashraf *et al.,* 2006). Magnesium and phosphorus were significantly higher on the open site than the moderate and severe encroached sites. These results contrast those that were reported by Abdallah *et al.,* (2012) who found high magnesium contents under tree canopies than in open lands. Grazers such

as cattle, sheep and donkeys spent most of their time grazing on the open site than the moderate and severe encroached sites. High soil P content on the open site agrees with the results of Sigua *et al. (*2011) who recorded high soil P in areas that were grazed the most. Animals tend to prefer certain areas than others on the rangeland as these animals preferred the open site.

High soil P content in the open site can be attributed to the inputs and outputs of the livestock that include excretions through faeces, urine and phosphorus loss into soils (Sigua et al.,2011). Grazing animals play an important role in phosphorus content in the soil through mineral excretion as they affect phosphorus cycling because of the return of phosphorus through mineral excretion (Sigua *et al*., 2011). Plant growth depends on variety of nutrients for many processes that are responsible for photosynthesis. The evaluation of micro minerals is very important so as to know the production capacity of the soil. Micro nutrients include elements such as Cu, Mn, Zn and Fe (Tiedemann and Lopez, 2004). In the current study, soil Cu and Mn levels were highest in the encroached sites compared to open site. This showed that tree leaf fall and animal droppings in more encroached sites might have played a role in the high soil Cu and Mn levels (Hagos and Smit, 2005).

The soil Zn content at Melani village ranged between 0.69 and 1.22 g/kg where the open site had the highest Zn content. The results showed that the Zn content is within the acceptable amount as it is within the quantities of 0.15 and 6.56 mg/kg as suggested by Tyrer *et al*.,(2007) and these amounts cannot lead to plant growth retardation. Soil Cu levels were also found to be within the required levels as suggested by Rhue and Kidder (1983), who suggested the normal levels of Cu to be 0.3 mg/kg. Open site had significantly higher soil pH (KCl) showing that the moderate and severe encroached sites had acidic soils while open site had alkaline soil. These results agree with those of Gemedo-Dalle (2004) who reported that soils become more acidic with the increase

in bush encroachment. The actual reasons for differences in soil pH on encroached areas are not well known (Hagos and Smit, 2005).

4.5 Conclusion.

The study showed that *Acacia karroo* had a positive effect on grass production up to a density of 2520 trees per ha after which it decreased. The encroached sites were dominated by highly palatable grass species than the open site. The grass biomass production was highest in encroached sites than the open site. *Acacia karroo* had a positive effect on the occurrence of *T. triandra* due to the increased soil N content. In summer, moderate and severe encroached sites were dominated by highly palatable species (except *D. eriantha*) whereas the opposite was true for the less palatable species which are increaser II species.

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Chapter 5. General discussion, conclusion and recommendations

5.1 General discussion.

Acacia karoo supports the growth of palatable grasses species such as *T. triandra* (57.6%) as they were abundant under the canopies of *A. karroo* (Table 3.1). Apart from species composition, the *A. karroo* the canopies also improved the biomass production. The grass biomass production was higher under tree canopies than open habitats. Although grass biomass production was higher under tree canopies it differed between tree sizes. *A. karroo* trees above the height of 2.5m had less grass biomass production as compared to trees which are >2m – 2.5m in height. The grasses appeared to be taller under tree canopies than open habitats although the differences were not significantly different. However, the tree heights had a significant effect on the grass height. The high grass biomass production under *A. karroo* trees can be attributed the conducive

influence of the micro-environment which might have led to increases in moisture content and soil fertility (Smit, 2004).

The high dry matter production can also be attributed to high yielding *T. triandra* which grew in association with tree canopies. This study demonstrated that isolated individual *A. karroo* trees improved grass productivity under canopy than open habitats. This implies that the grass production and the livestock production may be favoured by the occurrence of *A. karroo* trees up to a certain density and height. Therefore, this suggests that the *A. karroo* trees have a positive effect on the grass production and that they should not be totally removed from the rangeland but they should be controlled to maintain desirable and highly desirable grass species. Many researchers have come up with several theories to explain this phenomenon.

The rangeland at Melani village displayed signs of overgrazing that were revealed by the transition from open site, to encroached sites. The signs include the change in grass species composition and the increase in grass biomass production from open to encroached sites (Table 4.2 and Table 4.6). The open site was dominated by the less palatable species with only *D. eriantha* being the most common highly palatable grass species. The grass biomass production increased up to a certain density after which it decreased. *Acacia karroo* increase beyond the minimum threshold has negative consequences of reducing grass biomass production (Dube *et al*., 2009). *A. karroo* also hinders the accessibility of herbaceous vegetation in dense areas while their browse is also less accessible to browsers (Moleele et al., 2002). The *A. karroo* browse material browse material becomes less acceptable because of physical and chemical deterrents (Moleele et al., 2002).

The more encroached areas were those that were very far from the homesteads. The open site appeared to be more overgrazed than the moderate and severe encroached sites. The biomass was very low in all the sites, below the minimum threshold of 800 kg/ha for protection against land degradation (Teague *et al*., 2009). The grass biomass production was also less than the recommended level of 1500 kg/ha (Teague *et al.*, 2009) for animal production. The low grass biomass production at Melani means that the rangeland is vulnerable to land degradation. Therefore, the farmers at Melani village should take further steps to prevent more overgrazing from occurring which can lead to land degradation. However, Fort Hare farm had higher biomass production which is above 800 kg/ha. While the grass biomass production was above 1500 kg/ha in summer it was below 1500 kg/ha in winter.

The grass production at the University of Fort Hare farm is the true reflection of the Melani rangeland potential meaning that with good rangeland management Melani rangeland can be able to produce as much grass as the University of Fort Hare farm. Therefore, this suggests that the farmers have to properly manage their livestock so as to avoid overgrazing. The low biomass production poses negative implication on the animal production in the communal tenure system. Apart from overgrazing, drought and high inconstant rainfall and drought events were alleged as the causes of rangeland decline at Melani village. Periodic rainfall events may interchange with anthropogenic factors such as fire and heavy grazing to increase bush density (Angasa, 2005). Severe grazing in communal rangelands has very negative impacts on the rangeland condition through repeated consumption of plant seeds leading to reduced seed number of grazed plants (Snyman, 2004 and Solomon, 2011). The *A. karroo* trees had a positive influence on the basal cover as the cover improved with the increase in its encroachment levels.

Although the grass biomass production was generally low in all the sites the soil nutrients levels were above the recommended levels for rangelands (Baker and Gourley, 2011). The tree canopies improved the levels of many soil nutrients. The soil pH was also higher under tree canopies than open habitats while it was very low on the open habitats. These results showed that *A. karroo* has positive effects on soil chemical properties. The improved soil fertility under tree canopies led to improved biomass production. Soil fertility also improved with the increase in *A. karroo* density. This indicates that tree leaf fall is an important factor that contributes in soil fertility. On the other hand open habitats and open sites had low soil nutrients than canopied habitats and encroached sites.

5.2 Conclusion

Acacia karroo influences herbaceous layer under tree canopies. The more palatable grass species occurred under canopies than open habitats. *Themeda triandra* was dominant under tree canopies than open habitats. The grass biomass production and basal cover improved under canopies than open habitats. *Acacia karroo* improves grass growth up to a certain height after which it decreases. *Acacia karroo* density has a positive influence on grass production to a certain level after which it decreases. Soil fertility improves with the increase in *A. karroo* density. The interaction between *A. karroo* and grass is not always competitive. More research needs to be done to determine the morphological and the physiological attributes that grasses have pertaining bush encroachment. Poor management of *A. karoo* may have negative impacts in agricultural production as the grass production can be reduced.

5.3 Recommendations

At the University of Fort Hare grass grew well under > 1.5m – 2m and >2m – 2.5m nd deteriorated under > 2.5m trees, therefore it is recommended that the *A. karroo* trees be

maintained at the heights below 2.5m so as to avoid competition. It is recommended that the taller trees be removed through selective thinning so as to maintain higher grass biomass production. At Melani village the moderate encroached site performed better than the open and the severe encroached site. Therefore this suggests that the farmers should target moderate encroachment in order to improve their rangeland condition. Due to the fact that overgrazing has been identified as one of the major problems leading to bush encroachment, it is recommended that farmers formulate rules and regulations to manage grazing lands. The rules should be formulated in such a way that will lead to rangeland improvement.

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APPENDICES

Appendix 1 Ethical clearance certificate

University of Fort Hare
Together in Excellence

ETHICAL CLEARANCE CERTIFICATE
REC-270710-028-RA Level 01

Certificate Reference Number:	BEY091SMAG01
Project title:	**Effects of *Acacia karoo* Encroachment on Rangeland Productivity in the Semi Arid Savannas of the Eastern Cape, South Africa.**
Nature of Project:	Masters
Principal Researcher:	Thabo Pactrick Magandana
Supervisor:	Prof S.T Beyene
Co-supervisor:	

On behalf of the University of Fort Hare's Research Ethics Committee (UREC) I hereby give ethical approval in respect of the undertakings contained in the above-mentioned project and research instrument(s). Should any other instruments be used, these require separate authorization. The Researcher may therefore commence with the research as from the date of this certificate, using the reference number indicated above.

Please note that the UREC must be informed immediately of

- Any material change in the conditions or undertakings mentioned in the document
- Any material breaches of ethical undertakings or events that impact upon the ethical conduct of the research

Appendix 2 ANOVA tables

Individual trees ANOVA tables

Dependent variable: dry matter

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treesize	2	3155856.21	1577928.10	1.49	0.2296
Habitat	1	763429.10	763429.10	0.72	0.3974
Seasons	1	62217885.08	62217885.08	58.83	<.0001
Treesize*Habitat	2	2078256.46	1039128.23	0.98	0.3777
Treesize*Seasons	2	2642189.21	1321094.61	1.25	0.2909
Habitat*Seasons	1	1645756.36	1645756.36	1.56	0.2150
Treesi*Habita*Season	2	2139469.53	1069734.76	1.01	0.131

Individual trees dominant grass species ANOVA table

Dependent variable: *Cymbopogon plurinodis*

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treesize	2	5393.807426	2696.903713	3.04	0.0525
Habitat	1	837.066156	837.066156	0.94	0.3338
Seasons	1	423.075674	423.075674	0.48	0.4915
Treesize*Habitat	2	1370.918042	685.459021	0.77	0.4646
Treesize*Seasons	2	2720.049170	1360.024585	1.53	0.2212
Habitat*Seasons	1	74.740910	74.740910	0.08	0.7722
Treesi*Habita*Season	2	1319.549116	659.774558	0.74	0.4781

Dependent variable: *Sporobolas africanus*

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treesize	2	665.281582	332.640791	1.87	0.1601
Habitat	1	11.229934	11.229934	0.06	0.8022
Seasons	1	15.493956	15.493956	0.09	0.7686
Treesize*Habitat	2	69.671531	34.835765	0.20	0.8226
Treesize*Seasons	2	2752.332219	1376.166110	7.73	0.0008
Habitat*Seasons	1	101.000453	101.000453	0.57	0.4532
Treesi*Habita*Season	2	183.947237	91.973619	0.52	0.5982

Dependent variable: *Cynodon dactylon*

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treesize	2	182.9375507	91.4687753	0.70	0.4972
Habitat	1	165.4382993	165.4382993	1.27	0.2620
Seasons	1	202.5276585	202.5276585	1.56	0.2149
Treesize*Habitat	2	103.1937027	51.5968513	0.40	0.6734
Treesize*Seasons	2	105.8340783	52.9170391	0.41	0.6666

Habitat*Seasons	1	208.2742283	208.2742283	1.60	0.2086
Treesi*Habita*Season	2	239.2639795	119.6319898	0.92	0.4018

Dependent variable: *Themida triandra*

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treesize	2	13656.24096	6828.12048	10.48	<.0001
Habitat	1	309.99820	309.99820	0.48	0.4921
Seasons	1	1304.33819	1304.33819	2.00	0.1605
Treesize*Habitat	2	7545.54622	3772.77311	5.79	0.0043
Treesize*Seasons	2	13092.23419	6546.11709	10.04	0.0001
Habitat*Seasons	1	61.56135	61.56135	0.09	0.7593
Treesi*Habita*Season	2	432.68956	216.34478	0.33	0.7184

Dependent variable: *Digitaria eriantha*

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Treesize	2	61.689069	30.844534	0.25	0.7794
Habitat	1	243.392936	243.392936	1.97	0.1635
Seasons	1	1087.341944	1087.341944	8.81	0.0038
Treesize*Habitat	2	375.849262	187.924631	1.52	0.2234
Treesize*Seasons	2	14.842819	7.421409	0.06	0.9417
Habitat*Seasons	1	166.941269	166.941269	1.35	0.2477
Treesi*Habita*Season	2	288.908912	144.454456	1.17	0.3147

Individual trees soil nutrients ANOVA tables

Dependent Variable: Organic carbon

Source	DF	Type III SS	Mean Square	F Value	Pr > F
treesize	2	1.05832333	0.52916167	8.02	0.0009
habitat	1	0.07350000	0.07350000	1.11	0.2959
treesize*habitat	2	0.01225000	0.00612500	0.09	0.9115

Dependent Variable: Calcium

Source	DF	Type III SS	Mean Square	F Value	Pr > F
treesize	2	0.47217333	0.23608667	0.44	0.6479
habitat	1	1.08272667	1.08272667	2.01	0.1624
treesize*habitat	2	1.28277333	0.64138667	1.19	0.3125

Dependent Variable: Copper

Source	DF	Type III SS	Mean Square	F Value	Pr > F
treesize	2	24.87314333	12.43657167	18.50	<.0001
habitat	1	0.43520167	0.43520167	0.65	0.4245
treesize*habitat	2	0.78094333	0.39047167	0.58	0.5628

Dependent Variable: Iron

Source	DF	Type III SS	Mean Square	F Value	Pr > F
treesize	2	58174.04433	29087.02217	14.74	<.0001
habitat	1	1343.32017	1343.32017	0.68	0.4130
treesize*habitat	2	591.01233	295.50617	0.15	0.8613

Dependent Variable: Potasium

Source	DF	Type III SS	Mean Square	F Value	Pr > F
treesize	2	8796.13333	4398.06667	0.18	0.8392
habitat	1	45430.01667	45430.01667	1.82	0.1833
treesize*habitat	2	27484.13333	13742.06667	0.55	0.5804

Dependent Variable: Magnesium

Source	DF	Type III SS	Mean Square	F Value	Pr > F
treesize	2	2.41252333	1.20626167	9.69	0.0003
habitat	1	0.10500167	0.10500167	0.84	0.3625
treesize*habitat	2	0.10114333	0.05057167	0.41	0.6682

Dependent Variable: Manganese

Source	DF	Type III SS	Mean Square	F Value	Pr > F
treesize	2	291994.6385	145997.3193	6.37	0.0033
habitat	1	579.2069	579.2069	0.03	0.8743
treesize*habitat	2	5755.5723	2877.7861	0.13	0.8822

Dependent Variable: Nitrogen

Source	DF	Type III SS	Mean Square	F Value	Pr > F
treesize	2	0.00489333	0.00244667	8.58	0.0006
habitat	1	0.00016667	0.00016667	0.58	0.4479

treesize*habitat	2	0.00033333	0.00016667	0.58	0.5609

Dependent Variable: Phosphorus

Source	DF	Type III SS	Mean Square	F Value	Pr > F
treesize	2	5290.233333	2645.116667	33.99	<.0001
habitat	1	0.066667	0.066667	0.00	0.9768
treesize*habitat	2	18.633333	9.316667	0.12	0.8874

Dependent Variable: Zinc

Source	DF	Type III SS	Mean Square	F Value	Pr > F
treesize	2	0.38642333	0.19321167	2.41	0.0995
habitat	1	0.00006000	0.00006000	0.00	0.9783
treesize*habitat	2	0.09331000	0.04665500	0.58	0.5624

Bush density ANOVA tables

Dependent Variable: DM

Source	DF	Type I SS	Mean Square	F Value	Pr > F
site	2	151156.5766	75578.2883	62.67	<.0001
seasons	1	53778.5091	53778.5091	44.59	<.0001
site*seasons	2	25780.7533	12890.3767	10.69	0.0022

Species composition

Dependent Variable: *Cynodon dactylon*

Source	DF	Type I SS	Mean Square	F Value	Pr > F
site	2	1.00000000	0.50000000	0.03	0.9708
season	1	0.34722222	0.34722222	0.02	0.8881
site*season	2	21.44444444	10.72222222	0.64	0.5456

Dependent Variable: *Cymbopogon plurinodis*

Source	DF	Type I SS	Mean Square	F Value	Pr > F
site	2	12.44444444	6.22222222	3.61	0.0591
season	1	4.01388889	4.01388889	2.33	0.1528

site*season	2	34.77777778	17.38888889	10.10	0.0027

Dependent Variable: *Digitaria eriantha*

Source	DF	Type I SS	Mean Square	F Value	Pr > F
site	2	441.0011111	220.5005556	5.57	0.0195
season	1	216.3200000	216.3200000	5.46	0.0376
site*season	2	181.4233333	90.7116667	2.29	0.1437

Dependent Variable: *Sporobolas africanus*

Source	DF	Type I SS	Mean Square	F Value	Pr > F
site	2	86.02777778	43.01388889	1.28	0.3143
season	1	12.50000000	12.50000000	0.37	0.5538
site*season	2	18.08333333	9.04166667	0.27	0.7691

Dependent Variable: *Themida triandra*

Source	DF	Type I SS	Mean Square	F Value	Pr > F
site	2	3210.194444	1605.097222	11.92	0.0014
season	1	43.555556	43.555556	0.32	0.5800
site*season	2	305.027778	152.513889	1.13	0.3543

Bush density soil nutrients ANOVA tables

Dependent Variable: Organic carbon

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00333889	0.00166944	0.03	0.9666
Error	33	1.62082500	0.04911591		
Corrected Total	35	1.62416389			

Dependent Variable: Calcium

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.19770556	0.09885278	0.63	0.5366
Error	33	5.14215000	0.15582273		

Corrected Total	35	5.33985556			

Dependent Variable: Copper

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	5.86523889	2.93261944	14.43	<.0001
Error	33	6.70661667	0.20323081		
Corrected Total	35	12.57185556			

Dependent Variable: Iron

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1087.953267	543.976633	2.29	0.1173
Error	33	7844.197733	237.702962		
Corrected Total	35	8932.151000			

Dependent Variable: Potasium

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	17050.7222	8525.3611	2.47	0.1000
Error	33	113861.5833	3450.3510		
Corrected Total	35	130912.3056			

Dependent Variable: Magnesium

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.16300556	0.08150278	7.23	0.0025
Error	33	0.37185000	0.01126818		
Corrected Total	35	0.53485556			

Dependent Variable: Manganese

		Sum of

Source	DF	Squares	Mean Square	F Value	Pr > F
Model	2	50770.6940	25385.3470	4.05	0.0266
Error	33	206595.5037	6260.4698		
Corrected Total	35	257366.1977			

Dependent Variable: Phosphorus

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1700.222222	850.111111	82.98	<.0001
Error	33	338.083333	10.244949		
Corrected Total	35	2038.305556			

Dependent Variable: Zinc

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1.82437222	0.91218611	12.01	0.0001
Error	33	2.50719167	0.07597551		
Corrected Total	35	4.33156389			

Dependent Variable: pH

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	117.562222	58.781111	0.91	0.4113
Error	33	2125.134167	64.398005		
Corrected Total	35	2242.696389			

Dependent Variable: Nitrogen

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	0.00141650	0.00070825	5.19	0.0110
Error	33	0.00450225	0.00013643		
Corrected Total	35	0.00591875			