WOODY ENCROACHMENT AND PLANT-ROOT SOIL INTERACTIONS IN A SEMI-ARID SAVANNA

BY

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DECLARATION

I declare that “Describing the differences between three contrasting tree density classes in a semi-arid savanna: towards an improved understanding of woody encroachment’’ is my own research under the supervision of Dr K. Mopipi and Dr A.R. Palmer, and has not been submitted for any degree in any institution. All the information sources used in this thesis have been cited properly without any manipulation.

Candidate signature………………… Date…………………………….

Approved as to style and content by

Dr K. Mopipi…………………….. Dr A.R. Palmer… A.R. Palmer

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ABSTRACT

Savannas occupy 1/8 of the global land surface, support a large proportion of the world's human population and the majority of its rangeland and livestock. Woody encroachment has been reported as the major challenge in these landscapes. This study describes the differences between three contrasting tree density classes in a semi- arid savanna with the view to developing an improved understanding of woody encroachment which is prevalent in this region. The study attempted to determine if there was a relationship between lateral root distributions at varying soil depths with increasing levels of woody encroachment, and to compare species composition and soil water profiles in these rangelands.

Three homogeneous vegetation units, namely: sparsely encroached (HVU1), grassland (HVU2) and Albany thicket (HVU3) were identified for the study sites. A Trench method was used determine root biomass and a step point method was used to determine herbaceous species composition in all the HVUs. The results showed that more Decreaser species (especially *Themeda triandra*) were recorded in a sparsely encroached site (HVU1) and grassland site (HVU2), while *Cynodon dactylon* was mostly recorded in the thicket site (HVU3). *Acacia karroo* was mostly recorded in HVU1 while in HVU2 other woody species such as *Coddia rudis* and *Grewia occidentalis* were also recoded. HVU3 had the poorest basal cover (point to tuft distance) (22.60 cm) while HVU1 (9.93 cm) and HVU2 (7.73 cm) had moderate basal cover. The herbaceous standing biomass was significantly different across the HVUs. HVU3 was higher (1206.15 kg ha^{-1}) than HVU1 (942.43 kg ha^{-1}) and HVU2 (677.10 kg ha^{-1}). The soil moisture content was significantly different between the HVUs, but was not significantly different between the depths ($p < 0.05$).

High soil moisture content was recorded in HVU3 compared to other HVUs. The results of Analysis of Variance (ANOVA) showed that soil depth and the type of homogenous vegetation unit (HVU) had significant effects ($p<0.01$) on root biomass. The pair wise t-test showed that there were no significant difference in root biomass between sparsely encroached (HVU1) and grassland (HVU2) sites ($p>0.05$), but there were significant differences in root biomass between grassland (HVU2) and thicket (HVU3) site ($p<0.05$). The mean for total root biomass found in the study was 2.66 kg m^{-2}. In all the trenches most of the root biomass was found in depth 1 (0-30 cm) which was 2.43 kg m^{-2}followed by 1.32 kg m^{-2} in depth 2 (30-60 cm) and 0.49 kg m^{-2} in depth 3 (60-90 cm). According to the results on species composition, herbaceous biomass, basal cover, soil moisture content and the root biomass, Kwezana communal rangeland has a potential of running a sustainable livestock production enterprise if proper management practices can be implemented. To improve the rangelands of Kwezana communal rangelands, management such as proper resting, burning, proper stocking rates and physically clearing of bushes should be considered

Keywords: Herbaceous species composition, Homogenous vegetation units, Root biomass, Trenches, Woody encroachment.

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LIST OF ABBREVIATIONS

HVUs = Homogenous Vegetation Units

ANOVA = Analysis of variance

NCDP = Nguni Cattle Project Development project

UFH = University of Fort Hare

GMRDC = Govan Mbeki Research and Development Center

NRF = National Research Foundation

ECDRDAR = Eastern Cape Department of Rural Development and Agrarian Reform

IDC = Industrial Development Cooperation

LBM = Lowest Browsable Material

LSD = Least Significance Difference

CHAPTER 1 INTRODUCTION

1.1 Background

The majority of rangelands, livestock and a greater proportion of the global human population are supported by savanna ecosystems which occupy an eighth (20%) of the global land surface (Scholes and Archer 1997). The savanna biome is centred on the higher plateau of Southern Africa, and is also found between the wet equatorial forests and the arid regions in areas with warm, dry winters and hot, wetter summers (Skarpe 2009). The climate varies significantly in savannas (Hall and Scurlock 1991) which are well represented over the Lowveld of Mpumalanga and Limpopo Provinces of South Africa, as well as the Kalahari regions of Southern Africa, dominating landscapes in Botswana, Namibia and Zimbabwe (Adams 2013). An earlier study by Rutherford and Westfall (1994) indicated that, savannas are characterized by an upper layer of woody plants and a ground layer of grasses.

On the other hand, woody plants inhabit grasslands and convert them into savannas. They increase the complexity of the single-stratum structure by adding taller and longer lived elements. Trees affect productivity of the herbaceous undergrowth. In temperate and tropical savannas, trees are thought to reduce undergrowth plant productivity through competition for nutrients, light and water (Davis et al. 1998). A combination of trees and grasses dominate the composition of the savanna biome due to disturbances, soils and critical climates (Baldocchi et al. 2004). The ability of trees and grasses to absorb photons of light and transpire through interception varies because of the differences in their canopy covers. The regional climate can be modified by the effects of surface energy balance of a landscape and the composition (Zeng and Neelin 2000). According to Baldocchi et al. (2004), the exposure to continued dry and wet periods is a distinguished climatic feature among savannas, combined with grazing and fire which cause savanna cover to open with grass understories.

Trees and grasses maintain a balanced ecosystem and are able to co- exist in savanna through disturbance interactions.

The increasing abundance of trees in savanna rangelands has been considered as a challenge facing South African rangelands. Some plant ecologists such as van Auken and Bush (2012); Smit (2014) and Bond (2008), have identified woody plant encroachment as a developing problem since the late 19th and early 20th centuries that may affect livestock production. Woody species have invaded South African grasslands from protected sites due to a reaction to factors such as suppression of fire, abandonment of cultivation, relaxation of fuel wood harvesting and eroded hill slopes. As a result, this has been noticed in grassland of the Eastern Cape, South Africa (O'Connor et al. 2014). Therefore, a clear knowledge of tree-grass interaction may enhance the management responses of woody plant encroachment.

Furthermore, an assessment of the impact of influencing tree biomass through physical clearing requires knowledge of how trees modify the nutrient environment of grasses, light and water (Jackson 1996). Interactions between trees and grasses are characterized by strong relationships between functioning of the vegetation and its structure. Trees and grasses have different life strategies hence, they utilize diverse soil moisture reserves. Grasses have shallow root systems and are unable to access water in the deeper soil profile (Jackson 1996), while trees are able to access deeper sources of soil water (Sternberg et al. 1996). In order to characterize energy balances and water between the ecosystem and atmosphere on seasonal and annual time scales, it is essential to understand the hydrological and ecological terms that are used to describe the functions of vegetation in savannas (Silberstein et al. 2001). Long-term energy balance on savanna and annual grasslands is required to increase the knowledge of the biophysical functioning of these landscapes. A basic feature of savannas comprises the co-dominance of a constant grass layer with a discontinuous tree cover which contributes to the nutrient cycle and primary production of the ecosystem (Sternberg et al. 1996).

For instance, when the mean annual rainfall increases, the mean tree cover also increases (Bucini and Hanan 2007), but significant differences in tree cover arise with disruption and climate variation. The role of soil substrate is close to the role of water because it performs as a provisional store for precipitation inputs and as a controller for the major movements through deep percolation and evapotranspiration. Furthermore, the researchers state that the fine-textured soils support taller and denser perennial vegetation than course-textured soils in wetter climates (Bucini and Hanan 2007). There is substantial evidence to indicate that patterns of the availability of water in semi-arid and arid regions have an important effect on the presence of woody plants, and the stability between grass and woody plants distribution (Sankaran et al. 2004). Grasses utilize water sources near the surface, while woody plants are able to utilize water down the soil profile (Dodd and Lauenroth 1997). The dominant plant type in arid regions should be that which has the greatest competitive advantage in utilizing the largest soil water content.

Lavorel and Garnier (2002) argue that, water availability, light and nutrients are the key elements of plant community structure and function. In arid and semi-arid ecosystems, soil moisture availability drives major production and affects nutrient dynamics. Plant ecosystems are composed of species with numerous adaptations for obtaining and preserving soil moisture. When water necessities and rooting forms are similar, competition may arise. Woody plants and grasses are often expected to co-exist by separating the soil water (Midwood et al. 1998). Therefore the structure stability of tree patches in the savanna relies upon symmetry and intensity of evapotranspiration of species interactions. Moreover, co-existence of species in tree-grass ecosystems may be completed through horizontal and vertical stratification of roots which decrease below ground competition for nutrients and water (Midwood et al. 1998).

Carbon and energy from plant canopies to soils is transferred through roots. Within the sub canopy zone, root systems of some tree species are perhaps very significant factors in nutrient absorption. Some trees seem to have extensively spreading lateral roots, though the interspecific variation is high (Carter and O'Connor 1991). The root systems of mature trees may take up the nutrients found in low concentrations throughout the soil profile. The total nutrient source to the field layers is improved if nutrients are absorbed by the tap roots of woody species (Vetaas 1992). Furthermore, if nutrients are taken up by the lateral roots, there is relocation within the surface root zone and may encounter the effect of percolating of nutrients in less dry savanna. Estimating the root biomass of forests has expanded a lot of interest because of their role in regulating cycling of nutrients and carbon (Craine et al. 2003). Various methods for estimating the root biomass in the above ground tree component has also been recognised, however root biomass is challenging to measure in an ecosystem (Cairns et al. 1997). In woody plants, fine roots are the organs that acquire water which represent a low percentage of total root biomass of a mature tree (Craine et al. 2003).

The effects of trees on grasses may depend on the explicit appearances of the tree and grass growth forms, photosynthetic pathways, photosynthetic habitat and resource requirement (Scholes and Archer 1997). Any variations in savanna vegetation structure are a consequence of composite, mostly long-term, ecological interactions. Grass biomass productivity which in turn disturbs mortality and the establishment of trees and shrubs is determined by the amount of rainfall (Tews et al. 2006). Grazing livestock has been proposed by Tews et al. (2006), as the key threat for vegetation structure of South African savannas that lead to decrease in grass biomass and increases water availability for woody plants hence woody encroachment. Veld deterioration, which leads to decreased animal production and soil erosion, has long been a serious challenge in the rangelands (Trollope 1986). One of the reasons accredited to sustained rangeland deterioration has been the lack of any normally appropriate measurable method of determining the condition of veld relative to its potential under good management (Snyman and Fouche 1993). Hence, researchers have often struggled in measuring the impacts of management on small and large areas, and perhaps of greater importance, has been the failure of advisory personnel and landowners to assess the relative condition of veld (Trollope et al. 1989).

The methods for evaluating veld condition in the agricultural sector in South Africa are useful for determining the current condition of the veld and for recommending appropriate veld management practices (Trollope et al. 1989). An assessment of the veld condition shows what technique would be useful for assessing and managing the impacts of management practices on the vegetation (Foran et al. 1978). Of specific attention is the impact of the practices on the forage production potential of the grass sward and its capacity to defend the soil from erosion. Also important, is the consequence of the managements on the capacity of the veld to support a fire as this regulates the potential efficiency of burning in monitoring bush encroachment (Trollope 1990). An evaluation of methods used to index veld condition showed that the common provided indices were insensitive to long-term grazing impact (Hardy and Hurt 1989). However, certain species were found to either increase or decrease in relative abundance with an increase in grazing intensity (Mentis 1981). Numerous features of a technique that are currently developed to measure the agro-ecological condition of veld were determined.

1.2. Problem statement

In savannas, trees and grasses interact strongly with one another. Trees are strong competitors for light and soil resources, mainly where livestock production is a key land use practice (Roques et al. 2001). Eastern Cape communal rangelands are altered by the existence of woody plants which reduces the productivity of the herbaceous layer and may even lead to rangeland degradation. These rangelands are the primary source of feed for communal livestock production which people rely on. There are no studies that have been conducted in the communal rangelands of the Eastern Cape, South Africa to assess root interactions between grasses and woody plants. Riginos (2009) reported that one of the most intensely studied topics in terrestrial ecology is the co- presence of trees and grasses in savanna system. Communal people lack knowledge about the effects of woody plants on species composition. The root biomass of a woodland ecosystem is difficult to measure and little is known about above ground biomass. Herbaceous species composition layer (root/shoot) changes at the scale of tree and may respond individually from the isolated tree (Scholes and Archer 1997). However, Wigley et al. (2009) reported that woody plant encroachment is a worldwide problem in savanna rangelands and its abundance is driven by land use management such as heavy stocking rates with heavy grazing, altered burning practices and absence of fire, changes in fire regime, livestock grazing pressure, change in climate, loss of browsing herbivores and overgrazing (O’Connor et al. 2014). Changing climates, atmospheric nitrogen deposition and elevated carbon dioxide also lead to woody plant encroachment (Higgins et al. 1999; Higgins et al. 2000). These can again be compared with the long term changes in savannas under diverse land use systems which have altered effects on woody plant encroachment because of human population density, crop farming, herbivore density and fire management (Wigley et al. 2009).

1.3. Justification

Tree-grass interactions in savanna ecosystems may be strongly influenced by abiotic and biotic factors. Trees and shrubs can provide several ecosystem services such as improved forage quality for browsing livestock. The interaction results in changes in the vegetation composition and structure to produce substantial changes in carbon and nitrogen dynamics.

The maintenance of the mixed tree-grass state is, however, essential to the continued functioning of savanna ecosystem (Scholes and Archer 1997). Savannas of communal rangelands of Eastern Cape are mainly used for livestock grazing and production, but are being encroached by *Vachelia karroo* (*Acacia karroo*) and other woody species, which are able to absorb deeper soil water while grasses cannot. The growth in the density of woody plants is diverse and complex. An additional reason for close assessment of root interaction between grasses and woody plants in an African environment is that the available literature is dominated by North American research (e.g. van Auken and Bush 2012), although others such as Archer (et al.1995) have done research on woody plants encroachment in African savannas. Therefore a more scientific understanding about the causes of vegetation structure and dynamics in these savannas is significant for the control of woody plant encroachment to increase grass production for livestock production (Roques et al. 2001). This study will contribute to understanding the role of tree-grass root interactions and make recommendations on the adaptive strategies needed to control tree densities in rangelands to improve grass production.

1.4. Objectives

- To determine botanical composition, veld condition, basal cover and above-ground standing biomass of rangelands with varying levels of woody encroachment in Kwezana communal rangelands.
- To describe the soil moisture profile of Kwezana communal rangeland with increasing levels of woody plant encroachment.
- To determine root biomass and determine if there is a relationship between lateral root distributions at varying soil depths with distance from the main tree stem.

- To quantify changes in total fine and coarse root biomass with increasing soil depth and levels of woody plant encroachment.

1.5. Key questions

- Are there significant differences in the total root biomass between highly encroached and un-encroached landscapes?
- How does the total root biomass of the Kwezana communal rangeland compare with the results from studies in other semi-arid savannas?
- Are there any significance differences in species composition between three contrasting tree density classes in a semi-arid savanna?
- How does soil water content differ with different levels of encroachment?

CHAPTER 2 LITERATURE REVIEW

2.1. An over view of a savanna ecosystem

Savanna is an ecosystem categorized by the vegetation with herbaceous, usually graminoid layer, with an upper layer of woody plants, which can vary from widely spaced to 75 % canopy cover (Rutherford and Westfall 1986; Scholes and Archer 1997). Savannas cover about 40 % of the land surface of Africa and many people depend on the services of savanna ecosystems (Higgins et al. 1999). Climate and edaphic factors are the major determinants of the distribution of savanna. Climate, soil fire and herbivory are the external regulators of the comparative abundance of these two components. The herbaceous layer occurs mostly outside the effect of the rooting zone of the woody plants and the competition for water between them is an essential element of savanna (Scholes and Archer 1997). Trees have an observable influence on the micro climate under their canopies. Soil moisture does not vary between the open and tree canopy areas, rainfall may also counteract the influence of canopy shade on soil moisture. Tree canopies stop rainfall and reallocate the water from the ground to the atmosphere by evaporation.

Given this backdrop, if woody plants are lacking the land cover should be categorised as grassland and if the woody plants are so dense, with no grasses land cover should be classified as woodland. The density of trees and grasses can affect important aspects of ecosystem function, including hydrology, carbon, nitrogen storage and cycling, grass and herbivore productivity (Scholes and Archer 1997). The type, quantity and the functioning of savanna ecosystem can be changed by the type of land use practice. Different practices such as wildlife, cattle farming and subsistence are widely practiced in the savanna landscapes (Grossman and Gandar1989). Research studies show that, livestock production in the semi-arid Thornveld of the Eastern Cape of South Africa is established on the incorporation of grazing animals and browsers. This multi-species approach, using grazers and browsers is designed to promote the effective utilization of the herbaceous plants and utilization and control of encroachment (Stuart-Hill and Tainton 1989). Grass production is low at high tree densities and veld degradation is known to increase in such cases.

2.2. Factors influencing the structure and function of savannas

Trees and grasses co-exist to create the characteristics of savanna ecosystem. Relative abundance and spatial patterns of grasses and woody plants in savannas are influenced by dynamic interactions among soils, climate, topography, herbivory and fire. It has been suggested by Wilson and Bowman (1994), that trees and grasses avoid competition by utilizing different soil surface resources and their abundances is due to edaphic variations, differential impacts of fire and herbivory. In furtherance to the above views, vegetation changes in savannas occur as a result of an individual plant's response to the environment (Wilson and Bowman 1994). The structure and functioning of savanna ecosystem is influenced by human activities (Scholes and Archer 1997). Water, nutrients, fire and herbivory have been recognized by Sankaran et al. (2004) as the primary factors which are determinants of savanna structure and function. Water and nutrients are considered as primary determinants while grazing and fire are presenting modifiers. The differential capacity to obtain and partition limiting resources is the reason why trees and grasses coexist in savannas. The effects of climatic change and disturbances vary between life history stages of trees. The use of fire by hominoids has increased the frequency of fire in savannas and the present patterns of vegetation allocation in savanna landscapes reflect the activities of earlier inhabitants of the region. Tree-grass mixtures have been influenced by increasing human population. Herbaceous degradation and woody plants encroachment have increased due to suppression of fire, over hunting and introduction of heavy livestock grazing (Scholes and Archer 1997; Skarpe 1992).

2.3. Root and shoot competition in savannas

Competition is significant in natural plant communities. Variations in the competitive ability of plant species is known to determine their persistence and abundance in communities. Competitive ability can be separated into competitive response and competitive effect (Peltzer and Kochy 2001). It is further argued that, in unfavourable conditions, good competitors are able to survive suppression by neighbours and survive longer at low resource levels. Consequently, it has been demonstrated in highly controlled environment that there is a difference in competitive effect among species (Peltzer and Kochy 2001). Larger trees are the strong competitors against grasses, therefore grasses have a minimal effect on the growth and survival of bigger trees (Riginos 2009). However, grasses are assumed to suppress tree seedling establishment but do not to have a competitive effect on larger trees (Riginos 2009). Strong competition for limited soil moisture can exist between larger trees and grasses. Trees are able to coexist with grasses and shrubs during competition (Riginos 2009) and are known to obtain nutrients and water from lower layers of soil than grasses.

Competition based models (Figure 2.3.) are estimated on the standard functional mechanisms of co-existence and variances in resource acquirement of trees and grasses (Scheiter and Higgins 2007). Spatial differences between trees and grasses coexist in order to focus on intra-relative to inter-relative life form competition (Chesson and Huntley 1997). On one hand, the demographic bottleneck model argues that the main challenge for savanna trees is not competitive in nature but demographic (Higgins et al. 2000). Successful tree seedling germination is limited by disturbances such as grazing, fire and climatic variations where trees and grasses persist. The impact of various drivers such as herbivory, fire and climate variability are incorporated by the demographic bottleneck model. In plants, much of the competition takes place underground for resources such as soil minerals and water (Casper and Jackson 1997). Competition is important in natural plant community because the botanical composition of a mature plant community is determined by competition.

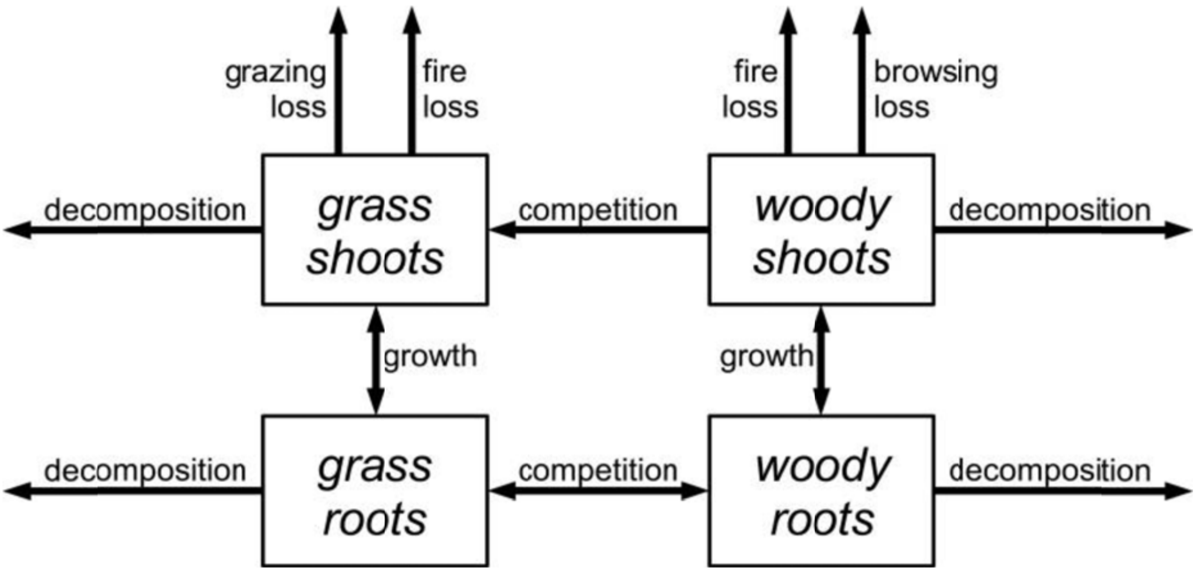


Figure 2.3: Theoretical representation of the tree-grass competition model. Belowground and above ground sections of grasses and trees (Scheiter and Higgins 2007).

2.4. Species composition in savanna landscapes

Herbaceous vegetation, perennial grasses and trees are the major characteristics of the savanna composition (Skarpe 1992). It has been reported by Skarpe (1996), that there are changes in the subtropical savanna ecosystem from over the period of 1858. Human land use is the most significant reason for change in the savanna biome which interacts with climate change (Skarpe 1996; Vitousek 1994). Changes in plant communities have not been hidden and have been affected by the allocation of diverse species according to their various environmental tolerances (Sankaran et al. 2004). An improved knowledge of the interactions between the environment and plants has become vital with existing changes in atmospheric composition, nutrient cycling, land use and existing global change (Cramer and Leemans 1993).

Rainfall and the resultant extent to which soils are leached can influence the distribution of 'sour' and 'sweet' grasslands. Sour grasslands refer to those rangelands that become unacceptable (to the herbivore) and less nutritious at maturity, while sweet grassland retains their acceptability and nutritive value after maturity (Tainton 1999). Savanna communities are species rich (Strydom and King 1999). Differences have been recorded in species composition between open grassland and sub canopy areas in savannas found in South Africa (Carter and O'Connor 1991). Spatial patterns due to slight change in climate and soil nutrient are caused by the indirect and direct effect in species composition, away from the tree trunk (Vetaars 1992). Species found below and outside covers have various eco- physiological traits in order to survive desiccation and shading. It is not easy to mention the direct factors to which various species respond to since there has been a limited attempt to separate the interactive factors initiated by the woody canopies (Blackmore et al. 1990). Factors such as fire and herbivory interacting with the occurrence of canopy micro habitat at the landscape scale will increase habitat variety in a savanna as compared to open grassland (Vetaars 1992). Better herbaceous production beneath tree cover can be described by the tree enriching the sub canopy soil at the expense of the nutrient content of open grassland (Archer 1990).

2.5. Vegetation cover and root biomass in savanna landscapes

Vegetation cover is the vertical projection of the top area and is vital factor for livestock production (Purevdorj et al. 1998). It is an essential indicator for degradation in arid and semi-arid lands. Vegetation cover also plays a vital role in determining the dynamics and morphology of desert. According to Lancaster and Baas (1998) vegetation cover protects the soil from direct trapping of the sand movements and extracting the momentum from air flow and is an important factor for a grass land status (Purevdorj et al. 1998). Vegetation degradation in African savanna biome is continuing towards desertification of some areas, with the loss of the vegetation strata, woody encroachment and landscape closure with increase of shrub-tree strata (Jacquin et al. 2010). There is growing interest in precisely estimating the annual production and total biomass of savannas, woodland and forests because of their role in modifying the cycling of carbon and nutrients. This has led to a diversity of well-known methods for determining the biomass of above ground tree components, but root biomass is not easy to determine in any forest or woodland ecosystem (Cairns et al. 1997).

Jackson et al. (1997) suggests that about half of the carbon being cycled is from root biomass production, and it is therefore important to obtain accurate estimates of below ground biomass. Thus, it is a paramount that root biomass should not be estimated using interactions developed in other ecosystems for scaling up in worldwide modelling efforts to predict forest growth responses to environmental stress (Vogt et al. 1998). Root biomass and production should be studied because few studies have been conducted (Scholes and Archer 1997), due to the extent of complexity and time linked with the methods of sampling approaches (Castro and Kaufman 1988). Trees have extremely unpredictable allocations of phothosynthates to fine roots, hence evaluation of fine root dynamics are related to the estimates of production and turn over. It is essential to investigate the role of roots in the savanna carbon cycle. However, the impact that roots have on soil biological and chemical performance can be direct or indirect (Vogt et al. 1991).

2.6. The role of soil water in savannas

Soil water content and the availability of water are two important factors to explore in semi-arid savannas. Trees and grasses have different abilities to absorb and intercept photons and transpire (Riginos 2009). Species composition can have an impact on the surface energy balance of a landscape, influencing the water balance. Trees and grasses have access to water in the soil surface and a healthy grass layer may out compete woody species. When water penetrates to the deeper layers of the soil, it is only available for woody plant growth (Skarpe 1990). Additionally, when the grass layer decreases more water becomes available in deeper soil layers for use by trees. Soil water capacity and spatial allocation in the soil profile can be discussed in relation to the vegetation structure (Skarpe 1990).

The balance between grass and woody plant biomass in the ecosystem is determined by water availability which has an important influence on the presence of woody plants (Dodd and Lauenroth 1997). Factors such as fire regime, grazing intensity and nutrient availability, influence savanna biome function if water is limited and therefore affect vegetation structure (Rodriguez- Iturbe et al. 1999). The impact of water stability on plants and the action of climate, soil and vegetation are primarily synthesized by soil moisture. A savanna ecosystem may suffer from water stress if soil moisture availability is limited. Variations in soil moisture are some of the causes of how certain vegetation will function (Porporato et al. 2004). The reaction to the water balance of the ecosystem primarily develops plant formations. Water accessibility is the primary factor determining ecological function and vegetation depends to the amount of rainfall and dry periods of uncertain duration. For growth and survival, plants require sustaining and sufficient level of water in their tissues (Porporato et al. 2001).

2.7. Communal rangelands and veld condition assessment

About 13 % of the entire land surface in South Africa consists of communal rangelands and are home to roughly 2.4 million people (Twine 2005; Vetter et al. 2006). Communal rangelands are the most important source of forage for livestock production which is a basic contribution to communal livelihoods. Communal livestock population in Southern Africa comprises of 52% of total cattle, 72% goats and 17% sheep (Palmer and Ainslie 2006) which is presently expected to be much higher due to exponential growth of human population. Everyone living in the community has access to the rangeland due to communal property ownership with poor management being practiced (Vetter 2005). Communal rangeland ownership was designated to formerly limit groups of black people by the former government. These communal areas are reported to be in poor condition, over populated with their rangelands being overstocked and continuously grazed (Vetter et al. 2006). Poor condition of communal rangelands resulted from poor knowledge of rangeland management (Smet and Ward 2005).

Poor rangeland administration and norms with the absence of fencing in communal rangelands also lead to continuous grazing. Even the betterment planning implemented around 1960s failed with most of fences being vandalized in communal rangeland due to free access (Vetter et al. 2005). Rangeland utilization benefits individuals while the consequences of overutilization are carried jointly by the whole community hence, degradation in these areas seems to predominate (Smet and Ward, 2006). Literature points out that, there is a need for assessment of a range condition to formulate rangeland management practices (Rezaei et al. 2006) and to estimate the extent of degradation in communal tenure systems. Range condition refers to the state of the vegetation in relation to some functional characteristic, which are usually constant forage production and resistance to accelerated soil erosion (Foran et al. 1978). An evaluation of the situation in the veld indicates a method that would be helpful for estimating and managing the impacts of management practices. On the vegetation of particular importance is the result of these practices on the forage production potential of the grass sward and its capacity to keep the soil from erosion (Trollope 1990).

Productivity of the veld can be improved and maximized by proper management. Therefore, it is advisable for a manager to know the state of the veld, since it indicates how many animals can be supported by the veld and it provides an indication of how the veld should be grazed and burnt (Trollope 1990). It is possible to select a comparatively small number of species which are characteristic to serve as indicators of different kinds of vegetation and of changes in vegetation (Acocks 1957). The state of the veld and grazing capacity of the reserve will differ from season to season due to rainfall received, history and utilization by animals (van Rooyen et al. 1999). To maintain and improve veld condition in all veld types it is vital to use optimal grazing and to prevent overgrazing (Frits 2012). Overgrazing results in replacement of palatable plants by unpalatable ones. These plants are frequently less acceptable and difficult to control, and the best remedy is to prevent them from becoming too abundant. An improved knowledge of the principles of good veld management, provide constant supply of fodder to sustain animal production, while avoiding extreme removal of top fertile soil (Tainton et al. 1999).

2.8. Importance of veld condition assessment

Veld is a collective term for native grasses, grasslike plants and shrubs that cover arid or semi-arid area (Allen et al. 2011). Vegetation is usually used to quantify veld condition since it is a more sensitive indicator of ecosystem change and is easier to measure than soil (Hardy and Hurt 1989). Veld condition assessment indicates if special management systems are essential for the veld (Smith 1988). Veld in poor condition is vulnerable to overgrazing, drought, and an increase in less acceptable grass and rainwater runoff (Frits 2012). This shows that there will be less feed available for animal. Moreover, when animals are hungry they become less selective and consume poisonous plants. These plants remain green in droughts and overgrazed areas. As a result animals die when large amount of poisonous plants are consumed (Hardy and Hurt 1989). Good veld management that provides for a growth season rest in every second or third year significantly improves both veld production and animal production (van Rooyen et al. 1999).

Numerous factors play a crucial role in determining veld condition which includes species composition, the vitality of the palatable species, basal cover and soil surface condition, rate of accelerated soil erosion and the encroachment of an area by undesirable plants and trees (Hardy 1999). Species composition can only be objectively determined, and the veld condition assessment method is thus based on this feature. The condition of a sample of veld is assessed by comparing its species composition with the species composition of a benchmark site (Camp and Hardy 1999). It is vital to assess the condition of veld to balance the ecology, stocking rate of unlike rangeland species with grazing and browsing capacity of the veld (Trollope 1990).

CHAPTER 3 RESEARCH METHODOLOGY

3.1. Description of study site

The study was conducted at Kwezana village on rangelands that are managed under a traditionally authority near Alice in the Eastern Cape. Kwezana is one of the communities which benefited from the Nguni Cattle Development Project (NCDP). In 2004, University of Fort Hare (UFH) in collaboration with the Eastern Cape Department of Rural Development and Agrarian Reform (ECDRDAR) and Industrial Development Cooperation (IDC) initiated the NCDP (Muselwa et al. 2008). The project focuses on re-introducing the Nguni cattle breed into communal areas of the Eastern Cape in South Africa (Mapiye et al. 2007). The NCDP operates in a 'pay it forward system' in which the project selects suitable communal areas and supplies the villages with two bulls and thirty pregnant heifers which are then passed on to the second community after five years (Muselwa et al. 2008). The rangelands of Kwezana (32°47'33.70"S) and (26°46'40.48"E) are at an elevation of approximately 719 m and consist of three contrasting land cover classes, these are grasslands (HVU2), grasslands recently encroached by *Acacia karroo* (HVU1), as well as a grass and Albany thicket mosaic (HVU3). These contrasting land cover classes provided an opportunity to conduct the study. Kwezana is situated approximately 80 km from the coast, in the False Thornveld of the Eastern Cape, where grasslands are being invaded by *Acacia karroo*. This semi-arid savanna is moderately fertile (Scogings 1998) and most of it is used for livestock grazing and production. The region also contains pockets of Albany thicket dominated by several species of evergreen and deciduous woody shrubs (Dziba et al. 2003). The grass cover is a dense sward dominated by *Themeda triandra*, *Panicum maximum*, *Digitaria eriantha* and *Sporobolus* species (Materechera et al. 1998). The climate is warm and temperate with a mean annual rainfall of 580 mm (Moyo et al. 2009), 70 % of which occurs in summer between October and March. Mean maximum temperature varies from 26^{o}C in July to 41^{o}C in January, while mean minimum varies from 5^{o}C to 11^{o}C in January (Materechera et al.

1998). The soils are derived mainly from shales, mudstones and dolerite stones (Hester et al. 2006).

Figure 3.1.Experimental sites at Kwezana communal rangelands.

Source: (Google Earth 2014). Point HVU1 is a sparsely encroached site, point HVU2 is Open grassland site and point HVU3 is a thicket site.

3.2. Determination of species composition

The step point method was used to determine the grass species composition of the herbaceous layer (Evans and Love 2006). This method provides a reliable estimate to determine botanical composition of herbaceous vegetation which enables one to determine the forage stand of an area (Evans and Love 2006). A 50 m by 100 m plot was demarcated and three parallel transects were laid inside the plot. To determine herbaceous species composition, 300 points were sampled in each site using a pointer, making sure that most species in the area were included. The mark on the point of shoe was used as a method to distribute the points. The observer raised the boot at angle of 30° to the ground and lowered the rod perpendicularly to the sole of the boot until it hits the ground. The plant hit by the pointer was recorded. If the pointer landed on bare ground, the nearest plant and the distance to that plant was recorded.

3.3. Determination of woody species composition

To determine the woody species composition, a 100 m by 2 m belt transect was established. A 2 m aluminium rod was laid across the 100 m belt transect and all woody plants in the transect were identified and recorded. Bush or tree height as well as the height of the lowest browsable material (LBM) for each species was also measured

3.3. Determination of basal cover

Basal cover of the area was estimated using a point to tuft distance (Hardy and Tainton 1993). While determining the species composition basal cover was also determined from the number of direct and nearest strikes on a species as a proportion of the total number of points sampled. A finger of the hand, which was estimated to be equal to 2 cm, was used to calculate the distance between the pointer and the nearest plant. When it pointed on a bare ground, the distance between the pointer and the nearest plant was calculated. If the pointer pointed in a plant, it was recorded zero as it was a direct strike. The mean point to tuft distance provided an estimate for basal cover and also provided a crude indication of vulnerability to soil erosion (Bennett et al. 2012).

3.4. Determination of herbaceous standing biomass

The herbaceous standing biomass was determined by harvesting the herbaceous species which was identified in each quadrant of 25 m^2. A total of 6 samples were randomly collected in each of the three homogenous vegetation units. Collected samples were then put in a paper bag, oven dried to a constant mass at 60^{o} C. The mass of the harvested samples was determined by weighing the samples on an electronic weighing scale after oven drying. After measuring the weights of the samples, the standing biomass was expressed in kg ha^{-1} and recorded on a dry matter basis.

3.5. Root biomass

Root biomass was measured using the trench method (Macinnis et al. 2009). A trench of variable length and at least 94 cm deep was excavated at each of the study site (HVU) between two large (>2.0m in height) individual *Acacia karroo* trees. At each of the three sample sites, three trenches were excavated to a depth of at least 94 cm (0-30; 30-60 and 60-94). From each trench soil cores, containing all the root material, were collected at three depths per trench (0-7cm, 57-64cm, 87-94cm). Soil cores were collected at 25cm intervals between trenches immediately adjacent to the large tree, and the middle of the trench. The same approach was used from the adjacent to the second tree and this proceeded until the middle of the trench. This was repeated for each depth until 15 samples were collected at each trench (5 sub-samples per soil depth). The stem diameter at breast height of the two trees at the beginning and end of each trench was measured using Vernier callipers. The root samples were collected by pushing a metal core of 7 cm diameter and a 9 cm height into the soil (volume 346.2 cm^3). Moreover, where large roots could not be extracted with the core, a shovel was used to remove the roots at appropriate points. The samples were then sealed in a plastic bag with rubber bands and returned to the laboratory. Root materials were extracted from the soil using a sieve and were then separated into fine roots (> 2 mm diameter) and courses roots (< 2 mm diameter). The roots were then cut, collected and recorded and put into paper bags, weighed using a weighing scale before and after oven drying at 70^{o} C for 72 hours.

The volume of a core was calculated as follows:

$$V = \pi r^2 h$$

$$= (3.14)\ (3.5)^2 (9)$$

$$= 346.19\ cm^3$$

3.6. Soil water content

Soil water content was determined gravimetrically through collection and drying of samples (Wagner et al. 1999). This was done by digging a hole of up to 94 cm deep between two trees, which were at 1m distance apart from each other. The soil samples were collected for the period of 3 months (September to November 2013) Soil samples were collected at different depths starting from the surface to the end of the trench (94 cm). A core with the volume of 346 cm^3 was used to collect the soils at appropriate points. A total of 9 samples were collected at each trench. Collected soil samples were put in sealed plastic bags to preserve their moisture content and then taken to the laboratory. At the laboratory, the samples were weighed using an electronic weighing scale and put in a paper bag, oven dried at 60 ^{o}C for 72 hours and weighed again after oven drying to determine the soil water content.

3.7. Statistical analysis

Root biomass and soil moisture at different soil depths, herbaceous standing biomass and basal cover were analysed using the R Statistical package where one–way analysis of variance (R module AOV) was used to test for significance. Once significance had been determined, boxplots were generated and a pairwise t-test comparison was used to test the difference. Descriptive statistics were conducted to compute means and standard errors of means for species abundances for the study sites. General Linear Model Procedures of SAS (2000) and a one-way analysis of variance were performed to test variation in abundances of dominant herbaceous and woody species. The LSD test was used to test variation between means of variables.

CHAPTER 4 RESULTS

4.1. Herbaceous vegetation composition

A total of nineteen (19) grass species were recorded in the study. These were in addition to several forbs and karroo dwarf shrubs. The herbaceous species by sample biplots following detrended correspondence analysis provides the representation of the distribution of species as indicated below (Figure 4.1.).

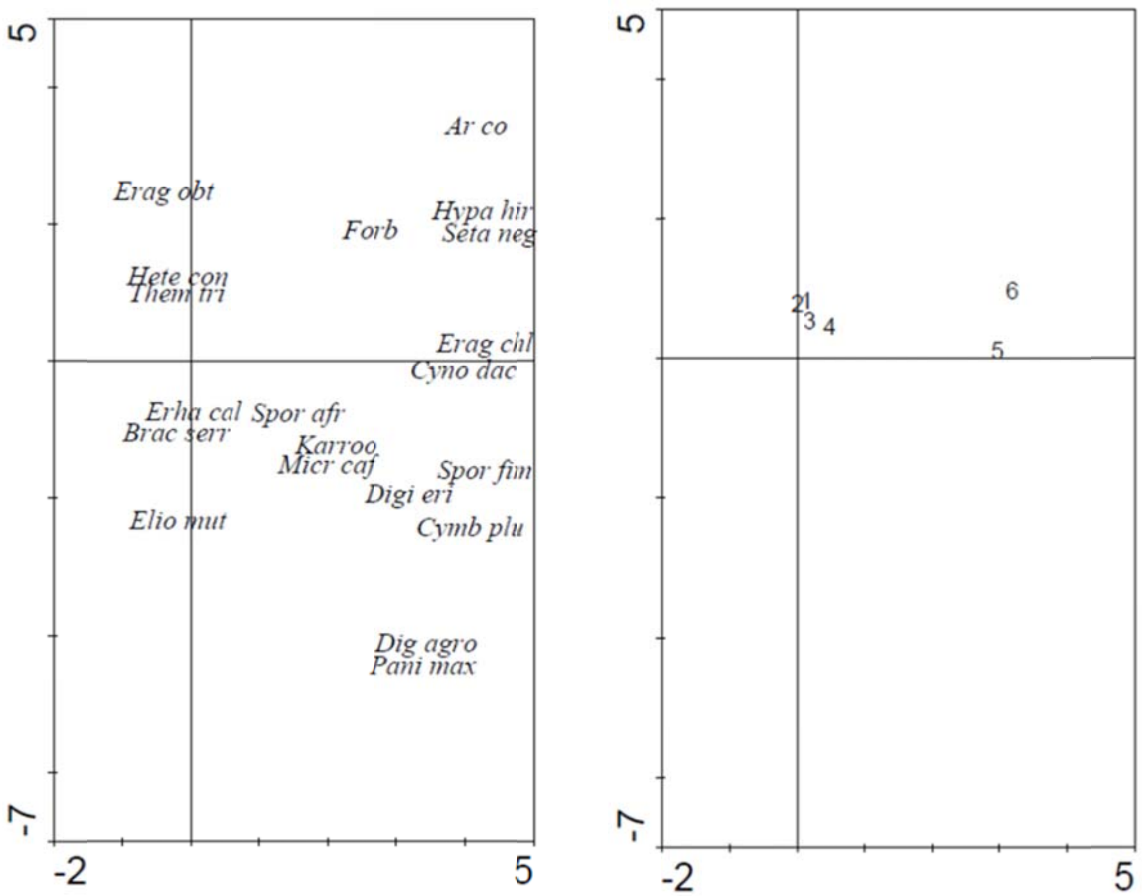


Figure 4.1: Species and sample biplots of the grass, dwarf shrub and forbs composition of the three sites following a Detrended Correspondence Analysis of the species by sample matrix (terBraak 1995). Sample numbers 1 & 2 were located in HVU1, sample numbers 3 & 4 were in HVU2 and samples 5 & 6 were in HVU3.

4.2. Veld condition assessment

For the purposes of this rangeland assessment, the forbs and dwarf shrubs were regarded as a single species in the survey and no attempt was made to identify these to species level as shown in (Table 4.2.). Sixty three percent (63 %) comprised of Decreaser species, thirty eight percent (38 %) Increaser II species and 8.3 % Increaser I species. As a result, in all the species found, 70.9 % had high grazing value, 12.7 % had moderate grazing value and 22.4 % had a low grazing value.

Table 4.2: Overall mean abundances (%) of herbaceous species composition in Kwezana communal rangelands.

Plant species	Ecological status	Grazing value	Plant life form	Mean % abundance
Forb	Increaser II	Low	Unknown	5.4
Themeda triandra	Decreaser	High	Perennial	43.5
Brachiaria serata	Decreaser	High	Perennial	6
Heteropogon contortus	Decreaser	High	Perennial	5
Eragrostis capensis	Increaser II	Moderate	Perennial	8.5
Sporobolus africanus	Increaser II	Low	Perennial	5
Elionurus muticus	Increaser I	Low	Perennial	1
Microchloa cafra	Increaser II	Moderate	Perennial	1
Cymbopogon plurinodis	Increaser I	Low	Perennial	3
Digitaria eriantha	Decreaser	High	Perennial	1
Cynodon dactylon	Increaser II	High	Perennial	7.2
Karoo dwarf shrub	Increaser II	Low	Perennial	2
Hyperrhenia hirta	Increaser I	Moderate	Perennial	1
Eragrostis obtusa	Increaser II	Moderate	Perennial	0.2
Eragrostis chloromelas	Increaser II	Low	Perennial	5
Sporobolus fimbriatus	Increaser II	High	Perennial	1
Setaria neglecta	Decreaser	High	Perennial	2
Digitaria argyrograpta	Decreaser	High	Perennial	0.1
Panicum maximum	Decreaser	High	Perennial	1
Aristida congesta	Increaser II	Low	Perennial	1.1

Themeda triandra was the most abundant species in HVU1 (68 %) and HVU2 (55 %), followed by *Eragrostis curvula* in HVU1 (9 %) and HVU2 (15 %). *Cynodon dactylon* (19 %), *Eragrostis chloromelas* and *Setaria neglacta* (15 %) were the most frequent species in (HVU3). Less abundant species e.g. *Microchloa cafra*, *Cymbopogon plurinodis*, *Sporobolus fimbriatus* and *Panicum maximum* were found at several sample sites (Table 4.2.1.).

Table 4.2.1: Mean (± SE) % of herbaceous species composition in the three HVUs.

SPECIES	HVU1	HVU2	HVU3
Aristida congesta	1.7(±1.67)	0	1.7(±1.20)
Brachiaria serrata	0.7(±0.33)	1.0(±0.57)	0
Cymbopogon plurinodis	0	1.5(±1.25)	8.5(±2.17)
Cynodon dactylon	1.0(±0.57)	2.0(±0.57)	18.7(±3.17)
Digitaria argyrograpta	0	0	0.2(±0.16)
Digitaria eriantha	0	1.0(0.57)	2.2(1.30)
Elionurus muticus	1.2(0.92)	0	0
Eragrostis capensis	9.3(2.33)	15.2(1.09)	1.2(1.16)
Eragrostis chloromelus	1.3(1.33)	2.7(2.67)	15.0(6.50)
Eragrostis obtusa	0.5(0.28)	0	0
Forb	6.2(2.12)	3.7(1.20)	6.5(3.50)
Heteropogon contortus	5.2(3.56)	2.0(0.57)	0
Hyperrhenia hirta	0.2(0.16)	0	11.7(2.72)
Karoo dwarf shrub	1.2(0.67)	5.7(2.84)	3.8(1.42)
Microchloa cafra	0	1.8(0.16)	0.3(0.33)
Panicum maximum	0	0	1.0(0.57)
Setaria sphacelata	0	0	15.2(1.92)
Sporobolus africanus	4.7(2.18)	6.7(2.33)	3.7(0.33)
Sporobolus fimbriatus	0	0	2.3(0.88)
Themeda triandra	68.3(3.84)	55.7(0.88)	6.7(5.23)

Key: HVU1= Sparsely encroached; HVU2 = Open grassland; HVU3 = Thicket

4.2.2. Dominant herbaceous species

There were six dominant herbaceous species found in the study area. *Themeda triandra* was the most abundant species and was significantly different ($p<0.001$) in HVU3. *Forbs* were not significantly different between the HVUs. *Eragrostis capensis* was significantly different ($p<0.001$) between HVUs. *Sporobolus africanus* was not significantly different. *Cynodon dactylon* was highly significant ($p<0.001$) in HVU3. Karoo dwarf shrub was not significantly different between HVUs.

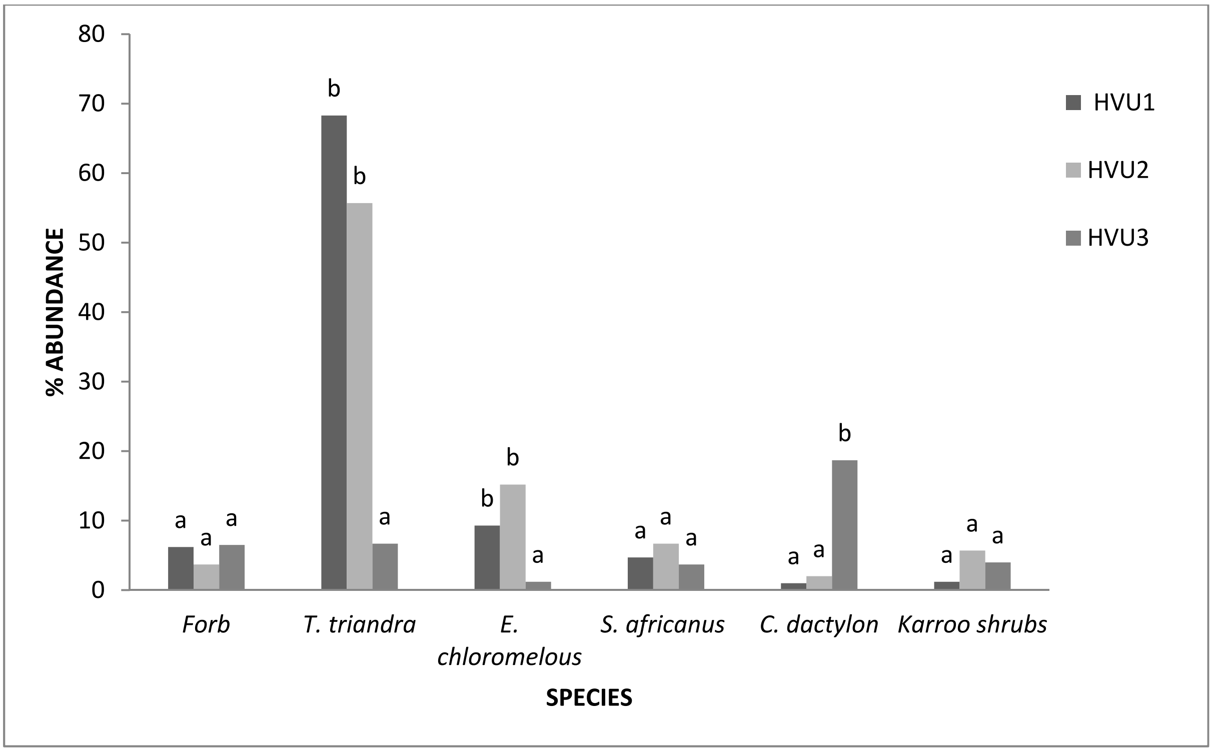


Figure 4.2.2: Mean abundances of dominant herbaceous species found in Kwezana communal rangeland (Means with different superscripts per HVU indicate a significant difference at $p<0.05$).

4.3. Woody species composition

Thirteen (13) woody species were found in the study area, with seventy seven percent (77 %) of species being palatable to browsers. *Acacia karroo* was the abundant species (66.7 %) followed by *Coddia rudis* (8.51%), *Dovyalis cafra* and *Cussonia spicata* were least abundant (0.5%). About (97.87 %) of species were acceptable woody plants to browsers and (2.13%) was not acceptable. Of the 13 species found in the study area, 6 of the species had thorns.

Table 4.3: Mean (%) of woody species found in three HVUs of Kwezana communal rangelands.

Species	**Acceptability**	**Thorns**	**Mean % Abundance**
Acacia karroo	+	+	66.72
Coddia rudis	+	_	8.51
Lippia javanica	+	_	4.33
Aloe ferox	_	+	1
Grewia occidentalis	+	_	6.48
Maytenus heterophylla	+	+	4.33
Scutia myrtina	+	+	2
Lantana camara / alien	_	+	2.63
Diospyros lycioides	+	_	1
Olea europeaea var africana	+	_	1
Rhus refracta	+	_	1
Dovyalis cafra	_	+	0.5
Cussonia spicata	_	_	0.5

Key: Acceptability = +; Unacceptable = -; Thorns = +; No thorns = -

4.3.1. Dominant woody species

Dominant woody species were found in the study area. *Acacia karroo* was the dominant woody species in HVU1 and HVU3, but was absent from HVU2. *Lippia javanica, Grewia occidentalis* and *Maytenus heterophylla* were only present in HVU3 as indicated in Figure 4.3.1.

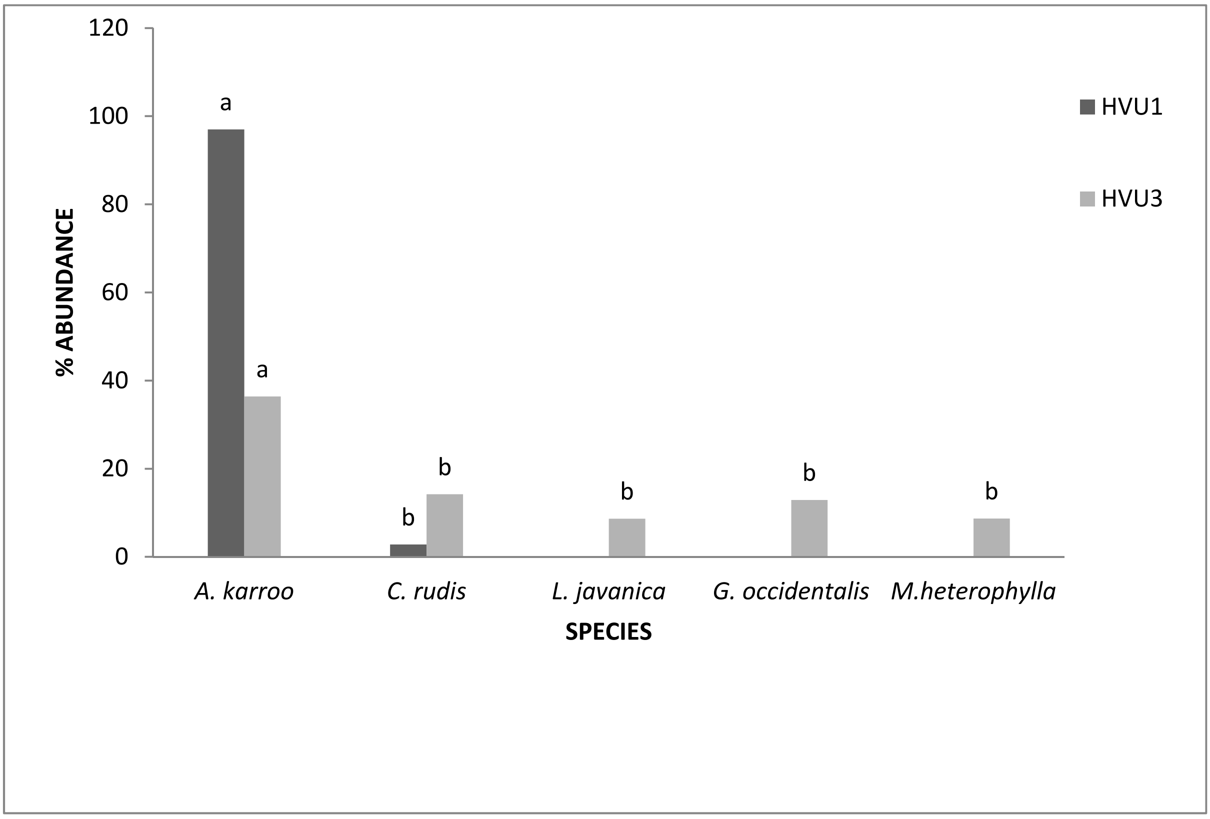


Figure 4.3.1: Mean abundances of dominant woody species found in Kwezana communal rangeland. Means with different superscripts per HVU indicate significant differences at p<0.05.

4.4. Herbaceous standing biomass

Differences in above-ground herbaceous standing biomass were significantly different between the three HVUs ($p>0.05$). However trends show that, mean herbaceous standing biomass in HVU3 (1206.15 kg ha^{-1}) was higher than HVU1 (942.43 kg ha^{-1}) and HVU2 (677.10 kg ha^{-1}). The significance can be attributed to the high variance with samples in HVUs 1 and 3 and this is shown in the table below (Figure 4.4.). The outlier in HVU1 (Figure 4.4) (value 268.77 kg ha^{-1}) results in the mean being much lower, whereas all other samples at this site were around 1000 kg ha^{-1}, and therefore the mean is strongly skewed away from the median indicated in the boxplot.

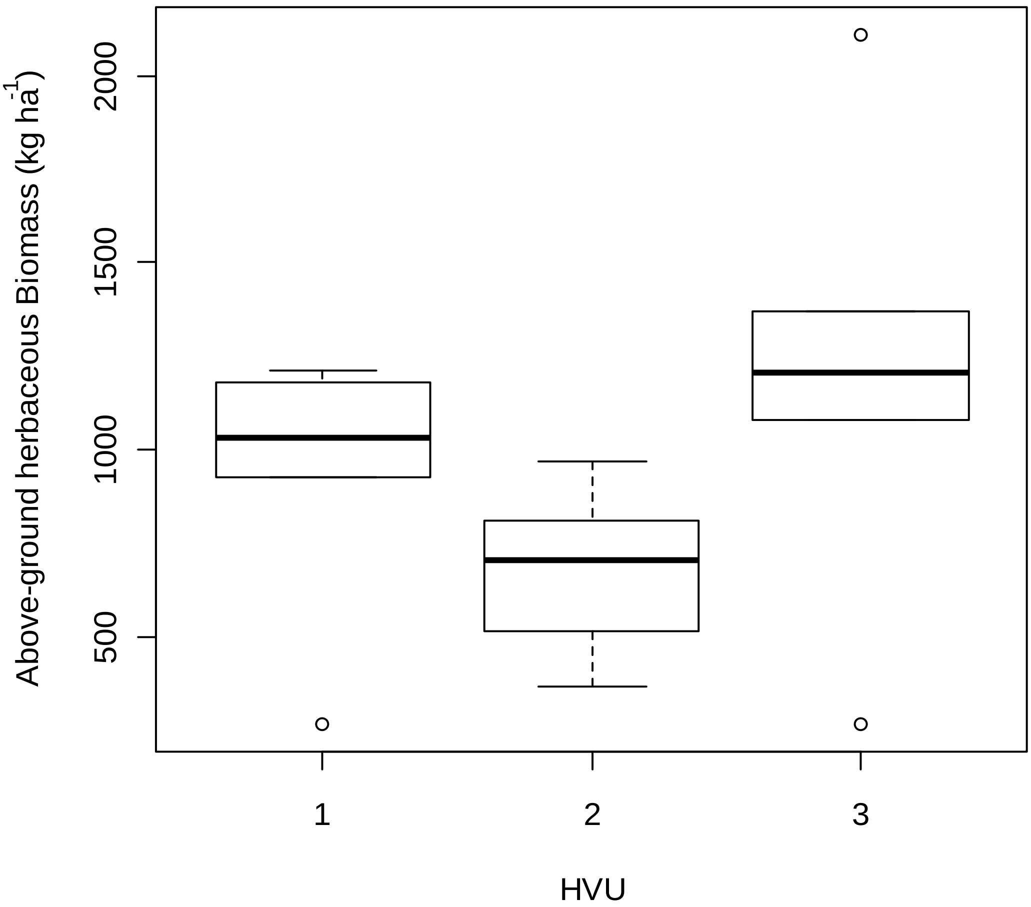


Figure 4.4: Boxplots for total herbaceous standing biomass found in the Kwezana communal rangelands. HVU1: Sparsely encroached site, HVU2: Grassland site, HVU3: Albany thicket.

4.5. Basal cover

The results of the Analysis of variance showed a significant difference (Appendix 1) in basal cover between the HVUs ($p< 0.05$). Of the total number of 300 points recorded in each HVU, the mean point to tuft distance (the inverse of basal cover) in HVU3 (22.60cm ± 0.151) was significantly higher ($p<0.05$) than HVU1 (9.93cm ± 0.151) and HVU2 (7.73cm ± 0.151). The results indicate that in Kwezana communal rangelands, the basal cover of HVU2 < HVU1 < HVU3. However HVU2 and HVU1 were not significantly different.

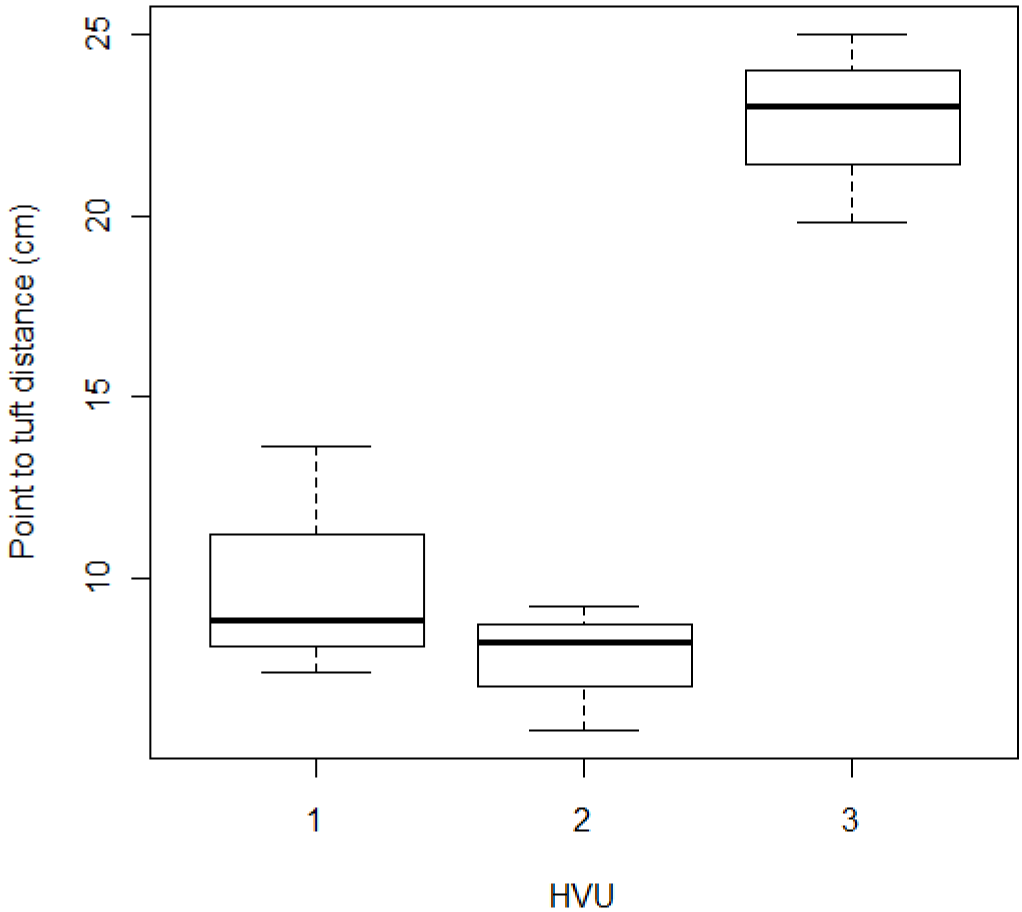


Figure 4.5: Boxplots for point to tuft distance in Kwezana communal rangelands.

4.6. Soil moisture content

The results of the analysis of variance showed a significant difference between HVUs but no significant differences occurred between depths ($p > 0.05$) (Appendix 4). Of the total number of 27 samples collected in each HVU, HVU3 (15 %) had the highest moisture percentage than HVU1 (9 %) and HVU2 (7 %). The results are illustrated in (Figure 4.6.) below.

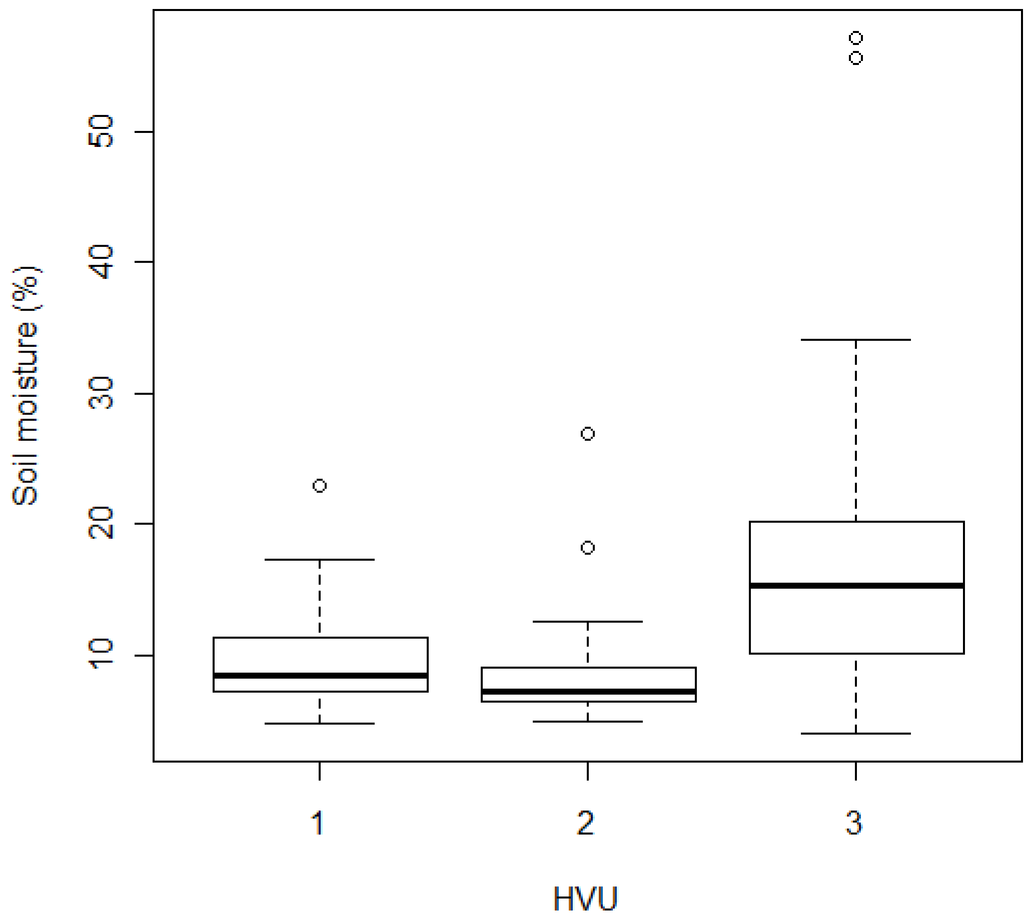


Figure 4.6: Boxplots for soil moisture content (%) in different HVUs at Kwezana communal rangelands.

4.7. Total root biomass

The results of the Analysis of Variance (ANOVA) showed that root biomass differed significantly with root depths (Appendix 5). A total of 35 samples were collected in each HVU. In all the trenches most of the root biomass (i.e. 2.43 kg m^{-2}) was found on the upper soil layer (depth 1 0-7 cm), followed by 1.32 kg m^{-2} in depth 2 (57-64 cm) and 0.49 kg m^{-2} found in depth 3 (87-94 cm) (Figure 4.6.1.). Root biomass did not differ significantly ($p>0.01$) between depth 1 (0-7 cm) and depth 2 (57-64 cm) whereas depth 2 (57-64 cm) and depth 3 (87-94 cm) were significantly different (Figure 4.7.).

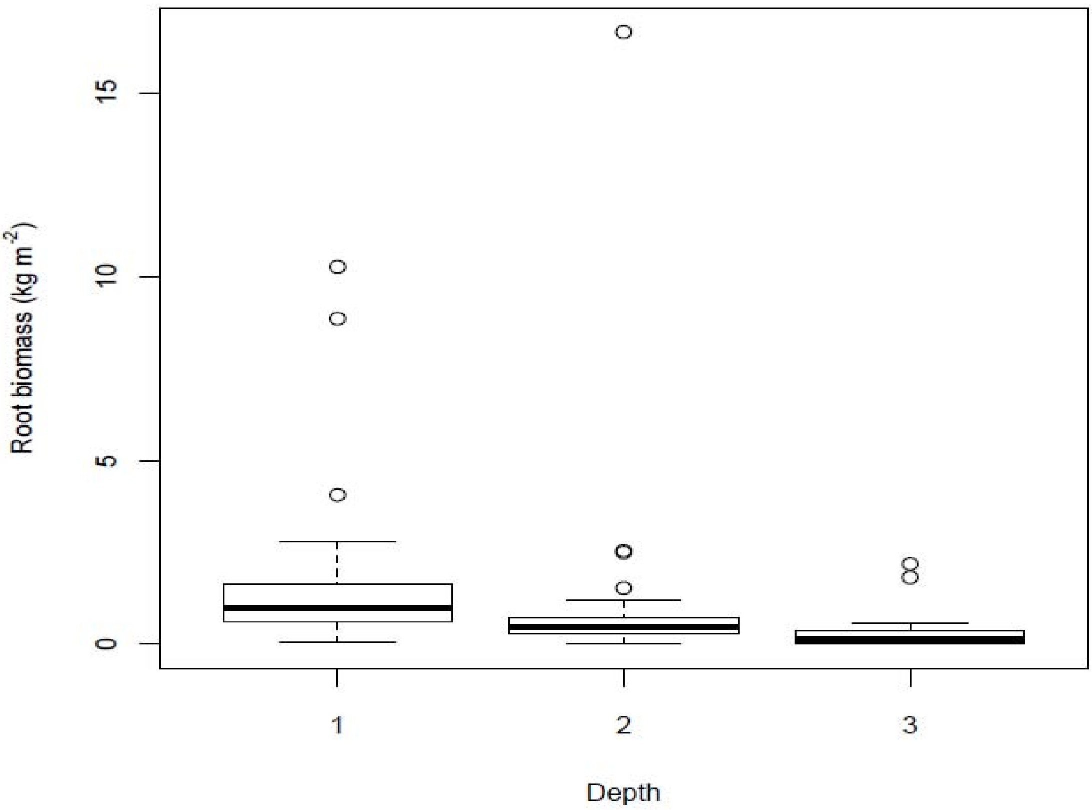


Figure 4.7: Box plots for total root biomass in different depths in the study area. Depth 1 (0-7 cm); Depth 2 (57-64); Depth 3 (87-94).

The results of the Analysis of Variance (ANOVA) showed that there were no significant difference in root biomass between sparsely encroached site (HVU1) and open grassland site (HVU2), but HVU3 (thicket) was significantly different (p <0.05) (Figure 4.7.1.). The highest root biomass was recorded in HVU2 > HVU1> HVU3 (Figure 4.7.1.). Root biomass did not differ significantly between HVUs (p<0.05) (Appendix 5).

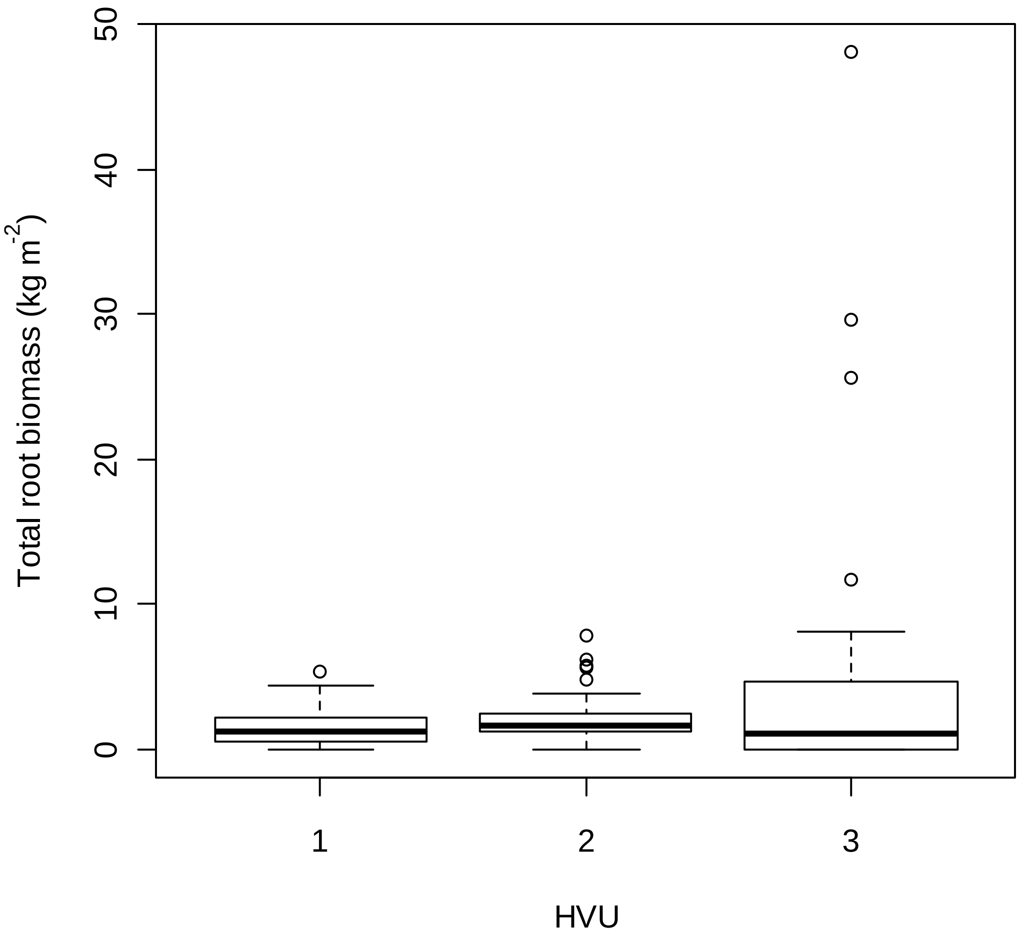


Figure 4.7.1: Boxplots for total root biomass found in three different homogenous vegetation units in the study area.

4.7.2. Fine woody root biomass

Most fine roots were found in HVU2 (mean = 2.145 kg m^{-2} ± 0.239) followed by HVU1 (mean = 1.3 kg m^{-2} ± 0.174) and HVU3 (mean = 0.808 kg m^{-2} ± 0.228) and this is shown in (Figure 4.7.2.). HVU1 was significantly different from HVU2 and HVU2 was significantly different from HVU3 while HVU1 was not significantly different from HVU3.

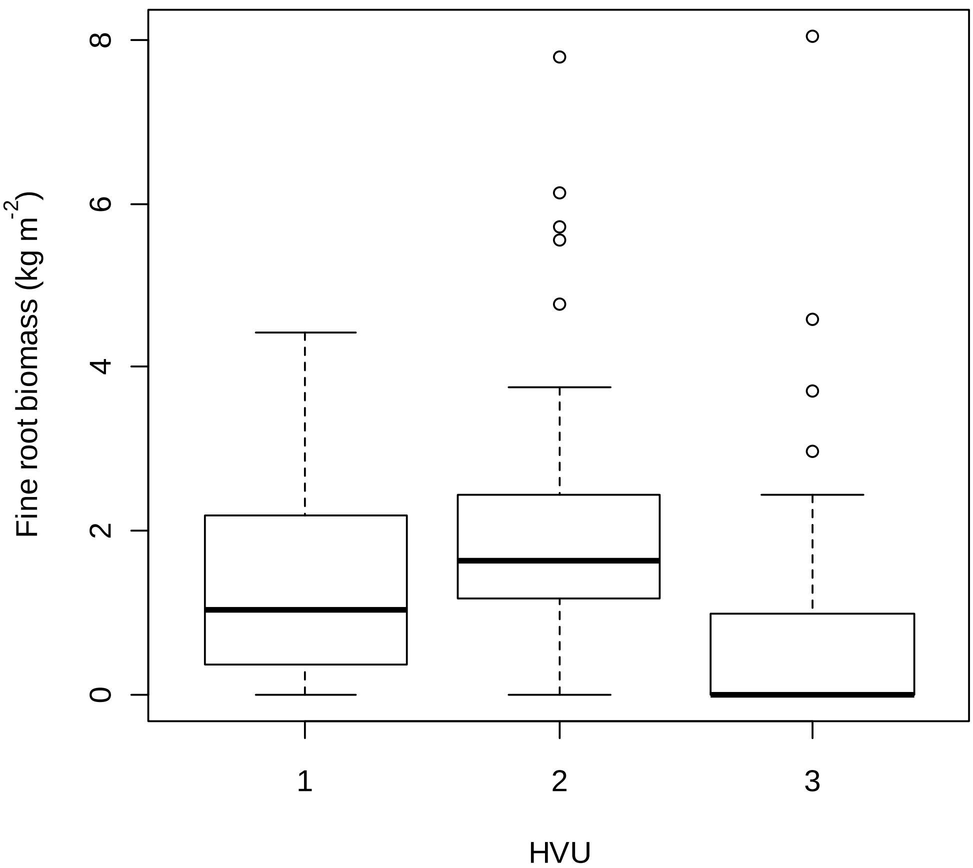
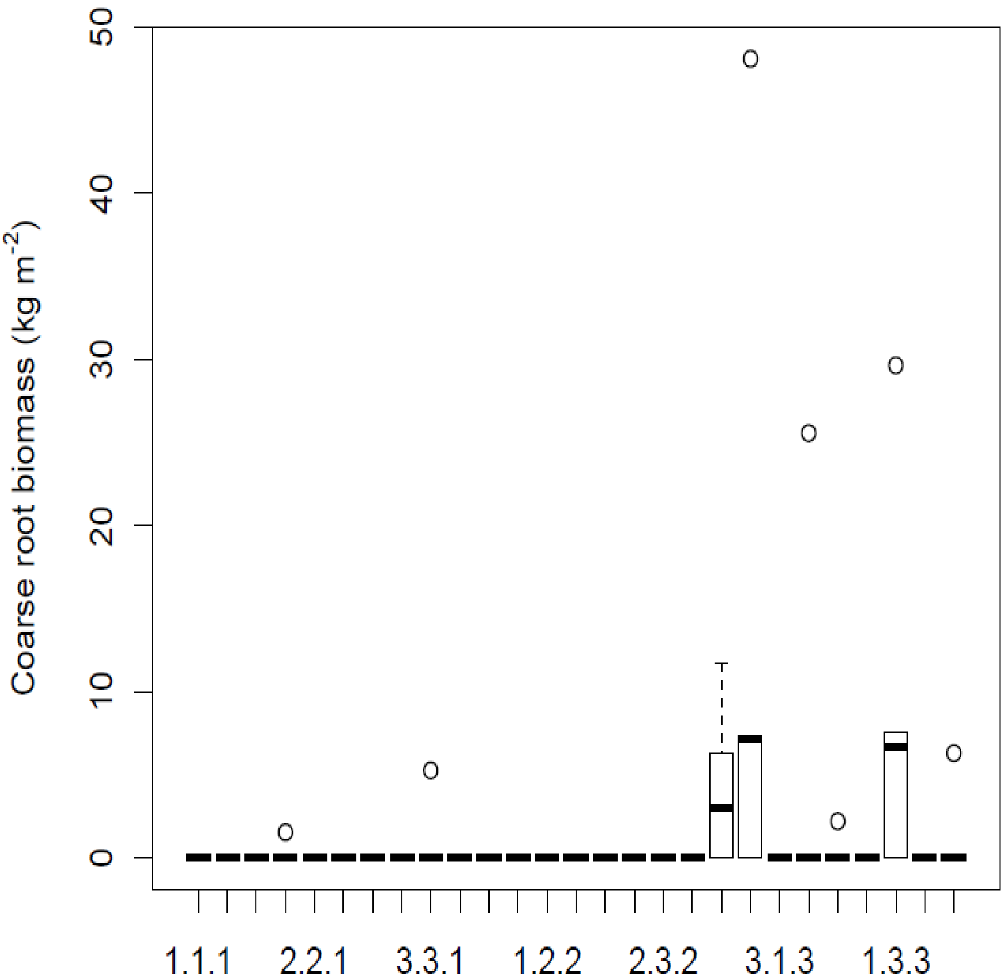


Figure 4.7.2: Boxplots for fine root biomass in the study area.

4.7.4. Coarse woody root biomass

The Analysis of variance showed that coarse root was significantly different between HVU and Depth ($p < 0.05$) (Appendix 5.2.). Coarse roots were only found in HVU1 and HVU3. There were no coarse roots found in HVU2. Below is an illustration of the results (Figure 4.7.4.).



HVU, Trench, Depth (cm)

Figure 4.7.4: Boxplots for coarse root biomass in the study area. The numbers represent HVU, Trench and Depth respectively.

CHAPTER 5 DISCUSSION

5.1. Herbaceous species composition

In this study nineteen herbaceous species were recorded in Kwezana communal rangelands which indicated moderately high species abundance relative to other sites. There were more Decreaser species (e.g. *Themeda triandra)* in the sparsely encroached site and open grassland than in the thicket (Table 4.2.1.). A possible explanation for these results is that these sites are prone to accidental veld fires such as the accidental fire which occurred during the study period, even though there are no fire records that have been kept. This was revealed by a personal communication with some communal farmers. In addition, regular fire is able to prevent the establishment of trees and maintain them inside the fire-trap (Govender et al. 2006). On the other hand, relatively few increaser I and II species were also recorded, which indicates that these rangelands are either over utilized or under-utilized (Angassa and Oba 2008) (Table 4.2.). In line with these results Angassa and Baars (2000) argue that, the impact of grazing pressure as a disturbance factor may change the floristic composition of herbaceous species. These dynamics of rangeland vegetation are influenced by high grazing concentration, suppression of fire (Angassa and Oba 2008), invasion of bush and maybe changes in climate (Angassa and Baars 2000; O'Connor et al. 2014). Worldwide, the variation of savanna ecosystems by accumulative abundance of shrubs has caused loss of herbaceous species and decrease in grazing ability (Sheuyange et al. 2005). In this study it was observed in the emerging results that continuous grazing in the thicket site resulted in a degradation of the grass layer. This was evidenced by a reduction in grass canopy cover (Figure 4.5.) and a change to less desirable Increaser II species (Table 4.2.). The results are similar to those observed by Abule et al. (2005) who reported that, further evidence of degradation in the thicket site is the woody encroachment by species such as *Acacia karroo*, *Coddia rudis* and *Lippia* species. Similar results were observed by Moleele and Perkins

(1998) in Botswana who indicated that cattle density associated with heavy grazing and trampling explained most of the variation in the density of woody plants. This confirmed that bush encroachment did occur on the thicket site. The number of different grass species found in the sparsely encroached site and open grassland sites were lower than those found in thicket site, yet most of these grasses were more desirable perennials than those found in the thicket site.

Furthermore, the study revealed that *Cynodon dactylon* which is classified as an Increaser II species was mostly found in the thicket site (Table 4.2.1.). It may be implied that such results were due to the fact that it increases with increase in bush density. These results are similar to those of Angassa (2012) who also recorded more *Cynodon dactylon* in bush encroached rangelands than non-encroached rangelands. *Cynodon dactylon* is known to be resistant to grazing, which makes it increase under continuous grazing. The results are also similar to those found by Abdallah eta al. (2012) who recorded more *Cynodon dactylon* under tree canopies which underpins the idea that *Cynodon dactylon* may be resistant to the influence of trees. The abundance of *Acacia karroo*, a leguminous tree in the soils of Kwezana communal rangelands could have encouraged the growth of *Cynodon dactylon* through addition of soil nitrogen. The creeping habit of *Cynodon dactylon* also makes it easy to access light in inter tree canopies space while its roots, which are produced on the nodes are able to absorb soil water nutrients.

On the other hand, variations in species composition in Kwezana rangelands such as Increasers species and Decreaser species drive the herbaceous composition to unpalatable / undesirable species composition. However, there is no clear explanation of the effects of bush encroachment on herbaceous species composition. For instance the results in this study indicated that the trend of Kwezana communal rangeland appears to move from Decreaser to Increaser II species and this is indicated in (Table 4.2.). Additionally the results suggested that there is no clear connection between ecological changes in herbaceous composition and bush encroachment hence the Decreaser, Increaser II and progressive bush encroachment are products of heavy continuous grazing. Of the species found in the Kwezana communal rangelands, six species were regarded as dominant herbaceous species. Decreaser species (*Themeda triandra*) and other species were increaser II species (*Eragrostis chloromelus*, *Sporobolus africanus*, *Cynodon dactylon*, *Forb,* and *Karoo dwarf shrub*) (Figure 4.2.2.). All these species, with the exception of forbs which was recorded in all the sites, were perennial plants which tend to produce more leaf material to protect the soil.

5.2. Woody species composition

Woody species that were recorded in the study area comprised of many highly acceptable species to browsers and relatively few unacceptable species (Table 4.3.). *Acacia karroo* was the most abundant species in a sparsely encroached site followed by *Coddia rudis* in the thicket. *Lippia javanica*, *Grewia occidentalis*, *Lantana camara* and other species were also recorded in the study area. *Acacia karroo* appears to increase rapidly and this had a negative effect on rangeland productivity which is changing in terms of species composition from Decreaser to Increasers. This was also observed in a sparsely encroached (Figure 4.3.1.) where its abundance was higher than 60 % (Table 4.3.). Moleele et al. (2002) also observed that continuous increase of *Acacia karroo* species in rangelands is mostly exacerbated by anti-nutritional factors such as tannins and thorns. *Acacia karroo* is a highly acceptable species for browsing goats. Depending on its density *Acacia karroo* can reduce soil erosion and desertification (Moleele et al. 2002). *Acacia karroo is* also known to improve the soil nutrients under its canopies, and is able to fix nitrogen and improve soil structure and water infiltration (Abule et al. 2005). On the other hand, *Lantana camara* was also recorded in the thicket site of Kwezana communal rangelands (Table 4.3.). *Lantana camara* is an invasive alien species that can poison livestock when it is consumed in large quantities. This species is an indication that the rangeland is in poor condition and often occurs in disturbed rangelands.

5.3. Dominant woody species

There were five woody species that were regarded as being dominant in all the HVUs. *Acacia karroo* was mostly dominant in all the HVUs especially in HVU1, *Coddia rudis*, *Lippia javanica*, *Grewia occidentalis* and *Maytenus heterophylla* were dominant in HVU3 (Figure 4.3.1.). Although grasses are superior competitors for water in the upper soil layers, woody plants in HVU3 are able to persist because they have exclusive access to water in the deeper soil layers (Riginos 2009). All the dominant species recorded were acceptable and available for browsers. Furthermore, this study showed that there is enough food available for browsers. This was supported by Dziba et al. (2003), who stated that *Acacia karroo* is an important forage species for browsing livestock production. *Acacia karroo* is a highly palatable browsing species, but if the rangeland is being mismanaged, it has the potential to form dense impenetrable thickets and possesses harmful thorns to stock. These species are among the species that make up most of the woody species found in Kwezana communal rangelands and provide a wide range of benefits to communal people.

5.4. Herbaceous standing biomass production

Above-ground standing biomass in the thicket was 1206.15 kg ha^{-1}, sparsely encroached was 942.43 kg ha^{-1}, and on open grassland was 677.10 kg ha^{-1} and were all significant from one another. The results showed that the thicket area contained the highest above-ground standing herbaceous biomass, followed by the sparsely encroached savanna then open grassland and these results were tabulated in (Figure 4.4.). The explanation could be that, the nature of the open grassland site has promoted the exposure of herbaceous vegetation by increasing light accessibility for photosynthesis. Continuous selective grazing in HVU2 and HVU3 is suspected to be the cause of the reduction in standing biomass of *Themeda triandra*. Unrestricted access of animals (continuous grazing) on open grassland has resulted in species being grazed at a very young age. As a result, this makes woody plants on thicket and sparsely encroached sites to out compete through uninterrupted access to growth resources as grasses lose their ability to capture these resources (Scholes and Archer 1997). These results contradict with those found by Angassa (2005), who recorded high herbaceous biomass on a non-encroached site than encroached site. This may be due to the fact that the species he found in a non- encroached were not palatable herbaceous species to animals. In all the HVUs the above-ground standing biomass was less than 1500 kg/ha which according to Teague et al. (2009) is an indication that the rangeland is not in a good condition and cannot ensure sustainable livestock production unless management is improved.

5.5. Basal cover

The results for the basal cover assessment indicated a significant difference ($p<0.05$) between HVU3 and the other HVUs (viz. HVU3<HVU1 <HVU2). Therefore it may be implied that these results are possible because HVU3 was located on rocky soils (Mispah rock complex). There is good basal cover (PTD <10 cm) at HVU1 and HVU2 which indicates that the soils are less susceptible to soil erosion. Even though the results of the biomass production were low the basal cover was at least better. Forage cover can be estimated according to the following categories (Trollope 1986).

<3 cm =Good cover

3-5 cm = moderately good

According to the results of the study, it also emerged that, thicket site had the highest basal cover followed by sparsely encroached and then open grassland site (Figure 4.5.).Open grassland and sparsely encroached was mostly dominated by *Themeda triandra*, while thicket was dominated by *Cynodon dactylon* and *Forbs*. These species are indicator of underutilization and overutilization.

5.6. Soil moisture content

High moisture content was recorded in HVU3 followed by HVU1 and 2, depth (0-30 cm). Most moisture was found in the upper top layer of the earth surface (0-30 cm) which was recognized as a key variable factor. The soil moisture in HVU3 and 2 was influenced by the nature of the soil which was sandy. One of the main reasons for these results was that these sites were located on a slanting slope and rocky area (Mispah rock complex) so water has the potential to sink in and accumulate underneath the rocks. The soil moisture in the upper layer was influenced by vegetation transpiration and soil evaporation. According to Venkatesh et al. (2011) soil moisture plays a vital role in plant growth. According to Tromp-van Meerveld and McDonnell (2005), soil moisture is the main heart of the ecohydrology and soil water balance. It controls vegetation dynamic and is in charge of various feedbacks to the atmosphere. The study shows that there is limited soil moisture available for the open grassland and sparsely encroached, while the thicket has relatively high moisture content available which is also favoured by the slope and nature of the soils.

5.7. Root biomass production

The mean total root biomass of 2.66 kg m^{-2} for all the trenches was recorded in the study area. In all the sites, most fine root (1.42 kg m^{-2}) biomass was found near the surface, which suggests that the roots obtain most of their water from the top soil surface (0- 30 cm) (Figure

4.7.). The highest total root biomass was found in open grassland site (HVU2) and these were fine roots. More coarse roots were found in HVU3 (Figure 4.7.1.). This was due to the fact that this site was mostly encroached with mixed mature trees which were up to 3 m high and up to 9.5 cm stem diameter. This had a negative impact on the species composition and on basal cover (Figure 4.2.2. and 4.5.). This site is also a Mispah rock complex which makes it easy to allow the establishment and penetration of woody plants roots and enables the trees (phreatic shrubs) to out compete the grasses. The mean total root biomass recorded in this study (2.66 kg m^{-2}) was very similar to those recorded by Macinnis (2009) (2.93 kg m^{-2}) in an Australian woodlands and was similar to those recoded (1.7 to 2.7 kg m^{-2}) by Barton and Montagu (2006) in the irrigated and non-irrigated components of 10 year old *E. camaldulensis* plantation. Eamus et al (2002) also found 3.84 kg m^{-2} in a savanna of North Australia. The findings of the study were directly comparable to those of Zerihun et al. (2006) who recorded 2.4 to 3.6 kg m^{-2} in a woodland community of North East Australia. From the top 40 cm of the soil depth, fine roots starts to disappear as the soil colour changes from black clay to yellow clay which is stony and does not allow root penetration beyond this profile. Few coarse roots were found at 94 cm. This study is in line with that of Knoop and Walker (1985) who recorded more woody plant roots in the top 10-60 cm depth. Rutherford (1983) also found that more woody plants roots lie at these depths. These roots cannot penetrate to further depths. Instead they spread and it is only the tap root which manages to go deeper. The following grass species were found near the tree canopies, namely *Cynodon dactylon, Cymbopogon plurinodis, Hyparrhenia hirta* and *Microchloa cafra.* All these species are found in a disturbed veld and are all Increaser II. The total root dry mass found was influenced by the tree heights and the fact that grass roots were in competition with the woody plants roots. Bigger coarse roots were found in the deeper depths (60-94 cm) where there was more moisture content. This was observed in HVU3 where most coarse root biomass was recorded (Figure 4.7.4.). In the thicket site, coarse roots may have out competed the herbaceous layer for soil mineral resources and due to the effect of shading hence, more *Cynodon dactylon* was recorded.

Open grassland also had a relatively high fine root biomass (Figure 4.7.2.). This site is only composed of grasses and by observation it is prone to veld fires even though there are no fire records that have been kept. According to Trollope et al. (1989), fire is a good management tool for controlling bush and invasive species hence *Themeda triandra* was mostly recorded in this site. The roots were closely packed in a mat form. This may prevent woody plants from multiplying (Liu et al. 2013) and the fact that the soil is sandy loam may further inhibit the growth of trees, but this still needs further investigation. The very fine roots were growing down up to a depth of 60cm in this site, due to the fact that they are able to grow without being in competition for soil resources. Knoop and Walker (1985) also recorded more herbaceous root density in the top 10 cm which forms a mat and rapidly declines with depth but few roots were also present even 120 cm down the soil profile. In contrast to Walter's (1971) and Walker and Noy-Meir's (1982) models, the grasses do have access to subsoil water. This is demonstrated by the root-distribution data as well as the soil water data. Strang (1969) working in highveld grasslands of Zimbabwe also found out that *Hyparrhenia* species extracted water to a depth of 150 cm. However, the two-layer model can still operate provided each component is the superior competitor in a different layer. The grassland site (HVU2) is located on the top of a sill with a very low to flat slope and may become water-logged when it rains. More grass roots could have been found in this site if it had not been continuously grazed. This site is continuously grazed throughout the year unless it is burnt, and as a result few forbs were recorded.

In the sparsely encroached site, few roots were found with both fine and coarse roots and this was shown in (Figures 4.7.2. and 4.7.4.). This site comprised of trees which had a mean height of 2.8 m and a stem diameter of 7cm. This site only had *Acacia karroo* trees and was mostly dominated by *Themeda triandra*. Furthermore, the site is also prone to veld fires which control the trees at available heights and according to the information given by the communal people, this site is used as a browsing camp for goats. This site is also stony and is located a slanting South facing slope. In this site there was also grass growing under the trees which experienced competition for soil resources.

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

The objective of this study was to describe the differences between three contrasting tree density classes in a semi-arid savanna, as an attempt towards an improved understanding of woody encroachment. It was hypothesized that, there were no differences in species composition, veld condition, basal cover, herbaceous standing biomass and total root biomass between open grassland, sparsely encroached savanna and thicket. This hypothesis has been rejected (variations between the HVUs among the parameters that were measured). Decreaser species were recorded in a sparsely encroached and in an open grassland site but these sites are very prone to continuous overgrazing. This is because they are the only sites which are seemed to have the potential of being grazed by livestock. The herbaceous standing biomass of the thicket site was higher than that of open grassland and sparsely encroached site.

Soil moisture content was significantly different in all the HVUs, having HVU3 (thicket) with the highest moisture content compared to HVU1 and HVU2 (Sparsely encroached and Open grassland). This may be due to that, the site is stony, mostly encroached and may preserve water for woody plants. The total root biomass was directly comparable with the studies that have been conducted in other savannas. According to the results on species composition, herbaceous biomass, basal cover and the root biomass, the Kwezana communal rangeland has a potential of running a sustainable livestock production if proper management practices can be implemented.

To improve the rangelands of Kwezana communal rangelands, management such as proper resting, burning, proper stocking rates and physically clearing of bushes as supported in the literature should be considered. These woody species are also important for fuel in the community. The results of the study showed that moderate and highly acceptable herbaceous plants that are recommended for livestock production decrease over time in the rangeland.

This suggests that there is more selective grazing and high grazing pressure. The formulation of proper stoking rates should be based on the carrying capacity for grazing and browsing capacity of the veld. Resting for seedling and plant vigour during growing season can be applied for promoting the seedling which will favour growth of Decreaser plants and improve the herbaceous standing biomass. Burning as mentioned in the literature will also control bush encroachment and maintain the existing bushes at available heights.

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APPENDIX 1

List of ANOVA tables for the statistical analysis conducted to test the significance variation between the parameters.

1. **Analysis of Variance for basal cover (Point to tuft distance) in Kwezana communal rangeland**

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	2	3.86302222	1.93151111	28.26	0.0009***
Error	6	0.41013333	0.06835556		
Corrected Total	8	4.27315556			

2. **Analysis of Variance for the dominant woody species found in the Kwezana communal rangeland**

2.1. Coddia rudis

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	1	193.8016667	193.8016667	3.71	0.1263
Error	4	208.7866667	52.1966667		
Corrected Total	5	402.5883333			

2.2. Lippia javanica

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	1	112.6666667	112.6666667	21.54	0.0097
Error	4	20.9266667	5.2316667		
Corrected Total	5	133.5933333			

2.3. Grewia occidentalis

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	1	252.2016667	252.2016667	22.90	0.0087
Error	4	44.0466667	11.0116667		
Corrected Total	5	296.2483333			

2.4. Maytenus heterophylla

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	1	112.6666667	112.6666667	22.87	0.0088
Error	4	19.7066667	4.9266667		
Corrected Total	5	132.3733333			

3. Analysis of variance for dominant herbaceous species found in Kwezana communal rangeland

3.1. Themeda triandra

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	2	6364.222222	3182.111111	74.00	<.0001***
Error	6	258.000000	43.000000		
Corrected Total	8	6622.222222			

3.2. Eragrostis chloromelus

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	2	296.7222222	148.3611111	18.55	0.0027***
Error	6	48.0000000	8.0000000		
Corrected Total	8	344.7222222			

3.3. Sporobolus africanus

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	2	14.00000000	7.00000000	0.68	0.5429
Error	6	62.00000000	10.33333333		
Corrected Total	8	76.00000000			

3.4. Cynodon dactylon

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	2	590.8888889	295.4444444	27.41	0.0010***
Error	6	64.6666667	10.7777778		
Corrected Total	8	655.5555556			

3.5.Karroo shrub

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	2	30.72222222	15.36111111	1.51	0.2941
Error	6	61.00000000	10.16666667		
Corrected Total	8	91.72222222			

3.6. Forb

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	2	14.3888889	7.1944444	0.39	0.6901
Error	6	109.3333333	18.2222222		
Corrected Total	8	123.7222222			

4. **Analysis of variance for soil moisture content found in Kwezana communal rangeland.**

Type	DF	Sum Square	Mean Square	F value	Pr(>F)
HVU	2	1280.4 1	280.44	22.2723	6.026e-06***
Rep	4	6.1	6.10	0.1061	0.7451
Depth	4	25.7	25.75	0.4479	0.5045
Trench	123	23.28	0.4049	0.5257	
Residuals	130	7473.7	57.49		

5. **Analysis of variance for total root biomass found in Kwezana communal rangeland**

Type	DF	Sum of Square	Mean Square	F value	Pr(>F)
HVU	2	196.0	196.013	7.5111	0.0069884
Depth	4	312.3	312.332	11.9684	0.0007307 ***
Trench	2	20.5	20.478	0.7847	0.3773341
Residuals	131	3418.6	26.096		

5.1. Analysis of variance for fine root biomass found in Kwezana communal rangeland.

Type	DF	Sum of Square	Mean Square	F value	Pr(>F)
HVU	2	5.446	5.446	0.07818	1.311e-10 ***
Depth	4	84.255	48.7522		0.24162
Trench	2	2.391	1.3836		
Residuals	131	226.397	1.728		

Significant codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

5.2. Analysis of variance for coarse root biomass found in Kwezana communal rangeland

Type	DF	Sum of Square	Mean Square	F value	Pr(>F)
Depth	4	3.884	3.8842	3.6498	0.058261*
Trench	2	0.095	0.0949	0.0892	0.765665
HUV	2	9.545	9.5446	8.9687	0.003285**
Residuals	131	139.413	1.0642		

Significant codes:0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1