# SPATIAL VARIATION IN DENSITY, SPECIES COMPOSITION AND NUTRITIVE VALUE OF VEGETATION IN SELECTED COMMUNAL AREAS OF THE NORTH WEST PROVINCE

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# DECLARATION

I, Khuliso Emmanuel Ravhuhali, confirm that this is my original research work, and the use of information and other materials from other sources was fully acknowledged. This dissertation has not been submitted for any degree or examination at any university other than the North-West University. The results reported here were produced by me and not any other student, company or organisation.

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# ABSTRACT

The study was designed to assess spatial variation in terms of density, species composition and nutritive value of vegetation in selected communal grazing lands located in the Ngaka Modiri Molema district municipality of the North West province. For the first study on tree species assessement, three 2.2 km transects, which served as replicates were established at each of the selected grazing areas. The three transects were placed at least 200 m from each other. Along each transect, points were marked within 500-700 m (considered as near sites), >700 m-1.4 km (middle site) and >1.4 km – 2.2 km (far sites) from the homesteads to form 9 sampling sub-transects. Three 10 m x 10 m homogenous vegetation units were marked at each sub-transect and spaced 20 m from each other. The homogenous units (HVU) were used to record density, height and canopy diameter of individual woody plants. Plant identification was carried out using a combination of scientific and indigenous local knowledge. A total of 21 browse species were found across all sites. *Grewia flava* and *Acacia erioloba* were the most dominant species in all soil types across the study areas. There was no significant effect of distance from the homesteads on density, canopy cover (CC), total tree equivalent (TTE) and plant height. There was a significant effect of soil type on density, canopy cover, total tree equivalent and plant height. The red-brown sand soil type had higher ($P<0.05$) total plant density (827.7 plant/ha), CC (9.6%); TTE (2886.4 TTE/ha) than in clay-loamy soil type area. Red-brown sand soil type area had higher ($P<0.05$) values for all height levels than clay-loamy soil type. For grass sampling and assessment of grass species composition, within each sub-transect, 10 m × 10 m homogenous vegetation unit (HVU) was marked. In each HVU, 1 $m^2$ quadrat was randomly placed to sample soil and grass species resulting in a total of 9 samples per site. Grass samples (per each species) were collected per quadrat, oven-dried and milled through a 1 mm sieve for chemical analysis. A total of 28 grass species were identified in all study areas, of which 23 species were perennials. Twenty one percent of the total grasses were classified to be of high grazing value, 50% medium grazing value and 29% as low grazing value. Most of the highly palatable species were found at sites far from the homesteads. *Cymbopogon pospischilii, Eragrostis bicolor* and *aristida species* were the most commonly occurring grasses in many sites in the grazing area under clay-loamy (CL) and Red-brown sand (RBS) soil types. Sodium, P, K, Ca, Mg and Mn concentration was higher ($P<0.05$) in CL soil than in RBS soil. Iron concentration was higher in RBS soil than in CL soil. Tree and grass samples were collected and analysed for chemical and *in vitro* ruminal degradability. *Eragrostis trichopora* (100 CP g/kg) in Tsetse, *Cynodon dactylon* (62 and 66 CP g/kg) in Six-hundred and Makgobistadt, *Melenis repens* (70 CP g/kg) in Loporung communal area had the highest CP values than all other grass species in their respective areas. *Cymbopogon pospischilii* (540.6 g/kg DM) and *E. trichopora* (562.0 g/kg DM) had the highest ($P<0.05$) DM degradability values at 48 h at clay-loamy soil type grass species. All grass species harvested in Makgobistadt and Loporung communal areas had similar DM degradability values at 48 h. The highest crude protein content ($P < 0.05$) was recorded in leaves of *Grewia monticola* (190.4 g/kg DM) than in all other species in the study area. Although all the browse species contained lower amounts of tannins in their leaves, the highest ($P<0.05$) CT content was found in *Dichrostachys cinerea* leaves (0.993 and 1.044 $AU_{550}$/200 mg) than all other browse species in the study areas. The last study was carried out to determine key characteristics of common grass species under controlled environmental conditions, including their phenological patterns, relative growth rates as well as their chemical composition, and *in vitro* ruminal degradability. Differences ($P<0.05$) were observed on morphological characteristics within grass species, growth stage and their interaction. *Fingerhuthia africana* had higher ($P<0.05$) CP content (102 g/kg) than all other grass species. *Eragrostis bicolor* had higher ($P<0.05$) number of tiller developed at reproductive stage than all other grass species. Due to different morphological characteristics and feeding value, these species could complement each other in rehabilitating the communal areas affected by heavy grazing. Changing the vegetation structure by reducing woody plant density in Makgobistadt and Loporung communal areas can create a conducive environment for open grasslands to occupy the communal area and create biodiversity within grass species.

**Keywords:** Spatial differences, Chemical constituents, *in vitro* ruminal DM and N degradation, tannins, phenols, tree species, green house, grass species.

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# DEDICATION

I dedicate this thesis to my mother, Masindi Mmbudzeni Ravhuhali, late father, Samuel Ravhuhali Negondeni, my siblings, my wife and my sons.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| ADF | Acid detergent fibre |
| ADS | Acid detergent solution |
| AOAC | Association official Analytical Chemists |
| AU | Absorbance Units |
| CP | Crude protein |
| CT | Condensed tannins |
| DM | Dry Matter |
| H | hour |
| iDMD | *in vitro* ruminal dry matter degradability |
| iND | in vitro ruminal nitrogen degradability |
| N | Nitrogen |
| NDF | Neutral detergent fibre |
| NDS | Neutral detergent solution |
| OM | Organic Matter |
| SAS | statistical analysis system |
| SCT | Soluble condensed tannins |
| Sph | Soluble Phenolics |
| Sph | Soluble phenols |
| TAE | Tannic Acid equivalents |
| TTE | Total tree equivalent |

# 1 CHAPTER ONE - INTRODUCTION

## 1.1 Background

Of the seven major recognized biomes of South Africa, only the savannah and grassland biomes occur in the North West province. Most of the province (71%) falls within the savannah biome that is commonly known as bushveld savannah (READ, 2015). The remainder falls within the grassland biome, which contains a wide variety of grasses typically found in arid and semi-arid areas (Wesson, 2006). Large portions of the communal grazing lands in the province are still managed under continuous grazing throughout the year. Most of livestock reared in these communal areas are cattle, sheep, goats and donkeys (Getchell *et al*., 2002; Ravhuhali *et al*., 2016). Grazing by domestic livestock affects vegetation productivity, soil and hydrological properties of the rangelands (Ibanez *et al*., 2007). Grazing impacts are a function of the density of individual herbivore species, their foraging behaviour and their dietary preferences. Due to the problem of non-regulatory utilisation of communal land, excessive stocking rates cause a reduction in plant cover, followed by a decrease in plant diversity (Heady & Child, 1994) and rangeland degradation.

For decades, semi-arid African rangelands have been prone to degradation, mostly due to bush encroachment, which results in the reduction of palatable perennial grasses (Jeltsch *et al*., 2000; Graz, 2008). Rangeland degradation leads to severe decline in ecosystem services such as maintenance of air quality, decomposition of waste and organic matter, nutrient cycling, pollination of plants, renewal of soil fertility, provision of genetic resources, natural control of pests and diseases. This may lead to reduction of ecosystem functions such as forage and livestock production, groundwater recharge, carbon sequestration and prevention of soil erosion (Graz, 2008; Lehmann, 2010). Additionaly, significant losses in biodiversity across taxonomic groups (Blaum *et al*., 2009) can occur. Rangeland degradation is the main ecological factor limiting livestock production in communal areas (Lesoli, 2008). The conventional explanation of rangeland degradation assumes an essentially stable system that has been perturbed by mismanagement such as overstocking and untimely utilization of forage (Selemani, 2014). However, the definition of land degradation, according to the users of rangelands, is likely to substantially differ from the available textbook definitions. Research has identified many factors, both proximate and distal, that influence the progression of rangeland degradation in different localities.

## 1.2 Problem statement

It is estimated that 91% of South Africa's total land area is semi-arid and prone to desertification (Hoffman & Aswell, 2001). According to Nyoike (2004), rangelands in Africa are under pressure from the increased human population that demands more land for food production and settlement. These factors lead to the concentrated use of land for grazing and settlement creating pressure on the vegetation and soil resources. As a result, rangeland health/condition continue to deteriorate in most communal farming areas in terms of quality and quantity to the detriment of animal production and livelihoods (Kosmas *et al*., 2015). The causes are various, ranging from climate change to uninformed utilization practices (Tokozwayo, 2016). For these farmers, the rangeland constitutes a valuable, yet inexpensive resource. Utilizing it in a sustainable manner is the social responsibility of the land users although concepts such as soil erosion and maintenance of biodiversity have very little emotional appeal (De Bruyn, 1998). There is little imperical data on rangeland vegetation spatial distribution, veld condition & nutritive value of rangeland forages of communal areas in South Africa. Understanding the species composition, their nutritive values and associated spatial variation is important for the formulation of integrated solutions to land degradation that farmers may identify with and thus ensuring successful implementation.

## 1.3 Justification

Vegetation condition is dependent on soil type, soil moisture and type of vegetation; all influenced by climatic elements such as temperature and rainfall. Among those many factors influencing vegetation dynamics, the climatic elements are very unpredictable and variable in short periods of time, both spatially and temporally. An understanding of variation in the vegetation density, species composition and nutritive value of vegetation in communal areas is the basic starting point in the prediction of the sustainability of both livestock and rangeland resources under the management of the communal farmers. Therefore, exploratory studies are required to generate information that would be useful in identifying existing and potential challenges pertaining to variation in the vegetation density, other indices of species composition, and nutritive value of vegetation. Such studies will add knowledge to our understanding of the optimal use of communal lands to minimize the depletion or degradation of natural resources. Agricultural officials and livestock farmers in North West province and country as a whole can utilize this knowledge through farmers days, information days to improve the condition of their rangelands and thus improve productivity of the animals. This can in turn, improve the economic status of farmers while ensuring the sustainable utilization of natural resources.

## 1.4 Overall objectives

The aim of the study was to assess spatial variation in terms of vegetation composition and nutritive value of forage plants found in selected localities of Ngaka Modiri Molema district of the North West province of South Africa. In addition, phenology and morphology of ecotypes of some common grass species in the study areas was analysed under greenhouse conditions.

The specific objectives of this study were to:

1. Assess spatial variation of plant species within communal grazing areas in selected localities of Ngaka Modiri Molema District municipality, North West province, South Africa.
2. Assess the chemical composition and *in vitro* ruminal fermentation of some grass species found in four communal areas in selected localities.
3. Assess the chemical composition and *in vitro* ruminal fermentation of some tree species found in four communal areas in selected localities.

4. To assess the phenological and morphological variation across various ecotypes of some common grass species under green-house conditions.

## 1.5 Research questions

The major research questions for the study were**:**

1. Are there differences in plant species distribution as influenced by soil characteristics across grazing sites?
2. Do grass species and growth environment affect nutritive value as assessed by chemical analysis and *in vitro* ruminal dry matter degradability?
3. Do browse species and growth environment affect nutritive value as assessed by chemical analysis and *in vitro* ruminal dry matter and nitrogen degradability?
4. Are there any phenological and morphological differences between ecotypes of some common grass species under greenhouse conditions?

## 1.6 References

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# 2 CHAPTER TWO - LITERATURE REVIEW

## 2.1 Introduction

The importance of livestock in the agricultural sector has been well documented (Ali, 2007; Moyo & Swanepoel, 2010; Bettencourt *et al*., 2014). They contribute to socio-economic activities of rural communities. Investments in livestock contributes to gains in smallholder farmer income and household nutrition (Bertram, 2014). However, the productivity of herbivores is generally considered to be low in communal grazing systems due to rangeland degradation caused by climate variability and sub-optimal resource utilization practices (Abusuwar & Ahmed, 2010), among other factors.

The limited success of a number of strategies designed to arrest rangeland degradation in communal farming areas is well-documented (Stringer & Reed, 2006). Efforts have been made to reduce rangeland degradation and rehabilitate degraded areas, but with little success. This is due to the fact that the inherent livestock management systems are a product of indigenous knowledge, farmer objectives, economic pressure, and affordability (Chinembiri, 1999). Most communal farmers manage their herds according to their economic situation (herd size and account balance) but may not take environmental variability (rainfall and vegetation) into account (Lohmann *et al*., 2014). For these farmers, the rangeland constitutes a valuable, yet inexpensive resource, immensely providing nutrients to the livestock so it is the responsibility of farmers to utillise it in a acceptable manner.

## 2.2 Rangeland deterioration in semi-arid areas

Land deterioration happens all over the world, but it is a major problem in southern Africa's communally grazed rangelands. The United Nations (UN) Environment Program classifies more than 90% of South Africa as arid, semi-arid or sub-humid. The consequences of land deterioration can be devastating for people and wildlife. It is often closely linked with other environmental and social problems such as climate change and poverty. Land deterioration remedies are influenced by climate and users' social status; thus land restoration is one of the biggest challenges in the management of many semi-arid areas (Yayneshet, 2011). Land deterioration is more than just an environmental problem in rural areas; it is also one of the causes of migration to cities, resulting in densely populated cities and high unemployment rate. It is, therefore, a social problem, which must be tackled in order to ensure sustainable animal agriculture.

## 2.3 Vegetation type and distribution in the North West province

The vegetation type in the western region of the province is largely comprised of Kalahari Thornveld and shrub bushveld, whereas the central region is dominated by dry *Cymbopogon-Themeda* veld and the eastern region is characterised by a number of mixed bushveld types (Wesson, 2006). The North West province has a wide array of plant species, ecosystem and habitats. This is largely due to the diverse nature of the province's landscape and variation in climate. The province has several endemic species (such as the *Aloe peglerae* in the Magaliesberg), as well as rare and threatened species (e.g. Wild dog) (Mampye, 2005).

For many rural communities in the province, where food security is a major problem, farming is a major economic activity. The development of community-based small-scale commercial farming on several lands in the province is underway. Given the arid and semi-arid conditions of the western half of the North West province, the vegetation of this region largely comprises xerophytes. As a result, plant biomass, productivity and species diversity tend to be low in this region (van Veelen *et al*., 2009). With the east-west variation in climate and rainfall, there is a corresponding gradation in the vegetation types from xerophytic in the west to open grassland and savannah in the central region and bushveld in the eastern region.

Low & Rebelo (1998) stated that different vegetation types can be identified in the North West province, belonging to the Kalahari, Kimberley, mixed bushveld and Highveld grassland categories. There is a predominance of Kalahari deciduous Acacia thronged (open savannah of *Acacia erioloba* and *A. haematoxylon* as well as desert grasses) and shrub bushveld in the dry western half of the province. The soils are varied and range from sandy to clay and it is conducive to Tarchonanthus veld (Daemane, 2007).

The northern and eastern regions reflect the greatest variability of vegetation types in the province. Vegetation types include mixed bushveld (open savannah dominated by *Acacia caffra* and grasses of the *Cymbopogon* and *Themeda* types), turf thornveld and isolated pockets of Kalahari thornveld and shrub bushveld. The mountainous areas of this region are covered by mixed bushveld (Richter *et al*., 2001).

Variations in the vegetation cover and species diversity is an important characteristic of rangeland ecosystems (Sarvade *et al*., 2016). Plants are also spatially and temporally variable in nutritional value, and thus animals select a variety of available forage to balance their nutrient requirement (Mnisi & Mlambo, 2016). Species richness and distribution is always influenced by several factors, either combined or in isolation. Yuan *et al*. (2013) highlighted that factors such as distance to roads, residences, and animal drinking water area influence vegetation distribution and species diversity. The area where most animals gather (near watering points, near homesteads, and roads) tends to be more degraded than the furthest ones, resulting in changes in species diversity and chemical composition of plant species (Tefera *et al.*, 2010). Maracahipes-Santos *et al.* (2017) indicated that geographic distance between communal areas has a greater influence on the occurrence and abundance of the woody plant species in some areas due to variations in soil properties that suit certain plant species. Tarhouni *et al*. (2010) found that high grazing value plants constituted the highest proportion of the vegetation close to the stream where the greatest disturbance occurred whereas an area close to the homesteads where some of the soil nutrients and water will be deficient will always be exposed to degradation and thus promote growth of pioneer or invasive species. Species composition is affected by many factors, and their combined effect on plant resource requirements (Smith-Martin *et al.*, 2017). For example soil moisture, nutrient availability, pH and organic carbon decreased with increasing distance from the watering points, and a variation in species composition was also observed in relation to these changes (Sarvade *et al.*, 2016). The degradation of these grass species richness may lead to the increase of the tree species diversity (Soethe *et al.*, 2008; Rutherford & Powrie, 2013). Moleele & Perkins (1998) highlighted that heavy grazing usually occurs in an area close to watering points thus creating a conducive environment for tree seedlings to flourish.

A slope is also another important topographic factor that influences species distribution, and plant diversity. A steep slope is characterised by poor soils due to high soil erosion and low moisture holding capacity which affect the soil physico-chemical properties and thus variations in plant distribution, diversity and richness (Esler & Cowling, 1993). Species distribution and diversity is also controlled by the interactions of topographic and biological factors such as competition through altering soil and other abiotic factors (Reddy *et al.*, 2009; Sarkar & Devi, 2014). Below ground resource availability also palys a significant role in influencing the biodiversity at local scales (Smith-Martin *et al.*, 2017)

## 2.4 Causes of rangeland degradation in rangeland ecosystems

### *2.4.1 Overgrazing*

In large portions of the communal grazing areas in the North West province rangelands are not managed. Grazing by domestic livestock affects vegetation, soil and hydrology (Ibanez *et al.*, 2007). Grazing impacts are a function of the density of individual ruminant species, their foraging behaviour and their dietary preferences. Excessive stocking rates cause a reduction in plant cover, followed by a decrease in plant diversity (Heady & Child, 1994). Long-term overgrazing can cause changes in species diversity. High grazing value and desirable species will eventually be replaced by low grazing value and less desirable species (Tefera *et al*., 2010). Once the palatable and desirable species disappear, pioneer and unpalatable species proliferate.

Chipika & Kowero (2000) indicated that increasing grazing pressure, through grazing large stock like cattle, and also small stock combined with human activity on natural rangeland can increase woody species (Bush encroachment) and land degradation. Bush encroachment is known as a natural phenomenon that results in the alteration of a grass-dominated ecosystem to a tree-dominated ecosystem through a process known as plant succession. This phenomenon happens in unmanaged grasslands that become colonized by hardy, pioneer tree and shrubs species. The shade from trees exploits and kills the natural grass-dominated groundcover (Ward, 2005).

Overgrazing reduces the usefulness and productivity of the land. It causes the livestock to press the subsoil into fine soil which is easily eroded by wind and water (Moleele & Perkins, 1998). Tefera *et al*. (2007) and Tefera *et al*. (2010) also highlighted the negative impact of overgrazing on soil depth, soil organic matter, and soil fertility and the land's future productivity.

It is difficult for communal farmers to control livestock numbers under the communal land use system as there is no individual ownership of the land. Thus absence of governance structures result in some individual farmers not limiting the number of livestock kept, but being driven by economic gains from large livestock numbers, thus ignoring environmental variability (rainfall, proper stocking rate and vegetation) (Lohmann *et al*., 2014).

### *2.4.2 Climate change*

Land degradation undermines the productive potential of land and water resources thus directly affecting human welfare (DEA, 2007). Along with land mismanagement, the level of vegetative cover and human-induced factors, climatic variability is a major driving force affecting land degradation. Given the high temperatures and limited rainfall already experienced in most drylands, semi-arid and arid areas are more sensitive and exposed to degradation (UNCCD, 2015). The UNFCCC (2008) defines climate change as “change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods”.

The effects of unsustainable land management practices on land degradation and desertification are being exacerbated worldwide by climate change, which include changing rainfall patterns, increases in global temperature (global warming) as a result of increased accumulation of greenhouse gases in the atmosphere; increased frequency and intensity of precipitation, floods, and droughts (UNCCD, 2015). Severe droughts or heavy rainfalls are likely to intensify wind or water erosion and that will contribute to severe loss in biomass and soil attributes. High temperatures also affect soil water by influencing evapotranspiration. Dry climatic conditions also contribute to the increment on the size and frequency of crack formation in soils (CCIRG, 1991).

### *2.4.3 Fire*

Fire is known as an important feature in the management of the vegetation dynamics and it is regarded by many to be one of the main present day soil erosion and degradation agents in the semi-arid rangelands (Ferreira *et al*., 2008; Pausas, 2008). Ultimately, humans are the single most important agent for the occurrence of both bush and rangeland fires (Langaas, 1995), which strip the soil of the organic matter and plant materials that prevents erosion of the soil. Furthermore, Snyman (2015) highlighted that fire increases soil temperatures and soil compaction, and reduces organic matter, which then reduces the water holding capacity and infiltration ability. Soil respiration also drops linearly with increasing number of fires and high fuel load (Tongway & Hodgkinson, 1992). Fire also negatively influences species richness and flush of seedlings from the soil over a first season following a fire.

Not all fires cause land degradation and the effect of fire varies over time depending on vegetation type (Dube, 2007). The effects of wild fires are not limited to the destruction of vegetation. Prescribed fire under the initiated personnel is an economical solution to the problem. Fire has been listed among the strongest factors of savannah dynamics and is one management strategy which has been recommended for shrub control (Hodgkinson & Harrington 1985; Rasmussen *et al*., 1996; Nielsen & Rasmussen, 1997). It effectively reduces shrub biomass and promotes pasture growth (Hodgkinson & Harrington, 1985). Fire has an influence on the shape and functioning of vegetation types, alter the hydrological response of soil, increasing overland flow production and overall ecosystem stability (Goldammer & de Ronde, 2004; Mataix-Solera *et al*., 2011). Fire may also affect soil fertility through neutralizing soil pH. Less frequent fires and less competition from perennial grasses by over-grazing, especially when shrub seedlings establish, are the main reasons for tree seedlings increment that might lead to bush encroachment. The utilisation of fire as a management tool in the form of prescribed burning enhances grassland condition. Dugmore (2012) higlighted that using animals to graze down moribund veld takes longer than using a prescribed fire. This prescribed burning of moribund had an advatage of converting the grazing areas from increaser I species to decreaser dominated grassland which can improve productivity of livestock at low cost (Dugmore, 2012).

## 2.5 Consequences of rangeland degradation

### *2.5.1 Loss of soil fertility*

Soil degradation has been defined as a process that leads to a decline in the quality or fertility or future productive capacity of soil as a result of improper use or human activity (UNEP, 1993). FAO (2014) also defined soil degradation as transformation in the soil health status resulting in a diminished capacity of the ecosystem to provide goods and services for its recipients.

It occurs whenever the natural resources in the landscape are changed by human activity through improper use of soil. It occurs when there is depletion in soil quality and nutrients due to various forms of soil erosions (Mekuria *et al*., 2007). It was estimated that some 10-20% of drylands have been severely degraded (Reynolds *et al*., 2007), meaning that soils are mostly exposed and severe erosion has occurred making nutrients leach from the land. Soil fertility decline happens when the quantities of nutrients removed from the soil in harvested products exceed the quantities of nutrients being applied. This normally affects growth and yield during the next growing season. Lal (2015) indicated that soil is a non-renewable resource vulnerable to degradation dependent on complex interactions between processes, factors and causes occurring at a range of spatial and temporal scales. Nutrient depletion as a form of land degradation has a severe economic impact in semi-arid areas, especially in sub-Saharan Africa (Eswaran *et al*., 2001). Stoorvogel *et al.* (1993) have estimated nutrient balances for 38 countries in sub-Saharan Africa. As the soil nutrient pool has to offset the negative balances each year. The authors also highlighted that there is gross nutrient mining in sub-Saharan Africa that creates negative balances each year. Important among physical and chemical processes are a decline in soil structure, imbalance in elements, soil compaction, soil erosion, poor internal drainage, salination, desertification, soil acidity, depletion of the soil organic carbon, unsustainable use of rangeland resources, leaching, decrease in cation retention capacity, loss of soil fertility, and low organic matter (Eswaran *et al*., 2001; Lal, 2015). Metabolic reserves play an important role in maintaining the organic matter that is useful in maintaining the raw materials in the soil. Organic matter plays a fundamental role in maintaining soil fertility through holding nitrogen and sulphur in organic forms and other essential nutrients such as potassium and calcium.

### *2.5.2 Loss of palatable species*

Levels of degradation in semi-arid zones have been completely overlooked if not poorly understood (Rouget *et al*., 2006). Rangeland degradation often leads to changes in the botanical composition of grass communities (Snyman, 2005; Shackleton *et al*., 2001). South Africa´s rangelands are increasingly threatened by overgrazing, followed by altered grassland composition and decline in total vegetation cover and palatable plant species, and the subsequent dominance by less palatable, herbaceous plants or invasion of non-native species (Huxman *et al*., 2005; Mekuria *et al*., 2007; Wheeler, 2010). Prolonged heavy grazing undeniably contributes to the disappearance of palatable species and changing vegetation from perennial to annual and this degradation therefore, may put pressure on the sustainability of both subsistence and small-scale farmers (Archer *et al*., 200; Nenzhelele, 2017). Nenzhelele (2017) data reflected that continous heavy grazing over a long periods changes vegetation from being perrenial to annual dominated. Scholes & Biggs (2005) also highlighted that the main cause of biodiversity loss in the arid and semi-arid regions is land degradation.

Severe degradation and loss of plant cover in most of arid and semi-arid regions are seen in most rangelands in drier climates, largely as a result of overgrazing and also due to seasonal variability that has an effect on defoliation (Dregne, 2000). Kotzé (2015) supports that land degradation also happens when the valuable portion of grassland and savannah ecosystems is over-utilized by livestock, due to improper rangeland management. Overgrazing can damage vegetation, but through proper rangeland management practices, the damage can be avoided. In the grassland biome, Snyman (2005) and Abdi *et al*. (2013) also observed a decline in the palatable perennial plants replaced by less grazing value pioneer grasses and herbs, and that can also threaten food security of the marginalised community.

### *2.5.3 Bush encroachment*

The productivity of the rangeland is threatened by land degradation mostly characterised by invasion by alien plant species (Lesoli *et al*., 2013) that suppress the production of herbaceous species due to increased bush cover (Ward, 2005). Bush encroachment has appeared as one of the top three perceived rangeland problems across 25% of the districts of South Africa (Hoffman *et al*., 1999). Bush encroachment has affected large areas of savannah to such an extent that keeping livestock is no longer viable (van Rooyen, 2013) and due to that it has the potential to compromise rural livelihoods in Africa, as many depend on the natural resource base (Kgosikoma & Mogotsi, 2013). Ward (2005) also stressed that bush encroachment affects the agricultural productivity and biodiversity of 10-20 million ha of South Africa. Bush encroachment is defined in this review as a directional increase in the cover of indigenous woody species in a savannah biome (O'Connor *et al*., 2014). Oba *et al*. (2000) and van Auken (2009) also defined bush encroachment as the proliferation of woody plants in savannah ecosystems through an increase of woody cover that reduces grazing resources.

The increase of woody species can lower the quantity of fodder and that directly threatens livestock productivity in many localities (Beyene, 2015). Beyene (2015) found that there was heavy bush cover of above 50% around the dipping tanks in semi-arid of Swaziland that might threatens the accumulation of grassland biomass needed by livestock. Kgosikoma & Mogotsi (2013) highlighted absence of fire, herbivores, nutrient availability and rainfall patterns as some of the causes of bush encroachment. Trollope (1980) also supported the use of fire as a tool to control bush encroachment in moist savannah but not in arid savannah. However, Ward (2005) disagrees on some causative factors of bush encroachment but emphasizes that bush encroachment is mainly an increase of woody species which suppresses palatable grasses and herbs thus reducing the livestock carrying capacity of the land. Wiegand *et al*., 2000 also highlighted that overgrazing in combination with rooting niche separation is not a prerequisite for bush encroachment because bush encroachment sometimes happen on soil too shallow to allow for roots seperation. Most of the mitigation protocols (reducing livestock densities in years with below-average rainfall, cutting of tree and alien vegetation species) have been applied and failed to reduce bush encroachment, indicating that the causes of the problem are poorly understood (Smit *et al*., 1996).

### *2.5.4 Reduction in livestock productivity*

Livestock plays an important role in the livelihoods of the rural poor households (Livestock in Development, 1999). Given the increase in human population, there will be an increased demand for livestock products and their potential contribution to poverty reduction in rural livelihoods is recognised (Kwon *et al*., 2015). Degradation of grazing lands poses a big threat to sustained and/or increased global livestock productivity, which serves multiple purposes including socio-economic, cultural and ecological benefits (Randolph *et al*., 2007; Nkonya *et al*., 2015). Land degradation can reduce the productivity of the livestock due to the reduction of grazing resources, and loss of palatable and more nutritious plant species. The deterioration through land degradation, reduce the carrying capacity of the land (Quan *et al*., 1994). This may lead to a decline in livestock numbers and also reduced animal weights culminating in poor animal productivity (Tesfa & Mekuriaw, 2014). Absence of rangeland management in communal areas leads to high stocking rates, and consequent overgrazing and ultimately a decline in reproductive rate and increased mortality. It has been stressed that, due to rangeland degradation and soil erosion, more than half of privately owned land are producing forage in order to maintain the productivity of their livestock (FAO, 1993). Thirty nine percent of niger cattle and 10% of its sheep and goats were lost due to land degradation (FAO, 1993).

## 2.6 Rangeland condition assessment

Ludwig & Bastin (2008) defined rangelands in good condition as those systems having healthy and biophysical functions that normally include a high capacity to retain water, capture energy, produce biomass, re-cycle nutrients and provide habitats for diverse populations of native animals, plants and microorganisms, as well as socio-economic functions that provide people with their material, cultural, and spiritual needs. It has been defined also as the state of health of the rangeland in terms of its ecological status, resistance to soil erosion and its potential for producing forage for sustained optimum livestock production (Tainton, 1999).

The current theories and practice of rangeland assessment have a long history that is closely related to the ways that rangelands were used and studied. This is where there is measurement of attributes and indicators of current functional state relative to an expected norm. Tainton (1999) stressed that assessment of a rangeland is done in order to evaluate its condition relative to its potential in that ecological zone; to evaluate the effects of current management on rangeland condition; and to monitor changes over time in addition to classifying the different vegetation types on the farm and quantifying their condition. However, if a rangeland is in a degraded condition, strategies to improve the condition should be considered.

Grassland rangeland condition assessments are based on the frequency of key grasses, edaphic and woody species available or vegetation cover (Ryan *et al.*, 2017). Tainton (1999) highlighted that an assessment of the plant community's condition constitutes a convenient means of comparing them as well as of providing a way to quantify and observe the spatial and temporal changes within a particular vegetation type. Monitoring rangeland health enables its sustainable management, ensuring continued provision of ecosystem services. In communal areas, livestock production objectives are seldom a priority and the whole notion of using rangeland condition to assess stocking rate appears problematic. Hoffman & Todd (2000) indicated that the applicability of rangeland condition assessment techniques in areas other than commercial livestock production systems may, however, be questioned.

There are challenges with the traditional approach to rangeland condition assessment that have been reviewed by many authors (Smith, 1978; Westoby, 1980). One problem is that vegetation changes may occur as a result of many factors other than grazing, e.g., fire, lack of fire, extreme weather events, climatic change and invasions by exotic species.

### *2.6.1 Weighted palatability composition method*

Barnes *et al*. (1984) were critical of the ecological methods developed in Southern Africa relating rangeland condition to livestock production potential. The approach looked at livestock production potential of a site being based purely on the immediate forage production potential whereby species allocation palatability rating signify their forage production potential. Only grasses and not browse or tree species are used in this classification. In general, current approaches to rangeland condition rely on comparisons of species composition of present vegetation compared to the "climas" or "potential natural" vegetation for the site. Barnes *et al*. (1984) adopted three different classes of grazing values (Highly palatable, intermediate and unpalatable grasses), whereas Smith *et al*. (1995) classify vegetation as a poor, fair, good, excellent according to its similarity to the climax. Vegetation state moves in sympathy with the environment between pioneer and climax community; it is equated with this axis of succession, with condition varying from poor (pioneer) to an excellent (stage dominated by climax or subclimax grasses). These principles are based on ecological principles index when assessing rangeland condition and are according to the response of the vegetation to abiotic and biotic environmental impacts (Tainton, 1999). Most grassland and savannah areas in South Africa apply these methods.

### *2.6.2 Benchmark method*

Since the basis of rangeland condition assessment is to compare a chosen site with a rangeland which is in excellent condition in the same ecological zone, the first requirement of the method is to characterise the excellent rangeland, which is then termed the benchmark site (Foran *et al*., 1978). In this method, species are allocated to ecological classes based on their assumed response to grazing. Mentis (1982) and Hurt *et al*. (1993) argue that not all species respond to grazing and thus expose some weaknesses in this method.

In addition, the identification of benchmark sites is subjective since it involves the selection of sites which are more productive and stable and are capable of supporting long term animal production while conserving water and soil resources. The selection of benchmark sites is critical for many of the methods used and is usually based on livestock production potential, palatability, vegetation successional status, ability to prevent soil erosion and also for that benchmark to represent a stable and productive site which reflects the pristine, climatic climax condition (Tainton, 1981). Once a benchmark site has been identified the proportional species composition of the site is quantified and the species classified into four ecological categories (Decreaser, increaser I, increaser II, Increaser III) (Tainton, 1999).

The use of subjectively derived ecological classes and non-responsive and rare species in the interpretation of monitoring results will reduce or distort the sensitivity of such techniques (Hurt *et al.,* 1993). A specialist's knowledge is always needed to classify the species according to their ecological status. Sample sites can be analysed in a similar way as the benchmark site. All the species recorded in the sample site are classified into their species categories (decreaser to increaser III) (Tainton, 1999).

### *2.6.3 Ecological index method*

This method was adopted by Vorster (1982) for assessing the rangeland condition in Karoo vegetation. It is similar to the benchmark method in that the vegetation in the sample site is compared to that of a benchmark site. It has shown to be the most promising technique in the development of rangeland assessment methods for the karoo areas. The group classification is based on the ecological importance of the grass species, while the index values accorded to the karoo bush species are based on relative palatability ratings (Botha *et al*., 2011). These index values are used when the rangeland condition scores are computed. The condition scores are indicative of the state of health of the rangeland (Tainton, 1981). The species are classified in a similar manner but with additional categories (Tainton *et al*., 1980) like decreaser species, Increaser Ia, Increaser 1b, Increaser IIa, Increaser IIb, and Increaser IIc, Increaser III and invaders. Relative index values are assigned to each group, 10 to decreaser species, 7 to increaser Ia and Increaser IIa, 4 to Increaser Ib and Increaser IIb species and 1 to Increaser IIc, Increaser III and invaders. The index values currently used to calculate the rangeland condition score may lead to either over or underestimation of the grazing capacity

(Tainton, 1999). A specialist's (botanical taxonomist) knowledge is normally required to classify the species accurately.

### *2.6.4 Key species method*

Rangeland condition assessments have to be ecologically interpretable to provide a scientific basis for management decisions. Humphrey (1962) stated that a rangeland condition classification should not be restrained by ecological concepts, but maximum forage production for the type of livestock being grazed should be a sole criterion used to estimate condition. Key species are generally an important component of a plant community since they serve as indicators of change (Coulloudo *et al*., 1999). As the species richness decreased with grazing intensity, the changes in evenness can contribute more to the rate of change in diversity than the change in species richness (Yang *et al.*, 2001). Key species may change from season to season and year to year. The use of key species for indexing rangeland condition in relation to the fire/grazing impact has potential for monitoring change in the sourveld (Hurt & Hardy, 1989). This method is adapted to areas where perennial grasses, forbs, and/or browse plants are the key species (Coulloudo *et al*., 1999). This method recognises that n ot all species encountered in grassland show the typical decreaser/increaser response to utilisation intensity. The condition score for a sample site was calculated as the sum of relative abundances of the key species. The results are normally compared with the ones from the benchmark site which is calculated in a similar fashion.

### *2.6.5 The use of degeneration gradients*

Understanding of the degradation processes is a prerequisite to ecological interpretation of a particular condition assessment. This requires the establishment of degradation gradients for each ecological zone in a particular region. Within each ecological unit, species composition data are collected from the rangeland in various stages of degradation (Tainton, 1999). Van der Westhuizen *et al*. (2005) also stressed that to ensure sustainable utilisation and production of the grassland ecosystem, it is essential to determine rangeland condition and trend. Bosch & Gauch (1991) developed a technique for assessing rangeland condition based on quantified responses of species and vegetation communities to their abiotic and biotic environment. Here the position of a particular sample of vegetation is quantified along the degradation gradient (a model describing long term vegetation and habitat changes from under-utilised to severely over-utilised).

Many studies have used grazing gradients to investigate the effects on vegetation (e.g. Thrash, 2000; Riginos & Hoffman, 2003) and relate degradation with plant composition change or biomass production. Van der Westhuizen *et al*. (2005) applied the degradation gradient to quantify rangeland condition of areas ranging from poor (trampled areas close to watering points) to well-managed areas and areas that degraded as a result of selective grazing due to under-utilisation. Changes in the proportion of species composition over the degradation gradient were determined using a nearest plant point technique. This method is applicable only to species which respond sensitively to grazing gradient (Tainton, 1999).

Tainton (1999) indicated that for the data to be available, long term grazing trials are needed, from obvious variations in the pastoral impacts on vegetation, such as one given by fence line contrasts, and by sampling at various distances from well-established points of animal concentration such as watering points or near river or homesteads.

Thrash (2000) stressed that the disturbances of these established areas (watering points or near river or homesteads) where animals normally concentrate show the impact these areas have on rangeland condition when moving with distance from these disturbed areas. The gradients obtained by these analyses are described in terms of floristic composition and soil factors and are subdivided into five categories (underutilised, under-grazed, moderately degraded, moderately to severely degraded and severely degraded). The extent of impact is important for determining the optimum density and distribution of watering points for minimum rangeland deterioration (Owen-Smith, 1996). These changes on the gradient are accompanied by significant changes in soil conditions (losing topsoil and soil compaction are used to establish possible thresholds of irreversible changes on the gradient). A change beyond such a threshold would imply a move to a completely new domain of attraction but the recovery from one domain of attraction to another is limited by soil condition factors.

### *2.6.6 Remote sensing*

The use of local and out-dated traditional methods (field surveys, literature reviews, map interpretation as well as collateral and ancillary data analysis) is not effective in acquiring vegetation cover. The traditional methods are time consuming, date lagged and labour intensive and often too expensive to acquire the information in the areas concerned. The technology of remote sensing offers a practical and economical means to study vegetation cover changes, especially over large areas (Langley *et al.*, 2001; Nordberg & Evertson, 2003).

The use of satellite data has become one of those methods offering more practical regional and global monitoring of vegetation activities (e.g. Health) (Rullan-Silva *et al.*, 2013). Selection of appropriate satellite data depends on the spatial and temporal scales of vegetation changes of interest.

Vegetation phenology derived from remote sensing is important for a variety of scientific applications. While many data sets related to plant phenology have been collected, remote sensing provides the only way to observe and monitor vegetation phenology over large scales and at regular intervals (Hufkens *et al.,* 2010). Assessing and monitoring the state of the earth's surface is a key requirement for global change research (Lambin *et al.,* 2001).

This remote sensing method assists in classifying and mapping vegetation in order to have a proper intervention in managing natural resources as vegetation provides a basis for all living organisms and plays an essential role in affecting global climate change, such as influencing terrestrial $CO_2$ (Xiao *et al*., 2004). It also gives valuable information for understanding the natural and man-made environments through quantifying vegetation cover from local to global scales at a given time point or over a continuous period. It is critical to obtain current status of vegetation cover in order to initiate vegetation protection and restoration programs (He *et al.,* 2005).

### *2.6.7 Assessment of woody species*

Assessment of woody species can provide information so that there will be a manipulation of rangelands so as to provide adequate forage to animals and also for planning to achieve optimum productivity of desired plant species (Danckwerts, 1989). Adjorlolo (2008) and Mnisi (2015) stressed that it is common ecological knowledge that woody vegetation is an important characteristic of woodland savannahs and it can also play a part in addressing feed shortage for livestock during winter times. Factors that contribute to woody species distribution can be the available plant moisture, available nutrients, soil types and geographical gradients (Adjorlolo, 2008). However, there have been major challenges to savannah vegetation studies when assessing the structure, composition and dynamics of the mixed trees in semi-arid areas. Assesment of the structural composition of the woody species in semi-arid areas normally follow the same procedures as those used for the grass (Tainton, 1999). The examples of valuable attributes of the woody species which may form a part during assessment include: the canopy cover and the density of the woody species available in that particular area. The recording of species may be done directly or indirectly from the survey data collected. Other information to be collected will be the woody species present and the density or the number of the key species among them. Normally these woody species may be grouped according to their role or usefulness as browse plants, and the density and distribution according to height categories (seedlings to mature trees).

A number of assessment techniques are available, but the most accurate method applied in woody species layer around savannah is the use of belt transect whose length and breadth will be determined by the density of the woody species (Tainton, 1999). In rangelands and very dry areas with extremely sparse vegetation, a line transect, replicated three times may need to be taken per site in order to provide the accurate output or data.

## 2.7 Land restoration in semi-arid areas

The semi-arid communal areas in the North West province rangelands have been subjected to degradation due to overgrazing and climate change. Combating land degradation is important to ensure long-term productivity of semi-arid environments. Decision support tools are an important component of restoration programs (Agar *et al*., 2013), and are typically leveraged to facilitate the planning and prioritization of restoration investments (Noss *et al*., 2009).

In most pastoral areas of sub-Saharan Africa, the main options for improving pasture quantity and quality where graminoid and nongraminoid herbaceous plant species have disappeared have been limited to destocking, bush management, and intermittent grazing (Opiyo *et al*., 2011; Angassa, 2014). Wilson *et al*. (2011) stressed that restoration can require considerable investments, and decision support tools and associated outlines or frameworks help ensure that the technique is efficient and that restoration goals are realized. Restoration strategies are needed in order to recover the rangelands structure and function. These restoration strategies can address social, economic, and ecological challenges. The efforts are based on realisation that rangeland restoration provides alternative food security in drylands, in addition to improving communities' adaptive capacity against land degradation and climatic change (Mureithi *et al*., 2016). Land restoration is regarded as the process of ecological restoration of a site to a natural landscape and habitat, safe for humans, wildlife, and plant communities. This includes rehabilitation of a site that has sustained environmental degradation, such as those by natural causes and those caused by human activity, to its natural state (Ahmed, 1993). Some restoration strategies are regarded as costly and their success often has significant financial implications.

### *2.7.1 Land restoration techniques in semi-arid areas*

#### 2.7.1.1 Re-vegetation of degraded rangeland

Semi-arid rangelands, which have retrogressed beyond a certain threshold and could not rest-recover, can only be restored by mechanical inputs to help the re-establishment of vegetation (Snyman, 2003). This is due to the fact that most of these areas are severely degraded and it will be hard for them to recover through natural succession processes. Re-seeding technology has been used successfully as a means of rehabilitating degraded rangelands in East Africa (Musimba *et al*., 2004). In order to re-vegetate rangelands degraded to different degrees of severity, there should be different approaches used, based on the soil type, the remaining range components and natural grass condition before sowing and also rainfall amount, before and during grass establishment.

Kitalyi *et al*. (2002) indicated that reseeding can be one of the best methods in which agro-pastoral communities can use in rangeland rehabilitation, and this can help in addressing food insecurity, alleviate poverty and restore rangeland productivity (Mekuria *et al*., 2011). Seeds play an important role in re-vegetation of degraded rangelands and will increase the organic material, biomass, vegetation cover, density of perennial and annual plants, forage production and improve the productivity of livestock and wildlife in general (Makokha *et al*., 1999; Van den Berg & Kellner, 2005; Ruiz-Fernandez *et al*., 2007). PRIMEFACT (2006) stressed that in order to replenish seed reserves, deferment rotation (3 to 4 years) should be given for the desirable plants to fully set seeds. Annual species rely mostly on seed reserves to survive, so it is imperative to ensure that enough time is given for plants to set the seeds. Zowe (2009) highlighted that *Eragrostis superba* is one of the most preffered species to used in revegetating the degraded land due to its higher seed production and potential role in improving the animal productivty. Even though this re-vegetation has a potential to provide direct economic benefit as a source of income through the pasture-related income-generated activities (Mekuria *et al*., 2011), this method has been criticised by several authors due to its high capital requirements (van den Berg & Kellner, 2005; Opiyo *et al*., 2011; van Oudtshoorn, 2015).

Checkerboard method pattern is one of the cultivation used to stabilise and restore the degraded land in arid and semi-arid regions (Cunningham, 1987; Ma *et al*., 2015). This type of cultivation depends on the soil type, the variability of the landscape and vegetation and slope of the land (Silcock & Hall, 2015). The Checkerboard pattern normally results from different crop stages and different tillage direction and it is generally more effective than aiming for low plant control levels over the entire area (Monsen *et al*., 2004). On top of stabilisation, the method also assist in improving soil quality through organic inputs of a decomposed grass (Kang *et al*., 2015), devoid trees and also assist in germination to take place (Chen *et al*., 2013).

Pitting also, is one of the reseeding methods to restore the degraded rangelands. This method is usually effective when it is done before rainy season and also requires non-shallow soils as it might remove the very top lay of the soil and organic surface material and may expose the infertile soil. The method had been known as practical and proven surface modification treatment (Bainbridge, 1996) due to its contribution in the water infiltration and retention, reduces evaporation in the soil (Schuman *et al*., 1987), assist in capturing blowing litter, seeds and fine dust, reduces gullies and stream erosion and provide the suitable niche for plant establishment and increase forage growth and production (WOCAT, 2018; Larson, 1980).

The alternate method of reseeding was described by van Oudtshoorn (2015) which involves seed being broadcasted over the bare areas and tramped in by a concentrated livestock and this becomes successful when the animals are herded to one site several times.

#### 2.7.1.2 The use of fire

Fire has been a influential ecological process in grassland and woodland systems throughout the world for millennia (Hamman *et al*., 2011). Fire is also known to destroy seeds and trees. Prescribed fires have a history of maintaining the diversity of the savannas (Williams, 2003). It can change the plant groupings or communities especially grass and shrubs especially when the succession or development has already started on the land. Fires are important in structuring plant communities and have the potential to influence the occurrence and density of species within a community (Croft *et al.*, 2015) by killing some organs or plants and stimulating others (Witt, 1994). In most grassland ecosystems, fire can become the primary mode of plant decomposition and that will make it crucial in the recycling of nutrients (DeBano *et al.*, 1998). Though fire can be harmful to vegetation; and upset ecological balance between plants, insects, birds, and animal, and also cause soil erosion, it is also known as an instrument that is used in maintaining grass cover by preventing successional development beyond the grassland stage to shrubs and trees (Holechek *et al.*, 1998; Tainton, 1999). It is also applied in controlling invasive species without resorting to herbicides or pesticides (Tainton, 1999).

Tainton (1999) emphasised that when burning to remove accumulated moribund and unacceptable grass material, cool low intensity fires of less than 1000kj/s/m are recommended and high intensity fires (in excess of 2000kj/s/m) will be required when burning undesirable plants. Normally the least damage occurs to the grass sward when it is burnt while the grass plants are dormant. Burns will only remove amassed moribund or unacceptable materials and it is recommended to apply fire immediately after the first springs in South Africa.

#### 2.7.1.3 Controlling bush encroachment

More research has been conducted on bush encroachment, and it is considered to be one of the most widespread forms of degradation in rangelands in all arid and semi-arid regions (de Klerk, 2004; Joubert *et al.*, 2009) with the increased rainfall as the possible driver (Joubert *et al.*, 2008). Bush encroachment can also be caused by fire suppression (Oba *et al.,* 2000; van Langevelde *et al.*, 2003) and soil characteristics (Sankaran *et al.*, 2008). It is known as an environmental problem in savannah ecosystems, but it is not yet clear whether it is more prevalent in communal or ranching grazing lands (Kgosikoma *et al*., 2012).

In order to control bush encroachment, scientific and conservative range management is required from every farmer (Kahumba, 2010) with the overall objective of promoting biomass production and species diversity (Angassa *et al*., 2012). Musa *et al*. (2016) explained bush encroachment control as a disturbance that reduces the threat of bush encroachment by disrupting the invasive woody plant community structure through transformations of biotic environments and habitat conditions in which colonization of the disturbed microhabitat takes place. Angassa *et al.* (2012) suggested that proper management of bush control methods needs to be effectively demonstrated to resource users because these bush control methods shift the rangeland vegetation from dominance by woody vegetation to dominance by herbaceous vegetation. The methods of controlling bush encroachment are mechanical, biological or chemical (Kahumba, 2010). Controlling encroaching tree/shrub species can create a conducive grazing area with palatable herbaceous species for the livestock and if sustained, it will contribute in stabilizing rangelands and help minimize the negative effects of feed and food crises in the future. The integration effects of fire, grazing and cutting can halt the succession of woody species (Sawadogo *et al.*, 2002). Thus, forage production of herbaceous vegetation increases with reduction of woody species (Musa *et al.*, 2016).

#### 2.7.1.4 Grazing management

Overgrazing is known as the main causes of soil degradation in Africa, and it was rated that overgrazing contributed at least 69% of soil degradation (Campbell *et al.*, 2008). The effects of over-grazing on communal rangeland biodiversity include the removal of biomass, trampling and destruction of root systems by livestock (Reid *et al.*, 2010). Factors such as indiscriminate and excessive stocking of large numbers of animals are some of the major contributors to land degradation in Africa. There is a growing consensus that the importance of overgrazing has been underestimated in the past, particularly in sub-Saharan Africa due to poor understanding of rangeland ecology and also lack of appreciation of traditional range management practices in arid and semi-arid areas. The degradation of savannah ecosystems due to overgrazing has led to some governments commercializing communal grazing land to privately owned ranches (Kgosikoma *et al.*, 2013). In order to have improvements in livestock management and enhance grazing management, best practice is important for sustaining the productivity and health of rangelands (Ash *et al.*, 2011). In degraded rangeland, the reduction of stock numbers and controlled grazing can be recommended to lower grazing pressure in order to facilitate rehabilitation. There should be a proper understanding of the effects of grazing management systems on vegetation ecosystem dynamics so as to maintain optimum carrying capacity and species diversity since changes in the species composition will have a significant influence on the sustainability of animal production (Sankaran *et al*., 2005).

## 2.8 Dependency of livestock on rangelands

In most parts of the communal grazing lands of South Africa, ruminant production systems depend mainly on natural vegetation as a primary source of forage and nutrients (Rust & Rust, 2013). The productivity of grazing lands through the amounts of forage and nutrients provided varies considerably between areas (Mary-Howell & Martens, 2008). The estimation of carrying capacity of communal rangelands in arid and semi-arid areas is crucial in the design of interventions for successful livestock production. This will promote the optimal use of rangelands, while encouraging competitive livestock production. Livestock production in many communal grazing areas is under threat because of the deterioration of rangelands caused by overgrazing, bush encroachment and loss of palatable grass species (Ward, 2005). Small-scale rural producers are faced with serious profitability constraints from livestock production on communal rangeland due to a lack of knowledge on both livestock and grazing management. Their farming system has evolved over time and is run by a complex cultural and social organization whose strategies and needs are little understood by those outside the system (Abate, 2006).

## 2.9 Feeding value of grass

The primary objective of forage-livestock managers is to utilize their land so that it can produce high-quality, high-yield feed with the least amount of money or damage to the environment. This principle portends less feed will need to be bought and brought to the farm if proper forage management is practiced. Grasses provide feed for many grazing mammals such as livestock. They are regarded as the most significant source of roughage used by farmers for livestock nutrition. Many types of animals depend on grass as their main source of feed, and are called herbivores and omnivores, these include fore and hind gut fermentator together with grasshoppers and caterpillars as invertebrates. Most of these grass species are produced as pasture or forage and fodder to serve during the winter or dry periods for domestic ruminants, particularly for sheep and cattle.

To maximize grass growth, yield and nutritional value, knowledge of different grass species must be acquired for proper application (Keba *et al*., 2013). A prerequisite for maximum production is a sufficiently high intake of nutrients to ensure that the animal can grow and produce after minimal maintenance requirements have been met. High intake occurs only when an adequate quantity of quality forage is available. Quality and quantity of grass consumed must be known to determine whether nutrients required during grazing by livestock are being provided. Quality is dependent on grazing period, grass species and soil fertility. Native grasses are the dominant plants in the vast rangeland plant communities and very importantly, because they have been used by livestock for years. Forage quality is a serious problem, especially during the dry season. Native grasses have relatively good nutritive value when properly utilized, but are frequently utilized at other than optimum times. Hay is often cut late and sometimes left on the ground too long following cutting resulting in low quality (Orloff & Mueller, 2008). Ball *et al.* (2001) argued that nutrient composition levels are not only necessary criteria in evaluating the nutritional value of forage, but also animal response and cannot be discussed in isolation. He stressed that the value of forage in animal productivity relies more on the quantity consumed than its nutritional composition. Well-managed pastures, regardless of the plant species, can be high in nutrient quality and often exceed the nutrient composition of high quality stored forages.

Grasses can have high feeding value if managed properly as they are able to recover throughout the season when defoliated at the right time and in the right way (Fernandez *et al*., 2014). The most desired characteristics of grass species are the ability of grass to withstand grazing, high palatability and drought tolerance. Grass species can adapt and thrive under different climatic conditions. In order to maintain the feeding value of grasses, there might be a better understanding of the dynamics and interaction between climate, soil, livestock, drought tolerance and rangeland condition. Percetti *et al.* (2017) stressed that plant selection can influence forage quality and high animal gain was observed with the improved and well managed cultivars than with the unselected line of lucerne (*Medicago sativa*). One of the important factors in determining forage quality is palatability, digestibility, and the higher the digestibility the more nutrients will be available and absorbed for use by an animal. When grass matures, leaf percentage decreases, and stem percentage increases, while protein and energy levels decrease. In addition fibre and lignin levels increase and pasture intake decreases (Archers & Detling, 1984). Digestibility is the most important single feature of forage affecting the nutritive value because it is directly related to the energy value and voluntary intake of forage and thus animal performance.  Ragnarsson & Lindberg (2010) found that forages harvested at late growing stage have poor nutritional values for animals. As the plant matures, there is a concomitant decrease in the leaf to stem ratio, and the proportion of highly available cell content (proteins, non-structural carbohydrates (NSC), minerals and lipids) falls and the proportion of the cell wall (dietary fibre- cellulose, hemicellulose and lignin) increases (Beever *et al*., 2000).

## 2.10 Importance of browse trees to livestock

The major problem limiting productivity of livestock is supply of low quality feeds during dry periods (Aregawi *et al*., 2008). Due to unreliable rainfall, the challenge of available vegetation or feed supply both in quality and quantity becomes a serious problem in arid and semi-arid areas. Thus, animals in these areas have to survive only on range vegetation that is of low nutritive value during dry periods (Aregawi *et al*., 2008). In an effort to alleviate the animal feed supply problem, it is imperative to look for potential feed resources, paying particular attention to those trees which survive during the dry season. In this regard, the use of browse species has great potential. Browse species contribute substantially to the availability of feed for livestock in many areas. Several studies (Aganga *et al*., 2000; Motubatse *et al*., 2008; Mokoboki *et al*., 2011) highlighted the significance of these browse species in arid and semi-arid areas. This is because the tropical woodland savannah, with the very rich open stand of trees and shrubs, represents the major grazing environment (Smit, 2008) due to their high contribution of crude protein (CP) of above 10% DM especially during dry periods when most of the vegetation is nutritionally inadequate (below 6% DM). Browse species, just like many other plants respond differently to different levels of defoliation. Both research and practical farm experience have reflected that plants remain productive and healthy when they are browsed moderately (Holechek *et al*., 1998; Tainton, 1999).

Woody plants have other values in addition to their use as forage that have been overlooked. Some of these ecological values include nutrient cycling; nitrogen fixation; organic matter enrichment of soil; site modification, which allows the interception of runoff and deep percolation of rainfall; creation of micro-sites favourable to many plants and soil microorganisms; and habitats for hundreds of wildlife and invertebrate species (Gutteridge &

Shelton, 1998). Restoring and maintaining soil fertility is a basic and critical environmental problem faced by farmers all over the world, and especially in countries in tropical and subtropical regions where most of the soils are deficient of nutrients and organic carbon. The nitrogen fixing ability of tree legumes allows them to grow on hard sites subject to erosion, low fertility or other adverse soil conditions. This may be a great opportunity for farmers to use nitrogen-fixing-bacteria browse species as an alternative to expensive chemical fertilizers (Kang & Gutteridge, 1998). The authors also indicated in their results that the dry foliage contains 2.5-5.5% N and leaf material incorporated into the soil improved fertility, moisture and nutrient retention. Although these functions may not be obvious, they are still important to the healthy operation of the rangeland ecosystem. Baumer (1991) also added that the browse produce wood for fuel and building purposes and provide food (leaves and fruits), fibre, drugs, pollen, nectar, dyes, gums, waxes, resins. Their importance is also recognized in providing shade, windbreaks and protection against heat and cold and in reducing erosion.

## 2.11 Chemical composition of browse species

The nutritional value of forage depends on the amount of proteins and digestible carbohydrates. A large percentage of, but not all, fodder trees are legumes. Compared to crop by-products, foliage is claimed to have a great potential as protein supplements to graminaceous fodder more than crop by-products that have low protein and fermentable energy values (El Hassan *et al*., 2000). This high protein content is not the only factor which makes it a good fodder plant; the digestibility, which varies with the type of animal, is of great importance (Baumer, 1991). Leaves and fruits of ligneous species have a much higher level of digestible crude protein (DCP) than other fodder sources (Table 2.1).

There is a higher concentration of CP (above 10%) in the leaves and fruits of the many of browse plants, even in winter when other forage species exhibit decreased crude protein levels (Dicko & Sikena, 1991). The dry matter digestibility, which is related to nutrient composition, varies widely among tree species. Boufennara *et al*. (2012) indicated that the dry matter digestibility of most browse species can range from 58-75%. Sometimes low intake and digestibility of browse may have some correlation with some deleterious substance that it may contain such as secondary plant compounds in the form of alkaloids and tannins (Motubatse *et al*., 2008; Mlambo *et al*., 2009). Tannins vary from 3g/kg to 100 g/kg among species (Scogings *et al*., 2011). High tannin concentration may exert negative effects on the nutritive value of forages by changing palatability or reduce intake and digestibility (Baba *et al*., 2002).

Table 2.1: Chemical composition of browse species

|  | Parameters |  |  |  |  |
|---|---|---|---|---|---|
| Species | DM % | CP% | NDF% | ADF% | Author |
| *Ziziphus mucronata* |  | 12.3 | 47 | 21.5 | Aganga *et al*., 2005 |
|  |  | 26.2 | 458 | 312 | Hassen *et al*., 2009 |
| *Acacia erioloba* pods | 91.6 | 13.2 | 44.6 | 31.7 | Mlambo *et al*., 2008 |
| *Acacia nilotica* |  | 12.76 | 40.00 | 35.00 | Mnisi, 2015 |
| *Acacia mellifera* |  | 19.9 | 50.7 | 33.5 | Abdulrazak *et al*., 2001 |
| *Grewia flava* | 90.0 | 11.0 | 41.6 | 28.0 | CIRAD, 1991 |
| *Dichrostachys cinerea* |  | 9.-19 |  |  | Choongo *et al*., 2008 |

## 2.12 Plant secondary metabolites in response to herbivory

Invasive herbivores can have significant negative impact on ecosystems. However, these impacts can vary greatly across a landscape. For instance, invasive herbivores often inflict patchy damage on plant communities, resulting in the mortality of some trees while others remain unaffected (Long *et al*., 2007). Difficulties in relating foliar nutritional quality to browsing preferences are due to the many dietary factors that can influence feeding decisions (Windley *et al*., 2016). When mineral and moisture in the soil is abundant, especially early in the growing season, trees have fast growth rates, plant parts tend to be more nutritive and low in anti-nutritional factors (Martz *et al*., 2010). These factors tend to decrease as plants grow or when they receive low rainfall (Nahm *et al*., 2007; Cernusak *et al*., 2011). Browsing intensity influences a plant’s response to herbivory (Kohi *et al*., 2009). The response to herbivory may be seen through changing in tissue chemistry, growth rate or morphology (Bryant *et al*., 1992). Several factors, such as browsing intensity, the soil nutrient status, amount of stored carbohydrates and the timing of defoliation have been highlighted as the ones that influence the observed responses (Smallie & O’Connor, 2000; Poorter & Kitajima, 2007).

Rangelands around the world need intensive assessment strategies on a large number of plants focusing on nutritional value, palatability and toxicity (Norton, 1994). Molyneux and Ralphs (1992) indicated that there is a spatial variation in plant secondary metabolites and is often specific to particular species or genera. Numerous classes of phenolics, glycosides, steroids, cyanogenic compounds, and alkaloids are some of the metabolites found on certain species.

Carbon-based secondary metabolites, such as tannins and polyphenols, are ecologically important compounds in plants for various reasons, for example, they function in protecting the plant against herbivores and pathogens (Rohner & Ward, 1997; Tharayil *et al*., 2011).

Their roles in plant-herbivore interactions include reducing plant palatability, intake and digestion (Basha *et al*., 2013). Some secondary metabolites also reduce internal parasite loads in herbivores (Copani *et al*., 2013). Plant secondary metabolites (PSM) have many ecological functions (Barry, 1986) especially at a low level (2- 4% DM) in the diet, as it has long been considered as defenses against pathogens or herbivores, reducing the likelihood and extent of attack (Mamashela, 2010). Though browsing herbivores are having physiological strategies to adapt with a number of anti-nutritional plant compounds, which include tannins (Mlambo *et al.*, 2015) herbivory by ruminants also affects the chemical defences of tree plants whereby a certain intensity of browsing results in increased defence mechanisms while in others decreased defence mechanisms (Bryant *et al*., 1992). This showed that, with increasing defoliation intensity, plants change their investment strategy in order to overcome the severe browsing habit from herbivores. Findings by Kohi *et al*., (2009) were that, if plants are half utilised (0.5 utilisation factor), browse trees tend to increase the production of secondary metabolites such as tannins that would be useful against browsing. When the plants are frequently defoliated, secondary metabolite concentrations dropped due to carbon being stressed and that may negatively affect growth rate and other morphological attributes. Stevens *et al.* (2007) stress that chemical defences are synthesised in response to browsing when the plant increases its fitness by reducing the herbivore performance and they are known to decrease the rate of herbivory. Most of the plants that are exposed to the herbivores more regularly are those located near the watering points, resting areas and flat terrain zones.

## 2.13 Communal farmers’ perceptions towards sustainable animal agriculture

The understanding of smallholders’ perceptions about sustainable agricultural practices is becoming increasingly important due to worsening land degradation through improper management of the land and climatic changes. The growing population struggles to produce more in order to satisfy the increased demand for foods (Ramakgwale, 2004). The widespread evidence had been observed with regard to the vulnerability of these land users involved in communal farming systems to unsustainable agricultural practices. In South Africa, the ability of local people in managing communal rangelands needs to be given adequate attention. The sustainable management in agriculture takes the concepts of sustainability and synthesizes them with the concepts of management. In order for the communities to be able to improve, sustainable management of rangeland needs to be in practice. If a farmer relies on the rangeland, which is in the surrounding area, then that area needs to be used sustainably to ensure the indefinite supply of the resources to livestock.

Sustainable agriculture, especially in rangeland, needs a method of farming that is not only humane and socially ethical, but a method that can regulate itself. In the broadest sense, sustainable agriculture puts back into the earth what it takes out making a cycle requiring no inputs from outside (Heitschmidt *et al.*, 2004). A community needs to work together to be able to be productive, and when there is a need to get things done, management is needed to take the lead. If sustainable management is in practice in a community, then people will want to stay in that community, and other people will realize the success, and they will also want to live in a similar environment. Part of a sustainable management system in a community is education, the cooperation, and the responsiveness of the people that live in the community.

## 2.14 Summary

Semi-arid lands are among the world’s most fragile ecosystems, made more so by periodic droughts and increases of the misuse or mismanagement of natural resources. Trees and grasses are essential constituents of semi-arid zone ecosystems in the North West Province and contribute to the maintenance of a suitable environment for agriculture especially in communal area rangelands. However, the natural distribution of vegetation has long been altered by human activities leading to the deterioration of many grazing lands. Excessive stocking rates cause a lessening in plant cover, followed by a decrease in plant diversity. Continuing overgrazing can drastically affect the vegetation or can make the palatable species disappear and be replaced by pioneer or invasive species. Livestock production improvement in communal areas can be achieved by understanding the browse and grass quality and factors affecting them as well as through rangeland assessment which gives an idea on the quantity of what the area can provide for the livestock. Every rangeland is a unique mixture of species differing in forage quality and this complexity makes it difficult to characterize its nutritive value. Clear understanding of the current state of rangelands, vegetation distribution and its chemical composition as well as the soil characteristics is vital for sustaining natural resources.

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# 3 CHAPTER THREE - SPATIAL VARIATION OF GRASS SPECIES IN SELECTED LOCAL GRAZING LANDS OF NGAKA MODIRI MOLEMA DISTRICT

## Abstract

The objective of the study was to determine the spatial distribution of grass species as influenced by soil characteristics in selected localities of Ngaka Modiri Molema district. Three transects (2.2 km), which served as replicates, were established at each of the selected grazing areas. The three transects were placed at least 200 metres from each other. Along each transect, points were marked within 500–700 metres (considered as near sites), >700 metres–1.4 km (middle site) and >1.4 km–2.2 km (far sites) from the homesteads to form 9 sampling sub-transects. Within each sub-transect, 10 m × 10 m homogenous vegetation unit (HVU) was marked. In each HVU, 1 $m^2$ quadrat was randomly placed to sample the soil and the grass species resulting in a total of 9 samples per site. Soil was sampled from each site at the depth of 20 cm and assessed for pH, soil organic carbon, total nitrogen, phosphorus, potassium, magnesium, manganese, iron, copper, and zinc. Field survey and sampling was undertaken to estimate plant diversity. Grass species compositions were grouped into (i) high grazing value, medium grazing value and low grazing value species. In addition, species were grouped into their life forms and abundance. There were two soil type found in the communal grazing areas (Clay-loamy in Tsetse and Six Hundred communal areas and Red-brown sand soil type in Loporung and Makgobistadt communal areas). Twenty one percent of the total grasses were classified as high grazing value, 50 % medium grazing value and 29 % as low grazing value. *Aristida* species were more common and dominant in both soil types and *Eragrostis bicolor* occurred as dominant in many sites in both soil types. *Aristida adscensionis* and *Cymbopogon pospischilii* were recorded as common species in clay-loamy soil type. There was a significant effect of soil type, distance from homesteads and soiltype x distance from homesteads interaction on the biomass production. Biomass production was higher in clay-loamy soil type than in red-brown soil type with increasing distance from homesteads. Palatable species like *Digitaria eriantha* were less common and *Themeda triandra* was more common in the middle and far site of the grazing areas. Distances from homesteads, soil type and their interaction did not (P>0.05) influence soil nitrogen content and pH. Soil properties like micro minerals were found to differ significantly across communal areas as influenced by type of soil (clay-loamy to red-brown sand). The data indicate that over-grazing and shortage of plants contribute negatively to soil quality.

Keywords: soil type, grass species, grazing value, soil minerals, semi arids.

## 3.1 Introduction

There is increasing evidence that the plant community structure affects the composition of soil communities (Broadie *et al*., 2000; Grayston *et al*., 2004). Hufford *et al*. (2014) as well as Allen & Wilson (1991) stated that the relationship between plant species distributions and soil properties may provide a means to determine which species are suitable for individual restoration sites. The current perspective suggests that shifts in plant community composition may affect soil organic carbon dynamics (Jin *et al*., 2010). This is due to different land-use practices (grazing and cultivation) that affect the distribution and supply of soil nutrients by directly altering soil properties and by influencing biological transformations in the rooting zone (Fraterrigo *et al*., 2004). Fertilization with dung and urine excreted by animals can contribute to a higher concentration of nutrients in the soil (Georgiadis & McNaughton, 1990; Jaramillo & Detling, 1992).

Grasses are the major feed resource for ruminants in the North West province (Ahamefule, 2006). Species distributions reflect spatial processes as well as adaptation to heterogeneous environments (Kramer *et al*., 2011). Species with limited dispersal show strong relationships with edaphic characteristics and their distribution declines rapidly towards watering points and homesteads (Soininen & Hillebrand, 2007). The climatic characteristics are severe and erratic, causing a strong seasonality in grassland production especially in arid and semi-arid lands (Perez-Corona, 1993). In the face of such a huge dependency on rangelands, little is known on the spatial variation and composition of grass species as influenced by soil characteristics in the communal grazing lands of North West province in South Africa. Furthermore, assessment of distribution or status of native vegetation is essential for sustainable management of this ecological system. This enables control of the movement and the number of animals to be kept over the grazing period. The objective of the study, therefore, was to assess the spatial variation of grass species as influenced by soil characteristics in selected local grazing lands of the Ngaka Modiri Molema District.

## 3.2 Material and methods

### *3.2.1 Study areas*

The study was conducted on four communal rangeland sites of Ngaka Modiri Molema district of the North West province in South Africa. The four selected communal rangeland areas were Tsetse, Six-hundred, Makgobistadt and Loporung with two different soil types. Livestock kept in the study areas are goats, sheep, cattle and donkeys. Tsetse and Six-hundred communal areas have clay-loamy soil type and are next to each other and approximately ±50 km from Makgobistadt and Loporung which have red-brown sand soil type. These sites were selected because field observations before starting with the trials had shown that they are highly overgrazed or mismanaged and spanned two different soil types.

Tsetse (S25°44.776 E025°40.533) and Six-hundred (S25°43.133 E025°38.597) are situated 15 kilometres away from Mafikeng town towards north and they are also adjacent to each other (Figure 3.1). The areas have an average altitude of 1296 metres above sea level. The villages are situated in the open veld, by the banks of the Upper Molopo River. Tsetse and Six-hundred are covered with Dry Highveld Grassland vegetation (Mucina & Rutherford, 2006). The soil in the area has a clay-loamy (CL) texture. The geology consists mainly of limestone, with only a small western segment consisting of quartz porphyry lithology. The soils resulting from this predominant limestone lithology are haplic lixisols and towards the town side, soils are ferallic arenosols that are highly weathered and iron-rich sandy textured soils and also lack any significant soil profile development (Munyati & Moeng, 2015).

Makgobistad (S25°46.198 E025°04.822) and Loporung (S25°46.909 E024°59.035) communal areas are also adjacent to each other and they are found at an average altitude of 1163 m above sea level (Figure 3.1). The vegetation is classified as Eastern Kalahari Bushveld. The soil in these areas is sandy loamy or ccontinental red-brown shifting sand. Given the relatively young geology and prevailing semi-arid climatic conditions, the soils tend to be relatively shallow, leached, and with an unappreciable/weatherable material reserves such that they are inherently infertile. This red-brown sand soil (RBS) is classified as a Rhodic Ferralsol (IUSS Working Group WRB, 2015) or Chromic Luvisol (FAO-ISS-ISRIC 1998). It is a red or yellow-brown sand soil with an orthic A horizon (Frey, 2010).

The rainfall for all areas varies from 400–450 mm/annum, the mean daily temperature is ranging from 2–36ºC throughout the year for all selected areas.

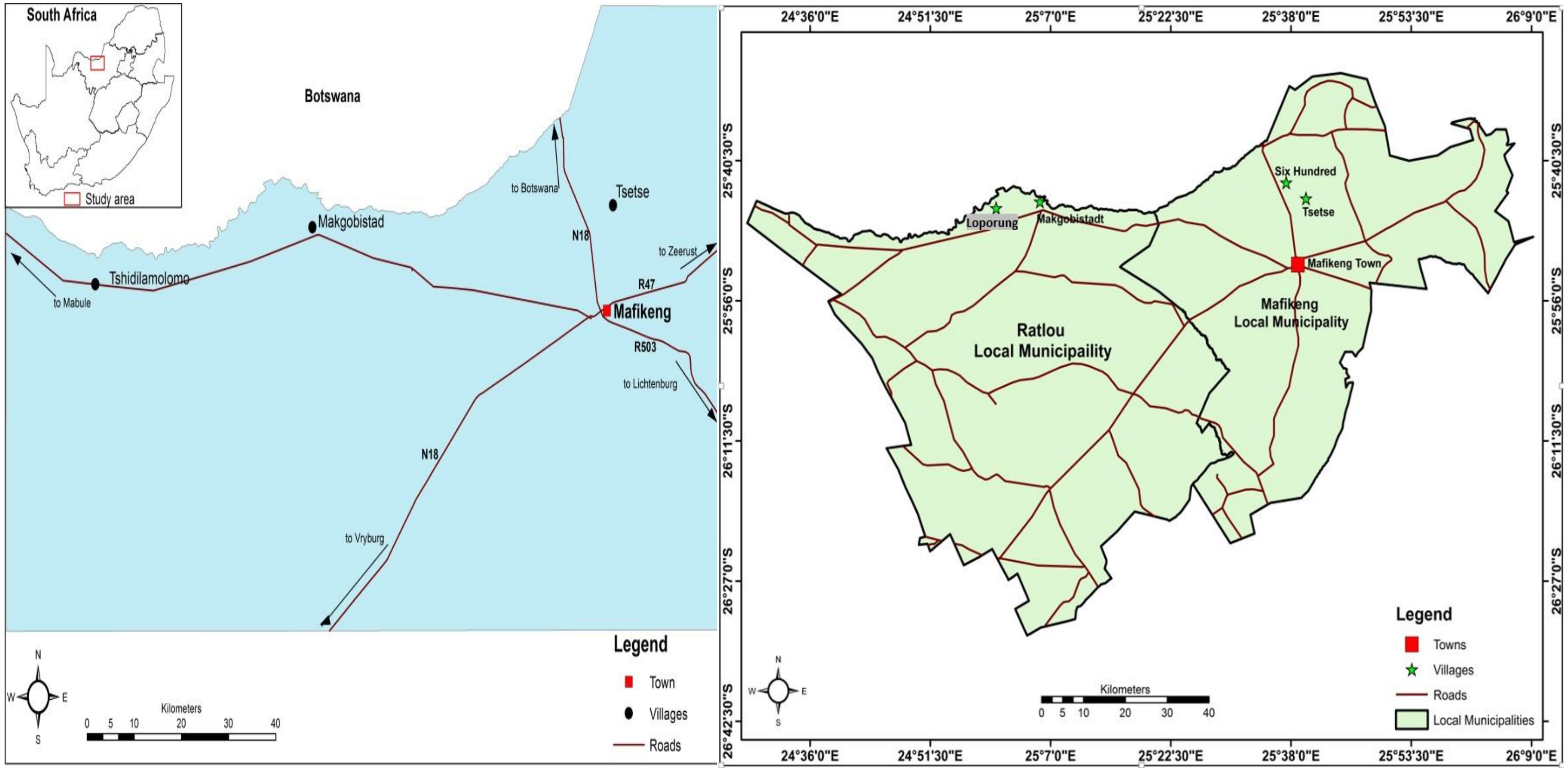

Figure 3.1: Map of the study sites around the Ngaka Modiri Molema district

### *3.2.2 Site selection and layout*

In each study area, the extensive grazing land surrounding a homesteads was identified for vegetation and soil sampling and divided into three main grazing sites. All grazing areas are located on a plain grazing land with negligible topographical differences along the distance from the homesteads. Therefore, the rangeland was simply divided into near (500–700 metre), middle (>700 metres–1.4 kilometre) and far (>1.4–2.2 kilometre) sites from the homesteads where animals are kept overnight. Soil type, altitude and coordinates of the selected sampling sites in the communal areas are indicated in Table 3.1.

Table 3.1: Soil type, altitude, coordinates, and carrying capacity of the selected sampling sites

| Communal | Distance | Soil type | Altitude | Coordinates | Ha/LSU |
|---|---|---|---|---|---|
| Tsetse | Near | Clay-loamy | 1308 | S25°44.284 E025°41.008 | 13/LSU |
| | Middle | Clay-loamy | 1302 | S25°44.776 E025°40.533 | 10.6/LSU |
| | Far | Clay-loamy | 1309 | S25°45.120 E025°40.490 | 9.7/LSU |
| Six hundred | Near | Clay-loamy | 1287 | S25°43.427 E025°38.170 | 14.4/LSU |
| | Middle | Clay-loamy | 1296 | S25°43.133 E025°38.597 | 8.8/LSU |
| | Far | Clay-loamy | 1299 | S25°42.755 E025°39.017 | 8.0/LSU |
| Makgobistadt | Near | Red-brown sand | 1160 | S25°45.687 E025°05.232 | 32.7/LSU |
| | Middle | Red-brown sand | 1177 | S25°46.198 E025°04.822 | 26.1/LSU |
| | Far | Red-brown sand | 1182 | S25°46.642 E025°04.141 | 22.2/LSU |
| Loporung | Near | Red-brown sand | 1117 | S25°45.957 E025°58.872 | 22.2/LSU |
| | Middle | Red-brown sand | 1148 | S25°46.909 E024°59.035 | 18.9/LSU |
| | Far | Red-brown sand | 1165 | S25°47.829 E024°59.597 | 16.0/LSU |

### *3.2.3 Grass sampling*

Three transects (2.1 kilometres) which served as replicates were established at each of the selected grazing areas. The three transects were placed at least 200 metres from each other. Along each transect, points were marked within 500–700 metres (considered as near sites), between 0.70–1.4 kilometre (middle site) and between 1.4–2.1 kilometre (far sites) from the homesteads to form 9 sampling sub-transects. Within each sub-transect, 10 × 10 metre homogenous vegetation unit (HVU) was marked. In each HVU, one square metre quadrat was randomly placed to sample soil and grass species resulting in a total of 9 samples per site. Grasses within each quadrat were harvested at stubble height of 10 cm, bulked and oven-dried for 24 hours at 80°C for biomass determination. Dried samples were milled through a one millimetre sieve pending chemical analysis.

### *3.2.4 Species identification and classification*

Grasses were classified based on the succession theory described by Dyksterhuis (1949) and on ecological information for the arid to semi-arid regions of South Africa (Tainton *et al*., 1980; Vorster, 1982). Accordingly, the species were grouped into (i) highly desirable species: those which occur in rangeland in good condition and decrease with overgrazing (decreasers), (ii) desirable species: those which occur in rangeland in good condition and increase with moderate overgrazing (increaser I), and (iii) less desirable species: those which occur in rangeland in good condition and increase with severe/extreme overgrazing (increasers II and III). In addition, species were grouped into their life forms (annuals or perennials) and abundance (dominant or common, rare, present) as described by Tefera *et al*. (2010) (Appendix 1). Sampling sites were geo-referenced using a GPS (Table 3.1). This was to allow the digitizing of all sample site locations, after being validated, for entry into a spread sheet or a database. Grass species were harvested between February and March 2015.

### 3.2.5 *Soil sampling and analysis*

Topsoil was sampled at a depth of 200 millimetres from each of the nine transects per grazing area resulting in a total of nine samples per site. Sub-samples were taken, air dried and sieved through a two-millimetre mesh screen pending analysis. Soil pH was measured in a 1:2.5 soil water relation extraction method. The Kjedahl method was used to determine percentage total nitrogen (N) (van Reeuwijk, 1992). Percentage organic carbon (OC) was analysed using a colorimetric method (Baker, 1976). Sodium (Na) and potassium (K) were determined using emission spectroscopy, while magnesium (Mg), calcium (Ca), zinc (Zn), copper (Cu), manganese (Mn) and iron (Fe) were determined by atomic absorption spectroscopy (Jackson, 1970). Phosphorus (P) was detected by an ultraviolet spectrophotometer (Olsen & Sommers, 1982).

### 3.2.6 *Statistical analysis: Soil samples*

Analysis of variance was used to test the influence of distance from homesteads on soil chemical constituents (homesteads in each communal area soiltype) using General Linear Model (GLM) procedures of SAS (2010). The following statistical model was used:-

$$Yijk = \mu + Vi + Dj + (VxD)ij + \varepsilon ijk$$

Where $\mu$ = overall mean, $V$ = effect of soil type, $D$ = effect of distance from homesteads, ($V$×$D$) = interaction between soil type and distance from homesteads, and $\varepsilon ijk$ was the error term associated with observation *ijk* assumed to be normally and independantly distributed. The probability of difference (pdiff) option in the lsmeans statement was used to separate the means (SAS, 2010).

### *3.2.7 Statistical analysis: Grass species distribution*

Analysis of variance was used to evaluate the variation across grass species in terms of distribution, height, density and shoot diameter using General Linear Model (GLM) procedures of SAS (2010) within completely randomized design. All data were analyzed within each soil type using a one-way analysis of variance according to the following linear model:-

$$Yij = \mu + Pi + \varepsilon ij$$

Where $\mu$ is overall mean, $P$ is the effect of plant species and $\varepsilon ij$ is the error term associated with observation $ij$ assumed to be normally and independently distributed. The probability of difference (pdiff) option in the lsmeans statement was used to separate the means (SAS, 2010). Statistically significant differences were declared at $P < 0.05$.

## 3.3 Results

### *3.3.1 Grass layer composition and distribution*

A total of 28 grass species were identified across all study areas, of which 23 species were perennials. Twenty one percent of the total grasses were classified to be of high grazing value, 50 % medium grazing value and 29 % as low grazing value (Table 3.2).

Table 3.2: Life form, palatability and abundance of grass species based on mean values in two soil types (CL, clay-loamy soil; RBS, red-brown sand)

| | | | | Clay-loamy soil | | | Red-brown sand | | |
|---|---|---|---|---|---|---|---|---|---|
| | Life form | Ecological status | Grazing value | Near | Middle | Far | Near | Mid | Far |
| *Aristida adscensionis* | Ann | Inc ii | LGV | C | C | C | C | C | C |
| *Aristida congesta* | Per | Inc ii | LGV | D | D | C | D | D | D |
| *Aristida diffusa* | Per | Inc ii | LGV | C | D | C | r | C | C |
| *Aristida stipitata* | Per | Inc ii | LGV | - | - | - | r | C | + |
| *Centropodia glauca* | Per | Dec | HGV | - | - | - | C | C | C |
| *Chloris virgata* | Ann | Inc ii | MGV | - | - | C | - | - | - |
| *Cymbopogon* pospischilii | Per | Inc iii | LGV | C | C | C | - | - | - |
| *Cynodon dactylon* | Per | Inc ii | HGV | C | C | r | C | C | C |
| *Bothriochloa insculpta* | Per | Inc ii | MGV | D | C | C | - | - | - |
| *Digitaria eriantha* | Per | Dec | HGV | - | r | r | - | r | r |
| *Eragrostis rigidior* | Per | Inc ii | MGV | r | r | C | - | - | - |
| *Eragrostis superba* | Per | Inc ii | MGV | r | r | + | - | - | - |
| *Enneapogon cenchroides* | Per | Inc ii | MGV | + | + | + | - | + | + |
| *Eragrostis bicolor* | Per | Inc ii | MGV | r | r | D | D | D | D |
| *Eragrostis echinochloidea* | Per | Inc ii | MGV | C | r | r | - | r | r |
| *Eragrostis trichophora* | Per | Inc ii | MGV | C | C | - | | | |
| *Fingerhuthia africana* | Per | Dec | MGV | C | r | + | - | - | - |
| *Heteropogon contortus* | Per | Inc ii | MGV | r | + | - | - | - | - |
| *Hyparrhenia filipendula* | Per | Inc i | MGV | - | + | - | - | - | - |
| *Hyparrhenia hirta* | Per | Inc i | MGV | r | - | - | - | - | - |
| *Melenis repens* | Per | Inc ii | LGV | - | r | + | - | r | + |
| *Panicum maximum* | Per | Dec | HGV | C | r | + | - | - | - |
| *Perotis patens* | Ann | Inc ii | LGV | - | - | - | r | + | C |
| *Setaria sphacelata* | Per | Dec | MGV | + | - | - | - | - | - |
| *Sporobolus fimbriatus* | Per | Dec | HGV | r | - | - | - | - | - |
| *Themeda triandra* | Per | Dec | HGV | - | C | C | - | - | - |
| *Tragus berteronianus* | Ann | Inc ii | LGV | - | - | - | r | + | r |
| *Urochloa mosambicensis* | Per | Inc ii | MGV | - | + | C | - | - | r |

Ann, annual; Per, perennial; Dec, decreaser; Inc i, increaser i; Inc ii, increaser ii; Inc iii, increaser iii; HGV, high grazing value; MGV, medium grazing value; LGV, low grazing value. D, dominant (>13%); C, common (>3-13%); r, rare (1-3%); +, present (<1%)

### *3.3.2 Composition of dominant and common grass species in clay-loamy soil type*

A species is considered dominant when its average frequency in a site exceeds 13% and is classified as common when average frequency is between 3 and 13%. In line with these definitions, *A. adscensionis* and *C. pospischilii* were classified as common species with increasing distance from the homesteads under clay-loamy soil type (Table 3.2, 3.3). *Aristida congesta* was found dominating (P<0.05) in many near and middle sites but no significant difference was observed from near to far sites (Table 3.3). *Aristida diffusa* was found to be common in near and far sites of the grazing areas and more dominant in the middle of the grazing areas.

In clay-loamy soil type, *Bothriochloa insculpta* was more dominant near the homesteads, and common in the middle and far sites of the grazing area. *Chloris virgata* was more common in the far site of the grazing area. *Cynodon dactylon* was more common near homesteads and in the middle site of the grazing area, and found to be very rare at far sites. *Eragrostis bicolor* was more dominant at far sites from homesteads. *Eragrostis trichophora* was more common near homesteads and middle site of the grazing areas. *Themeda triandra* was rare near the homesteads but common in the middle and far sites. *Digitaria eriantha* was not available near the homesteads and very rare in the middle and far sites. *Eragrostis rigidior* was rare near and middle sites, but it was common in the far sites. *Eragrostis superba* was very rare in near and middle sites, but was recorded as present in the far sites. *Enneapogon cenchroides* was recorded as present along the distant gradient.

Table 3.3: Grass species composition (%) based on the frequencies of occurrence of dominant and common grass species in clay-loamy soil

| | Near | Middle | Far | SE |
|---|---|---|---|---|
| *A. adscensionis* | $6.3^{ab}$ | $7.9^{a}$ | $3.8^{b}$ | 3.80 |
| *A. congesta* | 18.7 | 16.0 | 12.0 | 4.66 |
| *A. diffusa* | $10.4^{b}$ | $27.2^{a}$ | $6.3^{b}$ | 6.30 |
| *C. virgata* | - | - | 12.3 | - |
| *C. pospischilii* | $4.9^{b}$ | $5.6^{b}$ | $11.9^{a}$ | 3.24 |
| *C. dactylon* | 3.7 | 2.2 | 2.5 | 1.67 |
| *B. insculpta* | $23.5^{a}$ | $11.4^{b}$ | $8.9^{b}$ | 5.37 |
| *E. rigidior* | $1.2^{b}$ | $1.8^{b}$ | $8.8^{a}$ | 1.20 |
| *E. bicolor* | $2.4^{b}$ | $2.9^{b}$ | $18.8^{a}$ | 2.40 |
| *E. echinochloidea* | $11.3^{a}$ | $2.1^{b}$ | $2.1^{b}$ | 2.1 |
| *E. trichophora* | $3.6^{b}$ | $7.1^{a}$ | - | 1.65 |
| *F. africana* | 3.8 | 2.1 | 0.7 | 0.70 |
| *P. maximum* | 3.5 | 1.7 | 0.7 | 0.70 |
| *T. triandra* | - | 5.3 | 3.9 | 1.35 |
| *U. mosambicensis* | - | $0.214^{b}$ | $4.877^{a}$ | 0.21 |

$^{ab}$: Means in the same row with different superscripts are significantly different ($P<0.05$)
SE: standard error

### *3.3.3 Composition of dominant and common grass species in red-brown sand soil type*

*Aristida congesta* and *E. bicolor* were dominant in all the sites (Table 3.2 and Table 3.4). *Centropodia glauca, A. adscensionis* and *C. cynodon* were recorded as common in all the distances from homesteads as shown in Table 3.2. *Aristida diffusa* was rare near the homesteads whereas it was found to be common in the middle and far sites. *Aristida stipitata* was rare near the homesteads and recorded as common in the middle site and present in the far sites of the grazing areas. *Digitaria eriantha* and *E. echinochloidea* were not found near the homesteads but recorded as rare in the middle and far sites.

Table 3.4: Grass species composition (%) based on the frequencies of occurrence of dominant and common grass species in red-brown sand soil type

| Species | Near | Mid | Far | SE |
|---|---|---|---|---|
| *A. adscensionis* | 9.5 | 6.3 | 9.2 | 6.3 |
| *A. congesta* | 32.7 | 21.6 | 20.3 | 9.12 |
| *A. diffusa* | 1.2 | 10.5 | 4.9 | 4.52 |
| *A. stipitata* | 2.4 | 6.2 | 0.79 | 2.50 |
| *C. glauca* | 3.0 | 3.4 | 6.3 | 3.00 |
| *C. dactylon* | 8.5 | 7.8 | 3.7 | 3.70 |
| *E. bicolor* | 39.5 | 34.5 | 33.7 | 11.58 |
| *P. patens* | 1.7 | 0.56 | 6.6 | 0.56 |

SE: standard error

### *3.3.4 Grass species composition based on frequencies of desirability groups under different soil types*

The frequency of less desirable, desirable and highly desirable grass species is presented in Table 3.5. There was no difference ($P>0.05$) in the distribution of species according to desirability in both clay-loamy and red-brown sand soil types.

Table 3.5: Grass species composition (%) based on frequencies of desirability groups

| Soil type | Grazing value | | |
|---|---|---|---|
| | LGV | MGV | HGV |
| *Clay-loamy* | | | |
| Near | 10.1 | 6.533 | 1.8 |
| Middle | 14.2 | 3.912 | 2.3 |
| Far | 8.48 | 7.342 | 3.0 |
| SE | 2.24 | 1.047 | 0.73 |
| *Red-brown sand* | | | |
| Near | 9.49 | 39.45 | 5.76 |
| Middle | 9.06 | 34.74 | 5.60 |
| Far | 8.68 | 33.73 | 5.02 |
| SE | 2.82 | 11.59 | 2.49 |

LGV: low grazing value; MGV: medium grazing value; HGV: high grazing value

SE: standard error

### *3.3.5 Biomass production of grass layer under two different soil types along the distance from homesteads*

The results for biomass production (kg/ha) of grass layer on two different soil types are presented in Table 3.6. There was a significant effect of soil type, distance and soil type x distance interaction on the biomass production in both soil types. In general clay-loamy soil type had higher ($P<0.05$) biomass production than red-brown soil type. In clay-loamy soil type, middle (1489 kg/ha) and far (1570.5 kg/ha) sites had higher ($P<0.05$) biomass production than the site near homesteads (562 kg/ha). In red-brown sand soil type, the area near the homesteads had lower ($P<0.05$) biomass production, whereas middle and far sites had higher ($P<0.05$) biomass production (698 kg/ha and 813 kg/ha, respectively).

Table 3.6: Biomass production (kg/ha) of grass layer under two different soil types with distance from homesteads

| Distance | Clay-loamy | Red-brown sand |
|---|---|---|
| Near | $562.4^{bA}$ | $231.7^{bB}$ |
| Middle | $1488.8^{aA}$ | $698.00^{aB}$ |
| Far | $1570.5^{aA}$ | $813.3^{aB}$ |

$^{AB}$: Means in the same row with different superscripts are significantly different ($P<0.05$) between soil type
$^{ab}$: Means in the same column with different superscripts are significantly different ($P<0.05$) between distance gradient
SE: standard error

### *3.3.6 Spatial differences in the height of some common grass species found in clay-loamy soil type*

The results on spatial differences in the heights (cm) of some common grass species found in clay-loamy soil type area are presented in Table 3.7. *Aristida adscensionis, A. diffusa, C. dactylon, B. insculpta, E. rigidior, E. bicolor, E. echinochloidea, E. trichophora, F. africana* and *P. maximum* grass species had approximately the same ($P>0.05$) height values with increasing distance from homesteads. *Cymbopogon pospischilii* and *A. congesta* (74.9 cm and 45.5 cm, respectively) near the homesteads had lower ($P<0.05$) height values compared with middle (107 cm and 69 cm, respectively) and far (121 cm and 69 cm, respectively) sites, which did not differ significantly ($P>0.05$) from each other.

Table 3.7: Spatial differences in the heights (cm) of some common and dominant grass species found in clay-loamy soil type

| | Near | Middle | Far | SE |
|---|---|---|---|---|
| *A. adscensionis* | 84.8 | 81.8 | 79.3 | 4.17 |
| *A. congesta* | $45.5^{b}$ | $68.9^{a}$ | $68.75^{a}$ | 7.15 |
| *A. diffusa* | 53.5 | 59.0 | 67.3 | 7.66 |
| *C. virgata* | - | - | 69.0 | - |
| *C. pospischilii* | $74.9^{b}$ | $106.57^{a}$ | $120.7^{a}$ | 7.08 |
| *C. dactylon* | 35.7 | 38.2 | 34.7 | 34.24 |
| *B. insculpta* | 60.2 | 60.5 | 83.1 | 6.33 |
| *E. rigidior* | 77.3 | 77.8 | 80.3 | 3.45 |
| *E. bicolor* | 69.7 | 69.5 | 86.9 | 6.01 |
| *E. echinochloidea* | 41.5 | 44.9 | 57.0 | 5.07 |
| *E. trichophora* | 79.0 | 61.6 | - | 5.74 |
| *F. africana* | 66.2 | 70.5 | 68.3 | 4.47 |
| *P. maximum* | $59.7^{a}$ | $77.0^{ab}$ | $95.3^{a}$ | 11.46 |
| *T. triandra* | - | 93.5 | 111.67 | 4.21 |
| *U. mosambicensis* | - | $71.3^{a}$ | $61.83^{b}$ | 2.146 |

$^{ab}$:Means in the same row with different superscripts are significantly different (P<0.05)
SE: standard error

### *3.3.7 Spatial differences in the height of some common grass species found in red-brown sand soil type*

The results on spatial differences in the heights (cm) of some common grass species found in red-brown sandy soil type area are presented in Table 3.8. *Aristida congesta* and *C. glauca* plants growing in the middle and far sites were taller (P<0.05) than those growing near homesteads. *Aristida diffusa* (83 cm) near the homesteads and middle (75 cm) site of grazing area were taller (P<0.05) than those in far sites. *Aristida adscensionis* plants growing in the middle site of grazing area had the same (P>0.05) height as those in the far and near sites. *Aristida stipitata* plants growing in the middle site of grazing area had higher (P<0.05) height value (84.9 cm) than those found near (73 cm) and far (73.7 cm) sites which did not differ significantly ($P>0.05$) from each other. *Cynodon dactylon* plants growing far site from homesteads had the highest ($P<0.05$) height value (38 cm) than all other sites. *Eragrostis bicolor* plants growing in the far site had the same ($P<0.05$) height value as near and middle sites. *Perotis patens* had the same ($P>0.05$) height values with increasing distance from homesteads.

Table 3.8: Spatial differences in the heights (cm) of some dominant and common grass species in Red-brown sand soil type

| Species | Near | Middle | Far | SE |
|---|---|---|---|---|
| *A. adscensionis* | $38.5^{b}$ | $55.3^{ab}$ | $72.8^{a}$ | 8.06 |
| *A. congesta* | $37.1^{b}$ | $56.7^{a}$ | $57.6^{a}$ | 3.69 |
| *A. diffusa* | $83.0^{a}$ | $75.0^{a}$ | $44.7^{b}$ | 9.77 |
| *A. stipitata* | $73.0^{b}$ | $84.9^{a}$ | $73.7^{b}$ | 3.72 |
| *C. glauca* | $52.67^{b}$ | $62.9^{a}$ | $71.0^{a}$ | 2.80 |
| *C. dactylon* | $15.3^{b}$ | $23.1^{b}$ | $37.7^{a}$ | 3.89 |
| *E. bicolor* | $52.3^{b}$ | $66.5^{a}$ | $61.8^{ab}$ | 4.28 |
| *P. patens* | 69.5 | 71.3 | 63.4 | 4.99 |

$^{ab}$ : Means in the same row without common superscripts are significantly different ($P<0.05$)
SE: standard error

### *3.3.8 Soil parameters*

#### 3.3.8.1 Soil pH, nitrogen and organic carbon

The results showing statistical significance (P value) of the effects of the main factors on the chemical constituents of the soil (N and pH) under two soil types are presented in Table 3.9. There was a significant effect of soil type on the chemical constituents from selected grazing areas. Both distance and distance x soil type interaction did not ($P>0.05$) influence soil nitrogen content and pH. There was a significant effect of soil type, distance and soil type x distance interaction on organic carbon percentage in the study areas.

Table 3.9: The results showing statistical significance (P value) of the effects of the main factors on the chemical constituents of the soil (N, pH and OC) from four different selected communal areas

| | N | pH | OC |
|---|---|---|---|
| Soil type | * | * | * |
| Distance | NS | NS | * |
| Soil*Distance | NS | NS | * |

NS: not significant (P>0.05); * :significant (P<0.05); N: nitrogen; OC :organic carbon

Soil pH values along the distance gradients in the two soil types are presented in Figure 3.2. In CL soil and RBS soil the pH values were similar (P>0.05) across the distance gradient, whereas between different grazing areas, there was variation (P<0.05) in soil pH, whereby the average pH value of CL soil type was higher than that in RBS soil type.

Nitrogen levels in all soil types are presented in Figure 3.3. In the two grazing sites there was no distinct trend in the levels of soil nitrogen moving away from the homesteads, but a significant effect due to soil type was observed. The clay-loamy soil type had higher (P<0.05) percentage of N (mean ± SE: 0.045 ± 0.0037%) in the near site than in RBS soil (0.0096 ± 0.0037 %). In the middle of the grazing area, clay-loamy soil type had higher (P<0.05) N percentage (mean ± SE: 0.040 ± 0.0037%) than in RBS soil type (0.013 ± 0.0037%)

Though there was some significant effect from soil types, distance and distance x soil type interaction on organic carbon, there was no consistent trend with increasing distance from the homesteads in both soil types (Fig 3.4). The clay-loamy soil had higher (P<0.05) organic carbon (mean ± SE: 1.115 ± 0.0051%) than RBS soil (0.27 ± 0.0051%) in the near sites. In the middle and far sites of the grazing area. The clay-loamy soil also had higher (P<0.05) organic carbon (mean ± SE: 0.985 ± 0.0051%, 1.05 ± 0.0051%, respectively) than RBS soil type (0.31 ± 0.0051% and 0.23 ± 0.0051%).

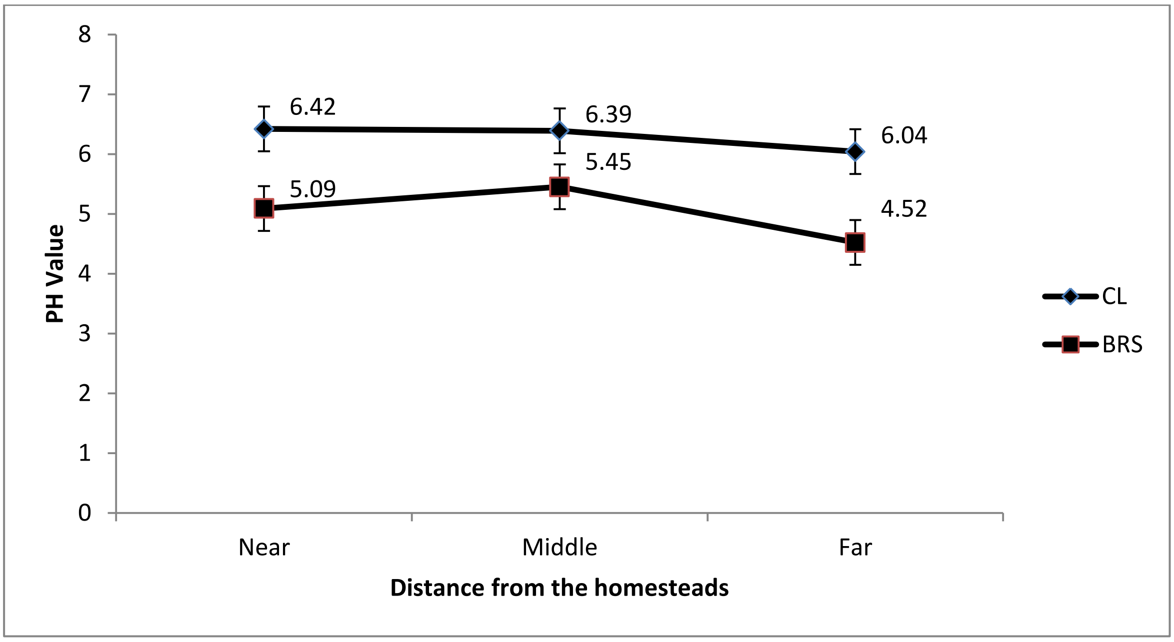

Figure 3.2: Mean values of pH along the distance from the homesteads in two soil types (CL = clay-loamy soil; RBS = red-brown sand)

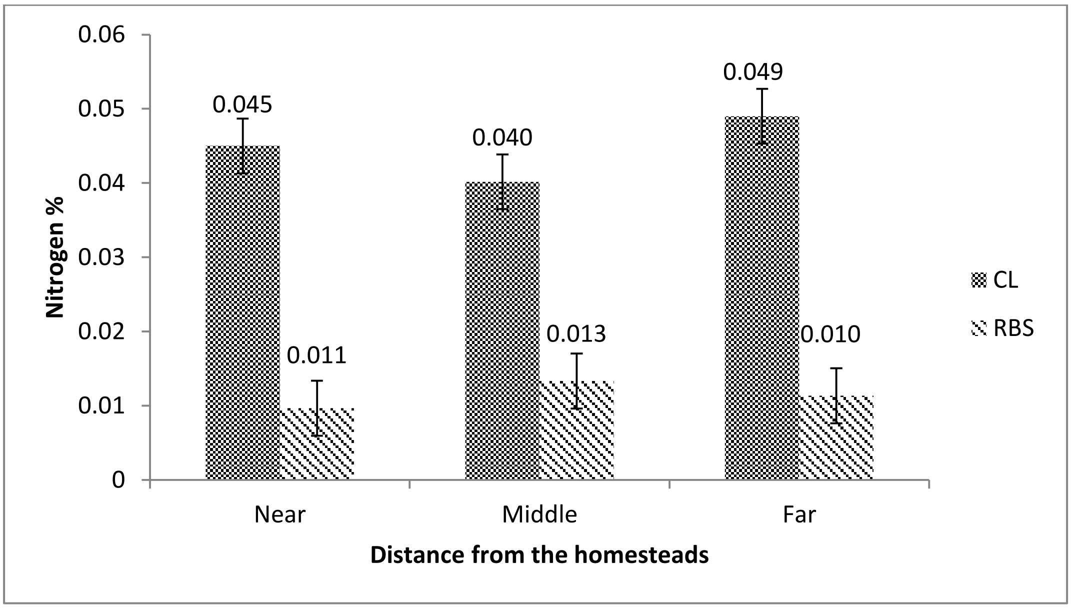

Figure 3.3: Mean values of N (%) along the distance from the homesteads in the two soil types (CL = clay-loamy soil and RBS = red-brown sand)

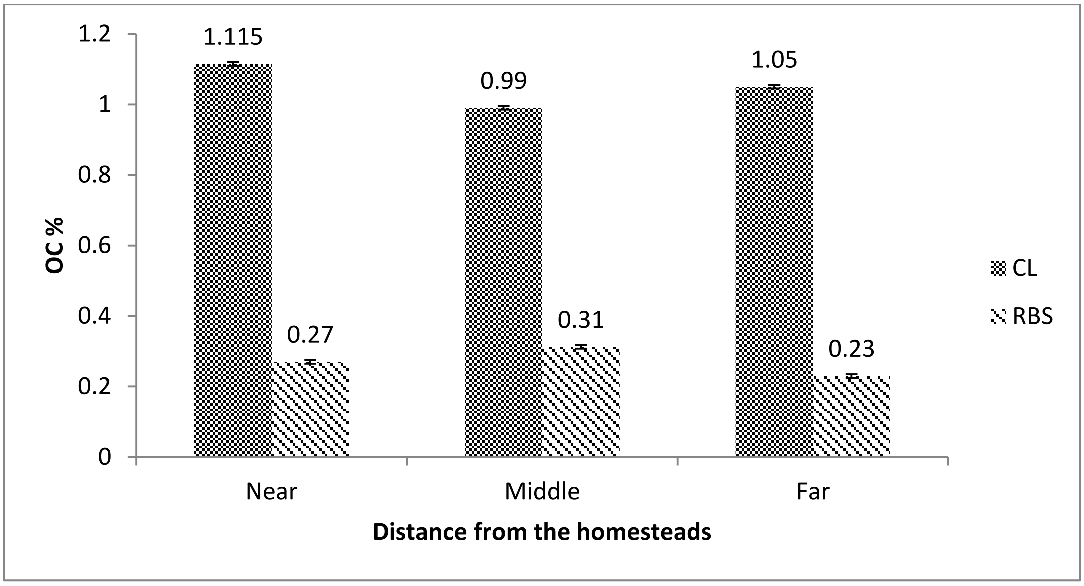

Figure 3.4: Mean values of organic carbon (OC) (%) along the distance from the homesteads in two soil types. (CL = clay-loamy soil; RBS = red-brown sand)

#### 3.3.8.2 Soil macro and micro mineral elements

The results showing statistical significance (P value) of the effects of the main factors on the mineral constituents of the soil from selected communal areas are presented in Table 3.10. There was a significant effect of soil type, distance and soil type x distance interaction in all macro and micro minerals, except for phosphorus.

Table 3.10: Statistical significance (P value) of the effects of the main factors on the Chemical constituents (macro and micro minerals) of the soil in selected communal areas

| | Macro | | | | | Micro | | | |
|---|---|---|---|---|---|---|---|---|---|
| Factors | P | K | Ca | Mg | Na | Fe | Cu | Zn | Mn |
| Soil type | * | * | * | * | * | * | * | * | * |
| Distance | NS | * | * | * | * | * | * | * | * |
| Soil type x Distance | NS | * | * | * | * | * | * | * | * |

NS: not significant (P>0.05); *: significant (P<0.05)

P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; Na: sodium; Fe: iron; Cu: copper; Zn: zinc; Mn: manganese

Phosphorus concentration in both CL and RBS soils did not differ (P>0.05) with increasing distance from homesteads and there was also no distance × soil type interaction effect on the same parameter (Table 3.10 and Figure 3.5). However, soil type affected (P<0.05) P concentration. In area near the homesteads and in the middle of the grazing area, clay-loamy soil type had higher (P<0.05) concentration (3.5 ± 0.215 mg/kg and 4.00 ± 0.215 mg/kg, respectively) of phosphorus mineral than RBS soil type (2.5 ± 0.215 mg/kg and 2.5 ± 0.215 mg/kg) at a similar distance.

Both soil types had higher (P<0.05) potassium concentration in the near sites (CL soil=375.00 ± 1.6 mg/kg and RBS soil = 67.5 ± 1.6 mg/kg) and middle sites (CL soil = 377.5 ± 1.6 mg/kg and RBS soil = 67.0 ± 1.6 mg/kg) (Figure 3.6). In the far sites from the homesteads, both soil types had lowest (P<0.05) potassium concentration values (CL soil = 286.67 ± 1.6 mg/kg and RBS soil = 58.0 ± 1.6 mg/kg, respectively). In CL soil type, Ca concentration was higher (P<0.05) in the middle sites and near (377.5 ± 0.72 mg/kg and 375.0 ± 0.72 mg/kg, respectively) than far sites (286.6 ± 0.72 mg/kg) whereas in the RBS soil type, the Ca concentration declined significantly with increasing distance from homesteads (Figure 3.7).

In the CL soil type, the Mg concentration declined significantly with increasing distance from homesteads (Figure 3.8). In CL soil type, Mg concentration was higher ($P<0.05$) in the middle and near sites (98 ± 0.577 mg/kg and 74 ± 0.577 mg/kg, respectively) than far sites (46.5 ± 0.577 mg/kg). The clay-loamy area near the homestead had higher ($P<0.05$) Sodium, Na, (70 ± 0.577 mg/kg) concentration than in the middle and far sites (Figure 3.9). Middle site had the lowest ($P<0.05$) concentration of Na (24 ± 0.577 mg/kg) in CL soil type. In RBS soil, Na concentration was higher ($P<0.05$) in the middle (6.5 ± 0.577 mg/kg) of the grazing area than near (5 ± 0.577 mg/kg) and far (4 ± 0.577 mg/kg) sites.

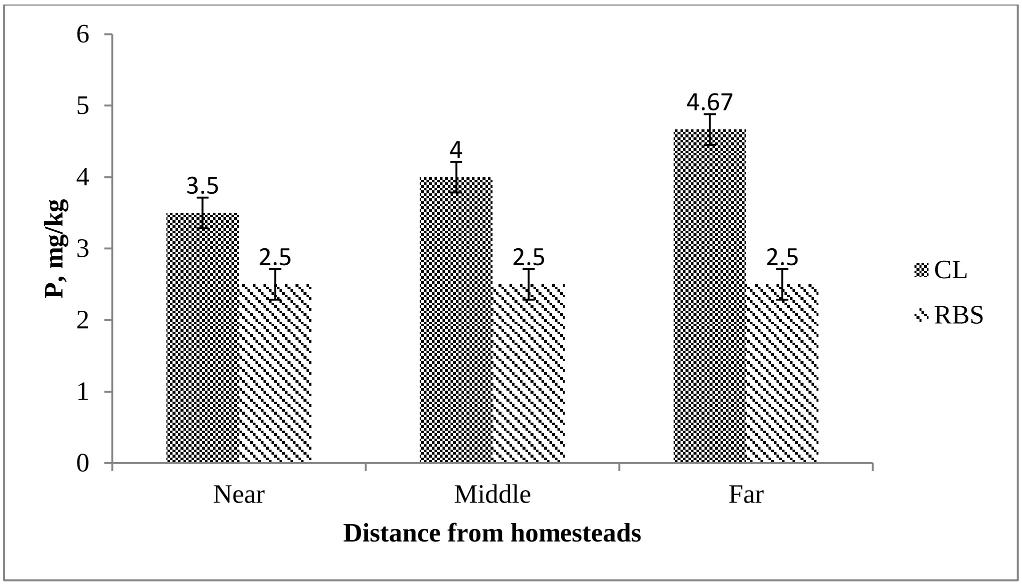

Figure 3.5: Mean values for phosphorus (P) (mg/kg) from near, middle and distant sites from the homesteads (CL = clay-loamy soil; RBS = red-brown sand soil)

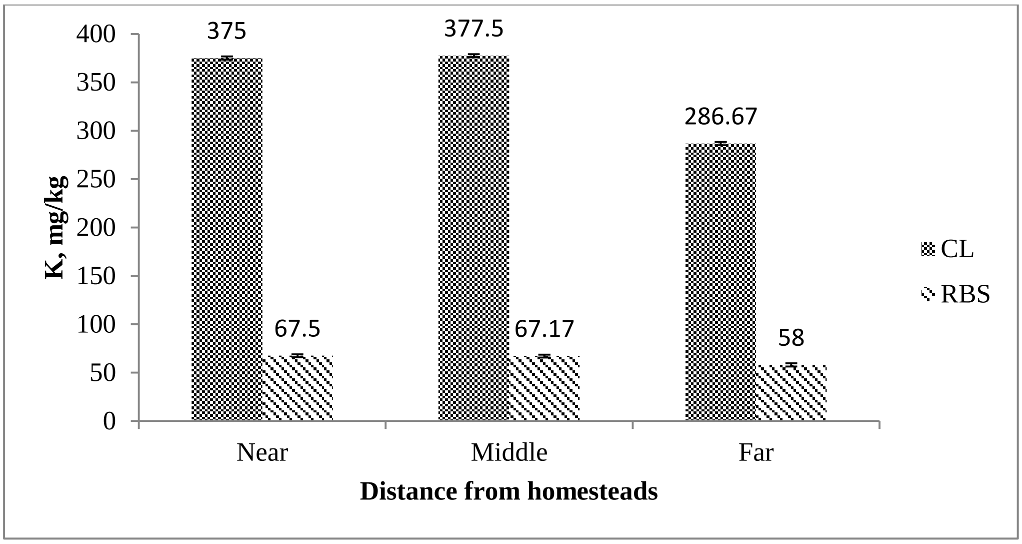

Figure 3.6: Potassium (K) values (mg/kg) from near, middle and distant sites. (CL = clay-loamy soil; RBS = red-brown sand soil)

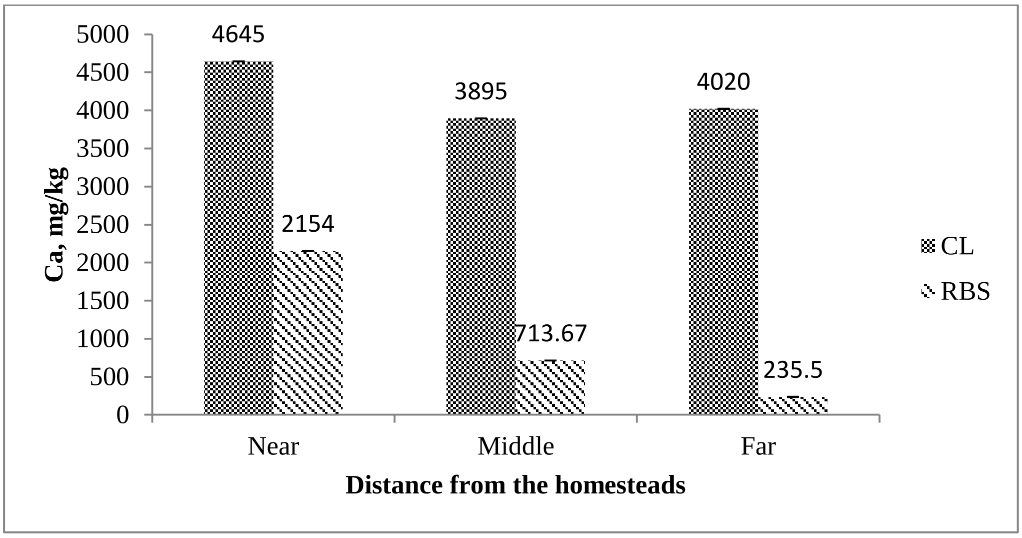

Figure 3.7: Calcium (Ca) values (mg/kg) from near, middle and distant sites (CL = clay-loamy soil; RBS = red-brown sand soil)

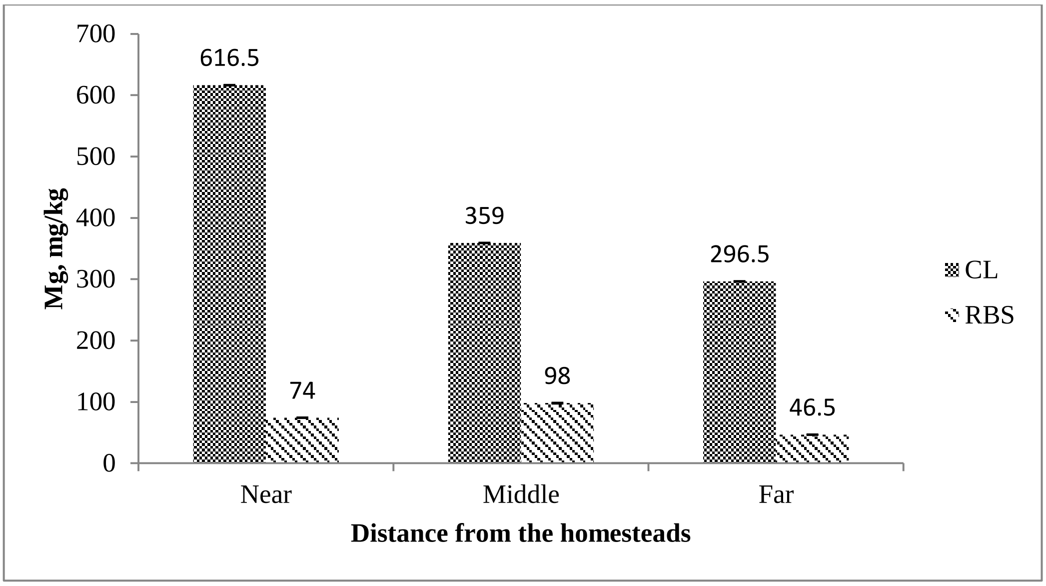

Figure 3.8: Magnesium (Mg) values (mg/kg) from near, middle and distant sites (CL = clay-loamy soil; RBS = red-brown sand soil)

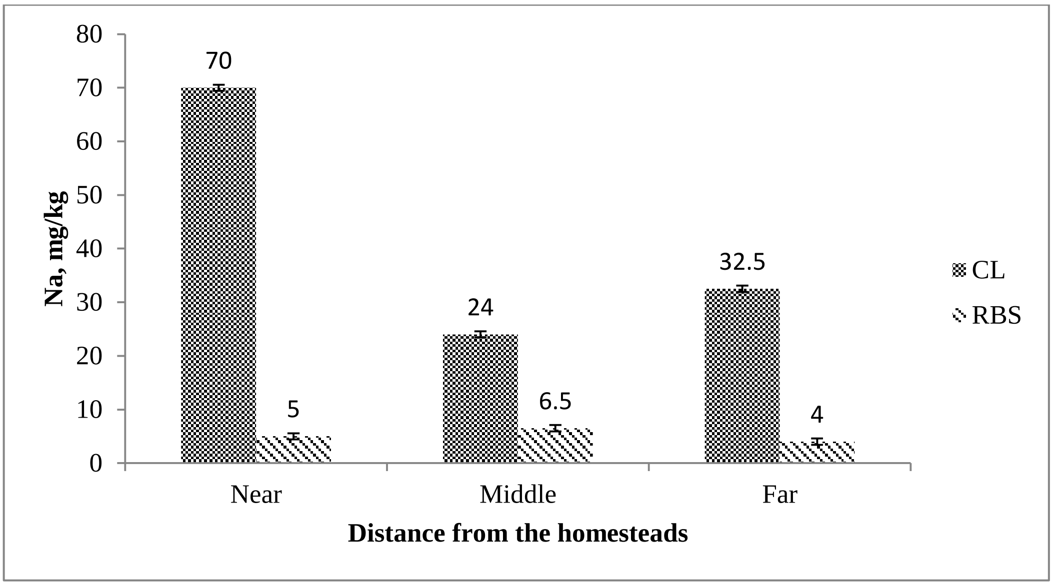

Figure 3.9: Sodium (Na) values (mg/kg) from near, middle and distant sites (CL = clay-loamy soil; RBS = red-brown sand soil)

Red-brown soil type had the highest ($P<0.05$) Fe (4.16 ± 0.014 mg/kg) concentration in the middle site than near (3.8 ± 0.014 mg/kg) and far sites (3.72 ± 0.014 mg/kg) (Figure 3.10). In CL soil type, the Fe concentration increased with increasing distance from homesteads with the values ranging from 1.04 to 1.4 ± 0.014 mg/kg. In the CL soil type, the middle grazing site had higher (P<0.05) value of Cu (0.24 ± 0.0044 mg/kg) than the near and far sites (Figure 3.11). In the RBS soil type, the Cu concentration declined significantly with increasing distance from homesteads with the values ranging from 0.2–0.32 ± 0.0044 mg/kg.

There was an increase in Zn concentration with increasing distance from homesteads on CL soil type (Figure 3.12). The near site mean concentration level was 0.32 ± 0.0054 mg/kg and furthest site level was 0.38 ± 0.0054 mg/kg. In RB soil type, the area near the homesteads had higher (P<0.05) concentrations of Zn (0.32 ± 0.0054 mg/kg) than middle (0.26 ± 0.0054 mg/kg) and far sites (0.28 ± 0.0054 mg/kg). There was an increase in Mn concentration with increasing distance from homesteads on CL soil type with the mean value ranging from 71.2 ± 0.12 mg/kg in near sites to 93.4 ± 0.12 mg/kg in the far sites (Figure 3.13). In the RBS soil tpye the middle site had higher (P<0.05) concentration of Mn (38.2 ± 0.12 mg/kg) than far (25.2 ± 0.12 mg/kg) and near sites (27.8 ± 0.12 mg/kg).

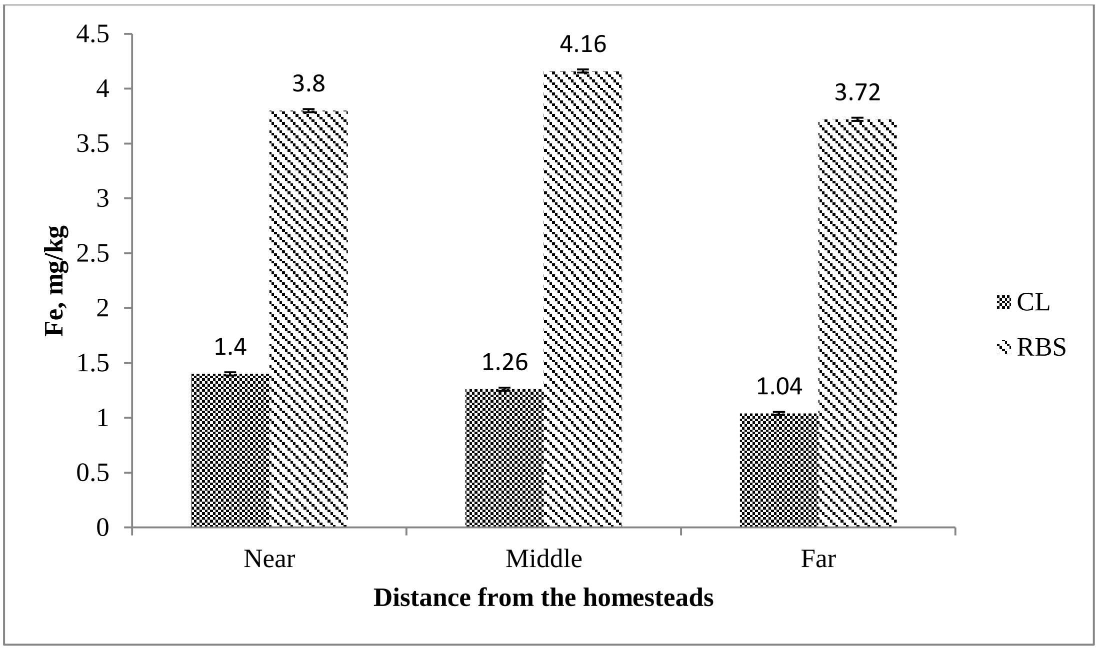

Figure 3.10: Mean values of micro element Fe (iron) (mg/kg) along a distance gradient from homesteads in two soil types (CL=clay-loamy soil; RBS= red-brown sand soil)

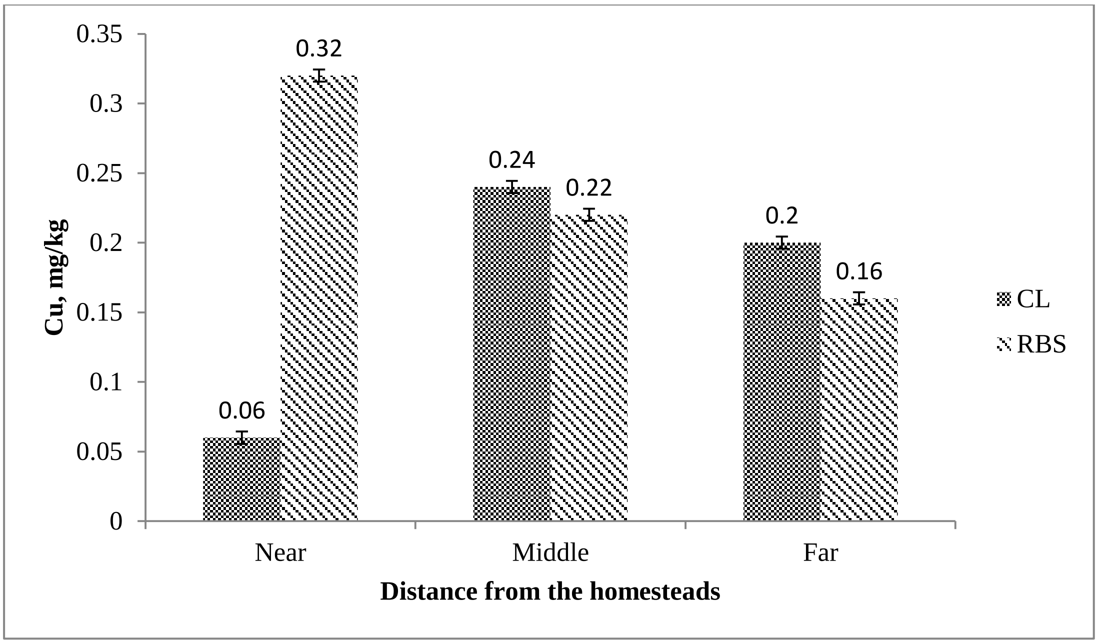

Figure 3.11: Mean values of micro element Cu (copper) (mg/kg) along a distance gradient from homesteads in two soil types (CL = clay-loamy soil; RBS = Red-brown sand soil)

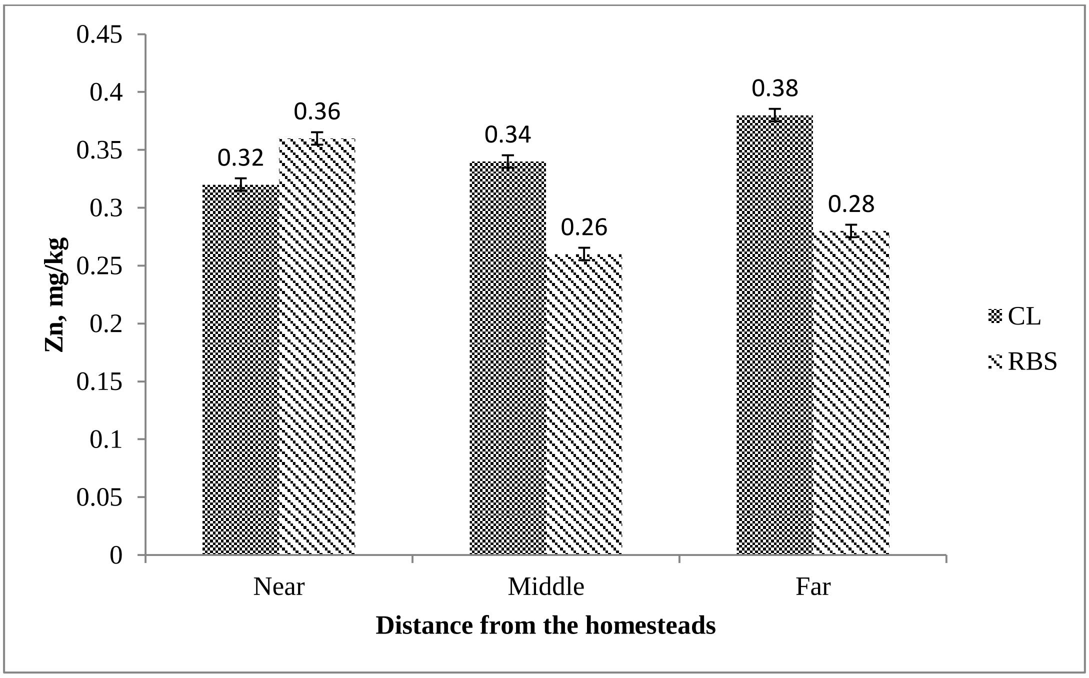

Figure 3.12: Mean values of the micro element Zn (zinc) (mg/kg) along a distance gradient from homesteads in two soil types (CL = clay-loamy soil; RBS = red-brown sand soil)

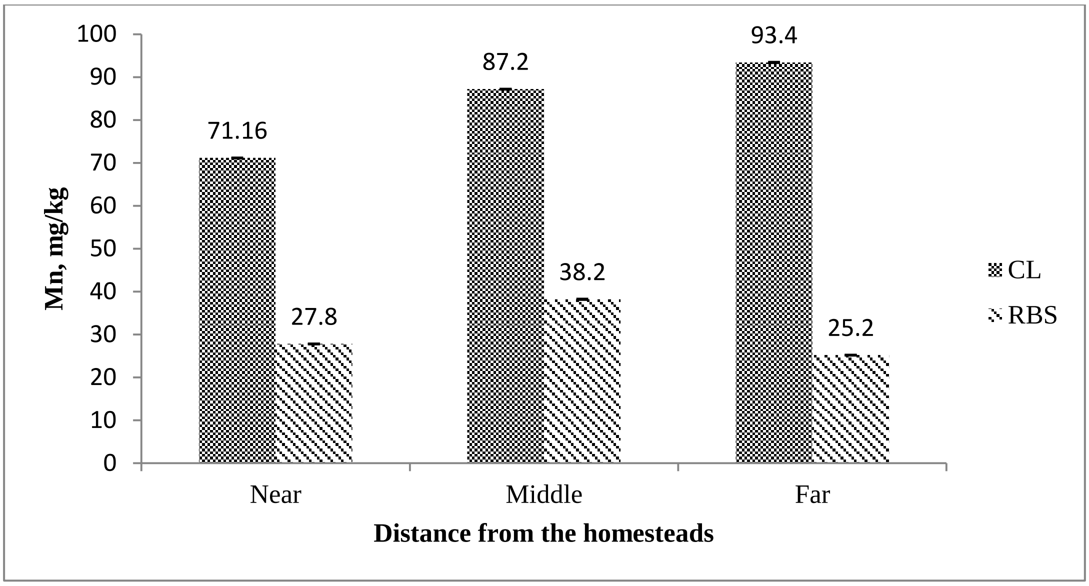

Figure 3.13: Mean values of micro elements Mn (manganese) (mg/kg) along a distance gradient from homesteads in two soil types (CL=clay-loamy soil; RBS= red-brown sand soil)

## 3.4 Discussion

### *3.4.1 Soil properties*

The areas Tsetse and Six-hundred have clay-loamy soil type whereas Makgobistadt and Loporung communal areas are dominated by red-brown sandy soil. All the communal areas selected were at an altitude of 1000 meters above sea level. The soil characteristics influenced the type of vegetation found in these areas. Nik *et al*. (2015) stressed that soil is an environmental component permanently changing due to the often cyclical processes of litter supply and vegetation cover. Clay-loamy soil type in Tsetse and Six-hundred had better pH values (6.0 to 6.4) than red-brown soil type in Makgobistadt and Loporung grazing areas (4.5-5.5). Soil pH of 5.2-8.0 is regarded as optimum for most agricultural plants, including grasses (Lake, 2000). This is because soil pH affects the availability of nutrients and how the nutrients react with each other. The major impact pH has on plant growth is also related to the soil concentration of plant-toxic minerals (Londo *et al.,* 2006). At low soil pH beneficial elements such as P, Mg, and Ca become less available to many plant species (Garrison, 2002). At this low pH other minerals may become more available and may reach the level where they can become toxic to plants (Lake, 2000).

Top soil in Tsetse and Six-hundred communal areas had better values of nitrogen, phosphorus and potassium content than in Makgobistadt and Loporung communal areas. Nutrients from topsoil are regarded as the most important contributors for shrubs and grasses nutrients as it was observed with number of grass species available in clay-loamy soil type. Heavy grazing has been shown to be a major contributor to massive losses of quality topsoil in most communal rangelands (Shariff *et al*., 1994; Steffens *et al*., 2008; Zarekia *et al.*, 2012). Thus, heavy grazing automatically changes nutrient availability and limits vegetative growth (Goldberg, 1990). Areas like Makgobistadt and Loporung grazing sites lost topsoil as it was seen through bare patches available on the grazing lands. Rest-rotation grazing system with moderate grazing intensity can lead to small changes in the increment of some of the physical and chemical characteristics of soil (Zarekia *et al*., 2012), but such action become impossible to apply due to shortage of infrastructure in communal areas.

There was no difference in P and N content and also in pH of top soil sampled at various distances from homesteads. The results on pH are similar to the ones reported by Le *et al*, (2002). The authors found that soil pH were relatively stable irrespective of distance from the homesteads in all directions. However, this is contrary to the findings of Kavianpoor (2012) who found that some minerals in the top soil were influenced by spatial changes. Again, on the contrary, Lempesi *et al*. (2012) reported that total nitrogen was significantly higher at the closest distance to the critical areas like villages when compared with far area. It is well known that in heavily grazed areas soil usually has higher N content (Lempesi *et al*., 2012; Diarisso *et al*., 2016). Liu *et al*. (2011) and Tamartash *et al*. (2007) stressed that higher soil nitrogen content in soil under heavy grazing can be probably caused by animal excrement and urine as animals will be concentrated in one area for long time.

Top soil from clay-loamy soil type (Tsetse and Six-hundred) had higher carbon percentages (0.99 and 1.12%, respectively) than in Makgobistadt and Loporung (0.20 and 0.30%, respectively). Normally, significant output can be an indication that organic matter decreased gradually as grazing intensity increased. The results from the study showed that there was an inconsistent trend in organic matter content along the gradient from the homesteads. The inconsistent flow in organic matter distribution along the gradient can be attributed to the fact that there was no specific preferred site by livestock. Soil organic matter plays an important part in maintaining soil health and its productivity potential as it was reported by several authors (Liu *et al*., 1997; Xie & Witting, 2004; FAO, 2017). Areas with clay-loamy soil had a better organic matter content. Abundance of plants in that soil type might have contributed to the greater amounts of organic carbon in the soil (Aandahl, 1981). Grazing intensity is known to directly influence the amount of carbon (Thomas, 2012). This is in line with the results by Bauer *et al*. (1987) who found that grazing reduced soil organic carbon. Heavy grazing can result in trampling that normally breaks up soil aggregates, exposing organic matter to decomposition and loss through erosion (USDA, 2001).

Top soil collected from Tsetse and Six-hundred communal areas had better micro mineral values than the soil from Makgobistadt and Loporung. These micro-minerals are also vital for plant growth. They are needed by animals in minute quantities (Munshower, 1994). Factors such as heavy grazing, deforestation, burning and the structure of the soil (texture) can reduce the concentration of minerals. This was also supported by Blank *et al*. (2007) who stressed that herbaceous vegetation removal decreased availability of nitrate, Ca and Mg. Differences were observed as influenced by distance from the homesteads in communal areas of selected study sites. This is also comparable to the findings of Blank *et al*. (2007) who reported that some macro minerals like Ca changed in concentration with distance.

### *3.4.2 Grass layer*

The vegetation in the study areas was made up of about 82% perennial plants. In semi-arid areas where rainfall is erratic, most perennial grasses are expected to dominate when compared with annual plants. These species tend to be drought resistant and it can be useful for grazing and hay production as long as half utilisation factor is applied. In Tsetse and Six-hundred communal areas (CL soil type), two year (biennial) and more than two year lifespan (perennial species) plants, whose grazing value ranged from low to medium, were more common. The availability of these perennial grass species can help in promoting organic carbon and soil friability as well as water-stable aggregation (Chan *et al*., 2001). The prospective benefits of perennial species include preserving the value of the fragile hardsetting soils in the low precipitation sites.

The ecological status of the grasses indicated that the clay-loamy soil type areas are covered with species ranging from increaser I to increaser III in all communal areas with some few species being decreasers. As van Oudtshoorn (2014) highlighted increaser I to increaser III are those species that are abundant in undergrazed and overgrazed rangelands. There is evidence that the areas were overgrazed or disturbed due to the occurrence (dominant and common ones) of some unpalatable species such as *C. pospischilii* and *Aristida spp*, particularly in areas closer to homesteads where animals are kept overnight. Overgrazing, burning and cultivation can create suitable environments for other unpalatable and semi palatable species to dominate the areas (van Oudtshoorn, 2014). Briske & Noy-Meir (1997) also stressed that livestock grazing can change the composition, structure of grasslands, and savannahs in semi-arid environments. Those species of high palatability will always be the most preferred species by livestock and that may result in the extinction of these high grazing value species (Todd & Hoffman, 1999). The increase in unpalatable species means a reduction in nutrient intake by animals (Gusha & Mugabe, 2013) and that will affect the productivity of animals.

*Cynodon dactylon* was the only palatable species found in both soil type areas. *Cynodon dactylon* grass is a highly variable, hardy, long-lived perennial grass, and one of the warm-season forages most used in the world (Hacker *et al*., 1998). The presence of *C. dactylon* in the overgrazed areas might be due to its morphological characteristics (Ecocrop, 2012; FAO, 2012). It is stoloniferous and rhizomatous, forming dense leafy mats that can reach 10-40 cm high in relation to response tolerance after defoliation and sometimes is not accessible to livestock due to its height. It is known as a species that is highly tolerant to drought and heavy grazing. *Themeda triandra* and *Panicum maximum* were the only perennial palatable species found in the CL soil type areas. Though these species' availability indicate a veld in good condition (Zacharias, 1990), *T. triandra* was located about middle and far from homesteads where there is light to medium bush encroachment, and hence, there was little access to grazing by livestock. *Panicum maximum* was only found under the tree species where there is little or no access to livestock. This was also supported by van Oudtshoorn (2014), who highlighted that *P. maximum* species prefer growing in the shade of woody species (trees and shrubs) where there is little or no access to livestock.

Both study areas had variation of biomass distribution along the distance length. Lower biomass accumulation was found in the areas near the homesteads. There was also variation in species distribution and composition along the distance length. Alder & Hall (2005) stressed that forage availability is always reduced to low levels near the resting areas and this can bring a unimodal relationship between distance from certain locations (watering point, resting and homesteads areas) and utilization. The biomass and diversity of high grazing value plants would decrease with increasing proximity to homesteads (Montague-Drake & Croft, 2004).

There were no spatial differences in the heights of some common species, which were mostly unpalatable and semi-palatable species across the communal areas. This was due to overgrazing that has occurred within these communal areas, which has created a conducive environment for the proliferation of unpalatable and semi-palatable species.

Even though there was no difference in the distribution of species according to desirability group in both clay-loamy and red-brown sand soil types, but the figures showed that there were gradual changes on species occurrence based on desirability. Areas near the homesteads were covered by more unpalatable species compared to palatable species and the trend gradually decreased with increasing distance from homesteads. Most palatable grass species were found far from homesteads where there was less grazing pressure.

With the exception of *C. pospischilii, A.adscensionis, A. congesta, A. diffusa,* and *B. insculpta,* the density of common grass species in clay-loamy soil type areas differed along the distance gradient from homesteads. The density of *C. pospischilii, A.adscensionis, A. congesta, A. diffusa* did not change with distance from homesteads probably because they are unpalatable and *C. pospischilii* has essential oils, which give the grass a bitter taste. Gonnet *et al*. (2003) also observed that the density of two undesirable grasses (*C. pospischilii* and *Aristida spp.*) showed no definite trend with distance from a watering point. The presence of *Aristida spp* close to the homesteads is an indicator of deterioration due to selective and preferential grazing of high forage value species (Gusha & Mugabe, 2013). *Cynodon dactylon* and *E. echinochlodea* were found to be the more dominant grass species in sites close to homesteads. Grazing pressure close to homesteads/villages is always greater than in sites further away. Papanastasis (2004), Rosales & Livinets (2005) and BMZ (2015) also found that overgrazing, especially in areas close to homesteads, or immediate areas surrounding homesteads resulted in serious degradation, while pastures that are more distant remained unused. Gonnet *et al*. (2003) observed a curve-linear gradient of decreasing utilization of grasses at greater distances from water, and that gradient declined at greater distances from water on high grazing value.

Red-brown sand soil type area was covered with more *of Aristida spp* and *E. bicolor*. The lack of rain and the type of soil might have contributed to the occurrence of such species. Compared to most grass species, *Aristida spp.* grow well in disturbed soil such as bare patches in overgrazed veld and it is a good indicator of overgrazing and other disturbances (van Oudtshoorn, 2014). *Eragrostis bicolor* is known for surviving in areas that are highly weathered and sandy textured soils that lack any significant soil profile development, especially in the semi arid and arid areas. This species is also known as an increaser II and only provides good quality forage during growing season (van Oudtshoorn, 2014).

## 3.5 Conclusion

Heavy grazing seems to be a common occurence in these communal areas. The data collected indicate that over-grazing and shortage of plants can contribute negatively to soil quality. Although all communal study areas were degraded, soil nutrient status (N, P, and K) was higher in the top soil (0–20 cm) in Tsetse and Six-hundred communal areas (Clay-loamy soil type) than Loporung and Makgobistadt communal areas (Red-brown sand soil type). Soil properties like micro minerals differed across communal areas. The results of this study could be used to make recommendations for best management and modelling of soil and plant relationships in future studies. Vegetation deterioration is taking place in most sites of the communal areas. There is a reduction in the occurrence of most palatable species (*T.*

*triandra*) and a general increase in grass species that cannot be used by livestock. This threatens livestock production and people's livelihood.

## 3.6 References

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# 4 CHAPTER FOUR - SPATIAL VARIATION OF WOODY SPECIES IN SELECTED COMMUNAL AREAS OF NGAKA MODIRI MOLEMA DISTRICT

## Abstract

The objective of the study was to determine the spatial distribution of browse species under two different soil types (clay-loamy and red-brown soil types) in selected localities of Ngaka Modiri Molema district. Distance from homesteads to the end of communal grazing lands was measured and categorized as near, middle or far (at 500 to 700 meters interval depending on size of grazing areas) with increasing distance. Field survey and sampling was undertaken to estimate plant diversity. For each communal area and at each grazing camp, 9 (3 per distance range) 10 metres x 10 metres homogenous vegetation units (HVU) were marked along the lengths of the distance to serve as replicates. Within each HVU, the number of trees, by species, were recorded at near, middle, and far sites from the homesteads, from the four selected grazing areas. *Grewia flava* and *A. erioloba* were the most dominant species in all types of soil from the study areas. *Acacia nilotica* dominated in clay-loamy soil types, whereas *D. cinerea* and *A. mellifera* were more dominant in red-brown sand soil type area. There was a significant ($P<0.05$) effect due to soil type on the density, canopy cover, total tree equivalent and plant heights. Distance from the homesteads and distance x soil type interaction did not have an effect ($P>0.05$) on plant density, canopy cover (CC), total tree equivalent (TTE) and plant height. Red-brown sand soil type had higher ($P<0.05$) total plant density (827.7 plant/ha), CC (9.6 %); TTE (2886.4 TTE/ha) than in clay-loamy soil type area. The overall vegetation cover is in a state of rapid transition from an open savannah to a shrubland and bushland state due to an encroachment of woody plants, especially in red-brown sand soil type sites. Changing the vegetation structure by reducing some woody plants (e.g. *A. mellifera, A. erioloba* and *A. nilotica*) especially in red-brown sand soil type, can create a conducive environment for open grasslands to occupy the communal areas and create biodiversity within grass species.

Key words: canopy cover, plant height, woody plants, plant density, total tree equivalent.

## 4.1 Introduction

The primary agricultural practices in the North West province consist of mixed crop and livestock farming in the east, with a progression to almost exclusively livestock farming towards the west (Masigo & Matshego, 2002). Diverse livestock species are raised on rangelands that are jointly owned by entire communities whose members have equal and unrestricted access to the rangeland resources. Browse species are the major feed source for ruminants and other herbivores especially during winter months. Impenetrable thickets, mainly consisting of *Acacia spp* and *D. cinerea* are some of the most serious problems in the savannah ecosystem of the semi-arid of NW province of South Africa (Tolsma *et al.,* 1987). Okiror *et al*. (2012) stated that tree species composition and distribution varies with altitude whereby species numbers generally dropping with elevation. Keddy (1992), Steege *et al*. (2003), Wartali *et al*. (2007) and Okiror *et al*. (2012) also highlighted that plant species that are distributed across spatial scales are, therefore, affected by several factors, such as climate, soil disturbances and biotic interactions such as human-induced and livestock effects. This can lead to loss of woody species diversity and composition and would have a negative impact on the ecological balance on that specific biome. These factors determine which species from the regional species pool are filtered into the local community. Despite the heavy dependency on rangelands by communal livestock, little research on tree species composition has been done within the study areas. Furthermore, assessment of the distribution or status of native vegetation is essential for sustainable management of this ecological system. Baseline data for the environmental parameters that are considered relevant to the ecology interpretation of plant distribution such as landscape type, lithology, soil type, slope, aspect, presence of tree species, proportion of bare ground and litter cover can be used to estimate the carrying capacity of the area (Martini *et al*., 2016). This will assist in the control of the movement and number of animals to be kept over the grazing/browsing period. Thus, the objective of the study was to determine the spatial distribution of browse trees in selected localities of Ngaka Modiri Molema district.

## 4.2 Materials and methods

### *4.2.1 Study areas*

The study was conducted on four selected areas (Tsetse, Six-hundred, Makgobistadt and Loporung communal areas) as described in section 3.2.1.

### *4.2.2 Data collection*

Three 2.2 km transects, which served as replicates were established at each of the selected grazing areas. The three transects were placed at least 200 m from each other. Along each transect, points were marked within 500–700 metres (considered as near sites), >0.70 –1.4 kilometres (middle sites) and >1.4–2.2 kilometres (far sites) from the homesteads to form 9 sampling sub-transects. Three 10 x 10 metre homogenous vegetation units were marked at each sub-transect and spaced 20 metres from each other making a total of 27 HVUs. These HVUs were used to record density, height and canopy diameter of individual woody plants. All rooted live woody plants were recorded and counted in each subplot. Within each sub-plot, trees that were 0–1 metre tall were identified, counted and classified as seedlings, those between >1–1.5 metres as young shrubs, >1.5–2 metres as mature shrubs, > 2–3 metres as young trees and >3 metres as mature trees (Appendix 2).

Within each subplot, the canopy diameter of every woody plant species was measured along two axes (length, L, and width, W) perpendicular to each other. Determination of the canopy cover (%) was done using the following equation by Blozan (2006) and Beyene (2015):

$$\text{Canopy cover} = \left(\frac{\pi}{2} + \frac{\pi}{2}\right) / \ 300\ \text{m} \times 100$$

This is the preferred method for measuring canopy cover (Blozan, 2006) by researchers due to its ability to measure or quantify the crown area and also easy to use where there is less number of trees available. When an overlap between the canopies of adjacent woody plants was encountered, the length of the overlap was subtracted from the length or width of either of the plants. Total tree equivalent (TTE) was calculated by dividing the total length of all trees in the marked area by 1.5. Total tree equivalent values are normally expressed as TTE/ha (Taiton, 1999). Plant identification was carried out using a text book prescribed by van Wyk *et al*. (2012) and a combination of scientific and indigenous knowledge from farmers. Those not found in van Wyk *et al*. (2012) were taken to the hebarium botanical garden in Pretoria for identification. Information on the indigenous knowledge on some woody plant utilisation was obtained from local farmers from the respective grazing areas. This study was conducted between January-May 2015.

### 4.2.3 Statistical analysis

Tree plant densities, canopy cover and height class distribution under each grazing area were evaluated using a two-way analysis of variance, within each site, according to the general linear model procedure of SAS (2010) to test the effect of plant species and distance from homesteads. Means were compared using the PDIFF option of the least squares means statement. The following statistical model was employed:

$$Yijk = \mu + Pi + Gj + (PxG)ij + \varepsilon ijk$$

Where $Y_{ijk}$ is the response variable (height, density and shoot diameter), $\mu$ is overall mean, $Pi$ is the effect of plant species and $Gj$ is the effect of distance from homesteads in each grazing site, $(PxG)ij$ is the interation between plant species and distance from homesteads and $\varepsilon ijk$ was the error term associated with observation *ijk*, assumed to be normally and independently distributed. Statistically significant differences were declared at $P < 0.05$.

## 4.3 Results

### 4.3.1 Distribution of browse plants found in communal areas

A total of 21 browse species were identified in the two soil types and they are presented in Tables 4.1a and b. Several woody species were observed outside the benchmarked areas of all sites and were not recorded for analysis. *Grewia flava* and *A. erioloba* were the most dominant species in all types of soil from study areas. *Acacia nilotica* dominated in clay-loamy soil types, whereas *D. cinerea* and *A. mellifera* were more dominant in red-brown sand soil type.

Table 4.1a: Identification (scientific and vernacular name), growth form, tree values and traditional uses of trees plants in the selected communal areas

| Scientific name | Common or vernacular name | Growth form | Preferred plant part by livestock | Herbivores | Other traditional uses (human/livestock) |
|---|---|---|---|---|---|
| *Acacia caffra* | Common hook thorn | T | Leaves | Cattle | Bark is used as an emetic leaf for stomach ache treatment in humans. |
| *Acacia erioloba* | Camel thorn | T | Leaves and pods | Goats, cattle, game | Burnt root are for headache for human |
| *Acacia galpini* | Mongangatau (Tsw) | T | Leaves/pods | Goats and cattle | No value |
| *Acacia hebaclada* | Mohae (NS) | S | Leaves/pods | Goats | No value |
| *Acacia karoo* | Mooka (Tsw) | S | Leaves/pods | Goats/Cattle | Uses ranging from wound poultices to eye treatments and cold remedies. The bark, leaves and gum are usually used by humans. |
| *Acacia mellifera* | Monga (Tsw) | S | Leaves and pods | Cattle and goats | Twigs are chewed and used by humans as toothbrushs |
| *Acacia nilotica* | Motsha (Tsw) | T | Leaves and pods | Goats and game | Bark used as a cough remedy. A root is used in the treatment of tuberculosis, impotence, diarrhoea, haemorrhages, toothache, dysentery and gonorrhoea in humans. |
| *Bosia albitruca* | Xukutsi (Tsw) | T | Leaves | Cattle and game | An infusion of the leaves is used to treat eye infections in cattle. |
| *Dichrostahys cinerea* | Sickle bush | S | Leaves | Goats | Leaves and roots are smoked for headache and tuberculosis for humans and fruits are ashed and used to treat wounds for both livestock and humans. |

T: tree; S: shrub; Tsw: Tswana; V: Venda; NS: Northern Sotho

Table 4.1b: Identification (scientific and vernacular name), growth form, tree values and traditional uses of trees plants in the selected communal areas

| Scientific name | Common or vernacular name | Growth form | Preferred plant part by livestock | Herbivores | Other traditional uses (human/livestock) |
|---|---|---|---|---|---|
| *Euclea divinorum* | Mutangule (V) | S | - | - | For toothache, the root is boiled and the decoction dropped into the ear to cure it for good in humans. |
| *Grewia flava* | Brandy bush | T | Leaves and fruits | Goats and game | Twigs are chewed and used as tooth brushes in humans |
| *Grewia monticola* | Mutafa (V) | | Leaves | Goats | Leaves are used to make tea for humans |
| *Grewia xexamita* | Mukunukunu (V) | S/T | Leaves | Goats/cattle/ sheep | No value |
| *Gymnosporia Buxifolia* | motlhonu (Tsw) | S | - | - | Is used in traditional medicine for pleurisy, diarrhoea, as a snakebite remedy, chest colds and coughs in humans. |
| *Melia azedarach* | Muserenga (V) | T | Leaves | Cattle and goats | Inoculum from an animal eaten this species leaves is used to change the flavour for meat soup. The fruit are less preferred due to unpleasant taste |
| *Peltophorum africanum* | Mosehla (Tsw) | T | Leaves and pods | Goat/cattle | Roots are used to heal wounds, toothache and throat sores; root, leaves and bark used to clear intestinal parasites and relieve stomach problems; bark relieves colic; stem and root used for diarrhoea and dysentery in humans |
| *Searsia lancea* | Mosilabele (Tsw) | T | Leaves | Cattle, goats, game | No value |
| *Searsia leptodictya* | Mutasiri (V) | T | Leaves | Cattle/goat/game | Fruits are edible by humans |
| *Terminalia Sericea* | Mususu (V) | T | - | - | Roots are used for treating colic, diarrhoea, menstrual cramps, stomach disorders, pneumonia and eye infections in humans. |
| *Vangueria infausta* | Mothwanyê (Tsw); | S/T | - | - | Fruits are edible to humans. roots have been used to treat malaria and pneumonia in humans |
| *Ziziphus mucronata* | Buffalo thorn | T | Leaves and pods | Cattle and goats | Fruits are eaten by humans |

T: tree; S: shrub; Tsw: Tswana; V: Venda; NS: Northern Sotho

### *4.3.2 Density of common tree species*

There was a significant effect due to the soil type on the density and canopy cover (Table 4.2 and Table 4.3). The distance from the homesteads and distance x soil type interaction did not have an effect on plant density and canopy cover.

The results showing density of common tree species with increasing distance from the homesteads are presented in Table 4.2 and 4.3. Although no statistical differences were observed in abundance of *A. mellifera* tree species (F = 0.25. P = 0.784) in the grazing areas, plant density tended to increase with distance from homesteads (155-283 plants/ha) in red-brown sand soil type. *Acacia erioloba* plants were more abundant (111 species/ha) near homesteads compared to middle (22.22 plants/ha) and far sites (94.4 plants/ha) in red-brown sand soil type. In contrast, the results showed a lower abundance of *D. cinerea* near the homesteads, which increased with distance from the homesteads, then decreased in the far distance from homesteads. *Grewia flava* plants were more abundant (200 plants/ha) in the middle of grazing area compared to far (172 plants/ha) and near site (133 plants/ha).

In clay-loamy soil type, *A. erioloba* plants were more abundant (78 plants/ha) far from homesteads compared to middle (11.0 plants/ha) and near site (39 plants/ha). *Acacia nilotica* plants were more abundant (106 plants/ha) in the middle of grazing area compared to near (28.0 plants/ha) and far from homesteads (11 plants/ha).

Table 4.2: Density (number of plants/ha) of common tree species along a distance gradient from homesteads

| | Distance | | | |
|---|---|---|---|---|
| Soil type | Near | Middle | Far | SE |
| **Clay-loamy** | | | | |
| *G. flava* | 2 | 0.3 | 2 | 0.80 |
| *A. erioloba* | 39 | 11 | 78 | 26.64 |
| *S. lancea* | 1 | 3 | 0.3 | 0.901 |
| *A. nilotica* | 28 | 106 | 11 | 30.02 |
| *Z. mucronata* | 0.2 | 0.1 | - | 0.096 |
| *A. caffra* | - | - | 6 | 3.20 |
| **Red-brown sand** | | | | |
| *G. flava* | 133 | 200 | 172 | 83.80 |
| *A. erioloba* | 111 | 22.22 | 94.44 | 53.23 |
| *A. mellifera* | 155 | 272 | 283 | 142.45 |
| *G. monticola* | - | 22 | - | 12.83 |
| *S. lancea* | - | - | 11 | 6.42 |
| *D. cinerea* | 61.11 | 100 | 61 | 43.84 |
| *Z. mucronata* | 11 | 6 | 11 | 6.57 |

SE: standard error

Table 4.3: ANOVA results of common tree species density between grazing areas in two soil types

| | Soil variable | | | |
|---|---|---|---|---|
| | Clay-loamy | | Red-brown sand | |
| | *F* | *P* | *F* | *P* |
| *G. flava* | 1.58 | 0.2385 | 0.16 | 0.854 |
| *A. erioloba* | 1.58 | 0.2385 | 0.79 | 0.473 |
| *S. lancea* | 2.82 | 0.913 | 1.00 | 0.391 |
| *A. nilotica* | 2.82 | 0.913 | - | - |
| *Z. mucronata* | 1.00 | 0.391 | 0.24 | 0.791 |
| *A.caffra* | 1.00 | 0.391 | - | - |
| *A. mellifera* | - | - | 0.25 | 0.784 |
| *G. monticola* | - | - | 1.00 | 0.391 |
| *D. cinerea* | - | - | 0.26 | 0.773 |

F: F ratio, P: probability value

### *4.3.3 Total plant density, canopy cover and total tree equivalents (TTE)*

There was a significant effect of soil type on the total plant density, canopy cover and TTE (Table 4.4 and Table 4.5). Distance from the homesteads and the distance x soil type interaction did not have an effect on total plant density, canopy cover and TTE (P>0.05).

Table 4.4: Statistical significance (P value) of the effects of main factors on canopy cover (CC,%), total plant density (TPD, number of plants/ha) and total tree equivalent (TTE) from selected communal areas

| | CC | TPD | TTE |
|---|---|---|---|
| Soil type | * | * | * |
| Distance | NS | NS | NS |
| Soil type x Distance | NS | NS | NS |

NS: not significant ($P>0.05$); *: $P<0.05$

The results of canopy cover percentage and total plant density of tree species in two soil types are presented in Table 4.5. Sites with red-brown sand soil type had higher ($P<0.05$) total plant density (827.7 plant/ha), CC (9.6 %); TTE (2886.4 TTE/ha) than those with clay-loamy soil type.

Table 4.5: Canopy cover (%), total plant density (Number of trees/ha) and total tree equivalents in two soil types (Clay-loamy and Red-brown sand soil type)

| | Soil type | | |
|---|---|---|---|
| | Clay-loamy | Red-brown sand | SE |
| Total plant density | $205.5^{b}$ | $827.7^{a}$ | 70.01 |
| CC | $2.5^{b}$ | $9.6^{a}$ | 0.76 |
| TTE | $602.6^{b}$ | $2886.4^{a}$ | 355.21 |

$^{ab}$:Means with common superscripts in the same row do not differ ($P > 0.05$)
CC: canopy cover; TTE: total tree equivalent
SE: standard error

### *4.3.4 Height class distribution*

There was a significant ($P<0.05$) effect due to the soil type on the densities of tree species at different growth stages (Table 4.6). Distance from the homesteads and the distance x soil type interaction did not have an effect ($P>0.05$) on density of plant height class distribution.

Table 4.6: Statistical significance (P value) of the effects of main factors on density for different stage of growth on tree species from selected communal areas

| | Seedling | Young shrubs | Mature shrubs | Young trees | Mature trees |
|---|---|---|---|---|---|
| Soil type | * | * | * | * | * |
| Distance | NS | NS | NS | NS | NS |
| Soil type x Distance | NS | NS | NS | NS | NS |

NS: not significant ($P>0.05$); *: significant ($P<0.05$)

The results for the densities of tree species (plants /ha) under different growth stages (Height) in the two soil types are presented in Table 4.7. Areas with red-brown sand soil type had higher ($P<0.05$) density of seedlings (198.15 plants/ha), young shrubs (231.48 plants/ha), mature shrubs (125.93 plants/ha), young trees (170.37 plants/ha), and old trees (92.59 plants/ha) than clay-loamy soil type areas.

Table 4.7: Densities of total tree species (Number of plants/ha) under different growth stages in two soil types

| Height | Clay-loamy | Red-brown sand | SE |
|---|---|---|---|
| Seedling (0-1 m) | $83.34^{b}$ | $198.15^{a}$ | 28.99 |
| Young shrubs (>1-1.5 m) | $55.56^{b}$ | $231.48^{a}$ | 27.99 |
| Mature shrubs (>1.5-2 m) | $24.08^{b}$ | $125.93^{a}$ | 20.07 |
| Young trees (>2-3 m) | $35.19^{b}$ | $170.37^{a}$ | 18.08 |
| Mature trees (3>) | $12.97^{b}$ | $92.59^{a}$ | 12.57 |

$^{ab}$:Means with common superscripts in the same row do not differ ($P > 0.05$)

SE: standard error

## 4.4 Discussion

### *4.4.1 Woody species distribution*

Acacia tree species dominated in the selected areas. Most of the tree species available in the study areas were preferred by livestock especially goats and cattle. The potential of Acacia species as the forage provider for various livestock species in communal areas has also been recognized world-wide (Aganga *et al.,* 2000). The leaves from the trees and shrubs have the potential to provide both protein and energy to herbivores during droughts (Lefroy *et al*., 1992). The potential of these tree species for livestock will depend on the livestock preferences (foliage, seed or pods) and also depend on the amount of nutrient available in those plant parts and the concentration of essential nutrients and secondary compounds as they might have detrimental effect on livestock ( Dynes & Schlink, 2002).

### *4.4.2 Dominant woody species*

In all soil types, distance from the homesteads and distance × soil type interaction did not have an effect on the population of dominant woody species. There was no significant difference in the woody species distribution with increasing distance from homesteads on the two soil types. This is contrary to the findings of Simon (2006) and Tefera *et al*. (2007) who studied vegetation distribution along distance gradients from watering points, dipping tanks and resting sites. These authors found a decline in the density of tree species with increasing proximity to watering points, resting places or dipping tanks. Cattle have been known to open up the grass sward and thus enabling woody tree species to have access to top soil nutrients that could otherwise have been used by the grasses (Bland, 1985). It was expected that areas close to the homesteads experience greater vegetation disturbances during the release and herding back of livestock to the kraal (Beyene, 2015). This intensive grazing pressure has resulted in rangeland degradation (Moleele *et al*., 2002) and has created a conducive environment for the dominance of woody tree species over the grasses. The lack of variation in the distribution of woody species along the distant gradient might have been influenced by the fact that animals in the areas do not have specific site where they can concentrate on for specific period like resting place in the grazing area.

### *4.4.3 Total plant density and canopy cover*

Woody plant density has been found to be a useful tool to determine the productivity of available browsable material for livestock and the control of bush encroachment (Smit, 1989). High density of plants is known to be the major cause of reduced grazing capacity of the range. Based on the density of plants per hectare, the study area was judged to have light bush encroachment.

Areas with red-brown sand soil type had higher density of trees when compared with areas with clay-loamy soil type. Although there was no significant difference, the level of bush encroachment tended to increase with the distance from homesteads for certain species. This is in line with the findings by Mphinyane (2001) who found that density of trees increased with distance from homesteads. This may be due to deforestation of woody plants near the village for fire wood as well as browsing by animals. Indeed browsing is known to have a negative long or short term effect on the regeneration of browse species (Lemus & Brown, 2008; Khatri *et al*., 2016; Owings *et al*., 2017).

There were spatial differences in the canopy cover recorded in this study. Red-brown sand soil type areas had higher percentage of canopy cover than clay-loamy grazing areas. This was influenced by high density of tree species recorded in red-brown sand soil type areas. Only two grass species were dominant in Loporung and Makgobistadt (Red-brown sand soil type) areas due to land degradation that might have been caused by climate and soil factors. Karuaera (2011) and Jordaan (1995) reported that bush encroachment is the main cause of land degradation and loss of resource productivity. Lack of competition in the veld from herbs and grass promotes bush encroachment (Jordaan & Roux, 1992). Soil fertility is also known to contribute to the disappearance of grass species. The topsoil from the red-brown sand soil type sites had lower concentrations of soil nutrients compared with that from clay-loamy soil type sites. This might have led to the lower distribution of grass species observed in those red-brown sand soil types. Depletion of soil nutrients can accelerate land degradation by gradually reducing vegetation layer in many semi-arid areas and allowing the emergence of woody species that access the subsurface moisture.

### *4.4.4 Height class distribution*

Height of plants has an influence on the availability of forage to livestock. All study sites had seedlings and young shrubs. Red-brown sand soil type areas had more woody species seedlings than areas with clay-loamy soil. Woody seedlings are in direct competition with grasses for topsoil resources. Drought and heavy grazing/lack of grass species encourage establishment of woody seedling by reducing competition. The availability of browse seedlings creates the competitive environment where young seedlings exploit the surrounding grass species. The height of plants can influence the type of livestock that utilize a specific area. The density of seedlings and young shrubs was higher in red-brown sand soil type areas when compared to those in clay-loamy soil type areas. Ruminants animals, especially goats can be used to control the rangelands by harvesting forage (seedlings and young shrubs) that may lead to change in plant composition and they are capable of reducing fuel loads in communal areas especially woody species that had become a problem for local farmers (du Plessis *et al*., 2004). The density of young and mature trees was higher in red-brown sand soil type areas when compared to clay-loamy soil type areas. du Plessis *et al*. (2004) indicated that height of the browse species might limit the practicality of using goats as bush encroachment controllers. Only wild animals like giraffe, elephants, and kudu can access browse species of above 2 m tall. Limiting the density of the woody plants so as to stimulate grass production for grazers should be emphasized in order for an area to play an ecological niche also to large-stock.

## 4.5 Conclusion

Even though there was a low density of woody vegetation cover in the clay-loamy soil type areas, overall vegetation cover is in a state of rapid transition from an open savannah to a shrubland and bushland state due to encroachment of woody plants, especially in the red-brown sand soil type sites. In areas with red-brown sand soil, woody species dominated over the grass species and were not influenced by heavy grazing, but driven by a variety of factors including lack of topsoil nutrients, high canopy cover as well as climatic changes in red-brown sand soil type. Changes in vegetation structure by reducing some woody plants (e.g. *A. mellifera* and *A. nilotica*) can create conducive environment for open grasslands to occupy the communal area and create the biodiversity within grass species. There should be programmes that involve local farmers' participation and the relevant authorities so that there will be an integrated approach for bush control and could reduce the cover and at the same time provide conservation plans for the tree species that play an ecological niche within piosphere.

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# 5 CHAPTER FIVE - ASSESSMENT OF CHEMICAL COMPOSITION AND *IN VITRO* RUMINAL DRY MATTER DEGRADATION OF SOME GRASS SPECIES FOUND IN COMMUNAL AREAS

## Abstract

The study was conducted to assess the nutritional composition and *in vitro* ruminal dry matter digestibility of some common grass species found in communal areas of selected localities. Grass species were harvested between February and March 2015 from Tsetse, Six-hundred, Makgobistadt, and Loporung communal areas and assessed for DM (dry matter), OM (organic matter), CP (crude protein), NDF (neutral detergent fibre), ADF (acid detergent fibre), ADL (acid detergent lignin) and *in vitro* ruminal DM degradability. Grasses from the different communal areas varied ($P < 0.05$) in terms of crude protein values. *Cynodon dactylon* had the same crude protein value as *E. trichopora, E. echinochlodea* and *E. rigidior*. *Bothriochloa insculpta* had the lowest ($P<0.05$) crude protein content (31 g/kg DM) in Tsetse communal area. In Six-hundred communal area, *E. echinochlodea* had the same ($P>0.05$) CP value as *F. africana, A. congesta, E. bicolor, C. pospischilii, C. dactylon, P. maximum, E. superba, A. diffusa, H. contortus* and *C. virgata*. *Cynodon dactylon* had the highest ($P<0.05$) CP content (66 g/kg DM) while *A. adscensionis, A. congesta, A. stipitata P. patens* and *E. bicolor* CP values did not differ ($P>0.05$) significantly from each other in Makgobistadt communal area. *Melenis repens* had the highest ($P<0.05$) CP value (70 g/kg DM) in Loporung communal area. In clay-loamy soil type, *C. pospischilii* and *E. trichopora* had the highest ($P<0.05$) DM degradability values at 24h and 48h. *Aristida diffusa* had the lowest DM degradability value which did not differ ($P>0.05$) significantly from *A. adscensionis.* In red-brown sand soil type, all grass species had similar ($P>0.05$) DM degradability values at 48h. Timing in the utilisation of grass species is important so that livestock can benefit in nutrient availability during growing stage. Those species having higher CP (*E. trichopora* and *C. dactylon*) and degradability (*E. trichopora*, *C. pospischilii*) values can complement each other with forage supplements in improving livestock productivity when these grasses are fed as basal diet. Therefore, supplementation with by-products or high protein content diet is necessary for low quality roughage especially at their reproductive stage and to those of low grazing value to sustain animal productivity and to avoid impairing growth.

Key words: grass species, crude protein, livestock productivity, *in vitro* degradation, fibre.

## 5.1 Introduction

Sustainability of grazing and forage resources available in communal areas requires the assessment and routine monitoring of spatial distribution and changes of these resources. Their biodiversity and chemical composition as well as the drivers of the observed change dynamics are of paramount importance (Feng *et al*., 2015; Gelaye *et al*., 2015). Angassa & Oba (2007) as well as Gwelo (2012) highlighted that rainfall and livestock together with anthropogenic factors are the principal features driving changes in biodiversity or ecosystem dynamics in the drylands or semi-arid areas of Africa.

Dietary information of free-roaming herbivores has become an increasingly important tool in natural resource management. Such information allows for the assessment of nutrient intake of animals and evaluation of potential forage competition among herbivorous species (Mcinnis *et al.*, 1982). The term forage quality encompasses the nutritive value and intake of the forage and should be regarded in terms of meeting the nutrient requirements of the animal (Longman, 2012). Grasses are well-adapted to frequent defoliation and to the presence of herbivores and, consequently, they cover large areas of natural and semi-natural vegetation. They are also widely used in intensive forage production systems. In the early stages of growth, the quality of semi-arid zone forage species is adequate for livestock production. During that stage, the greatest problem is quantity and availability. As the plants mature, the quality decreases so that the forage, even if adequate in quantity, cannot meet the livestock's nutritional demands (Ghadaki *et al*., 1975).

The chemical composition of different grass species and varieties has been studied widely, but there are many factors that cause variation in grass quality. The most important factors are growing conditions that are influenced by climate, soil type, water and nutrient availability, all of which are influenced by a geographical location (Särkijärvi *et al*., 2012). The determination of nutritional characteristics of these grasses is of paramount importance. There is a need to determine the potential feed value of grasses that are found in communal areas for grazing livestock, information that is not available for the selected communal areas in this study. Therefore, the objective of the study were to assess the grass species and growth environment variation in terms of chemical composition and *in vitro* ruminal degradation.

## 5.2 Material and methods

### *5.2.1 Study site*

Grasses were harvested from only four communal areas (Tsetse, Six-hundred, Makgobistadt and Loporung). Grass samples were collected in February and March 2015 towards the end of the rainy season, which would mean the grasses were towards the end of their growing cycle. Tsetse and Six-hundred had the similar soil characteristics (clay-loamy soil type) as presented in 3.2.1.

However, Makgobistadt and Loporung also had similar soil characteristics (red-brown sand) and the sites are located 50 to 60 km from the other two sites under clay-loamy soil type.

### *5.2.2 Sample collection and processing*

The three transects were placed at least 200 m from each other. Along each transect, points were marked within 500–700 metres (considered as near sites), >0.70–1.4 kilometres (middle site) and >1.4–2.2 kilometres (far sites) from the homesteads to form 9 sampling sub-transects. Within each sub-transect, 10 × 10 metre homogenous vegetation unit (HVU) was marked. In each HVU, one metre square quadrat was randomly placed to sample grass species resulting in a total of 9 samples per site. Grasses within each quadrat were harvested separately at stubble height, and oven-dried for 24 h at 80°C. Dried samples were milled through a one millimetre sieve and kept in air-tight plastic bags pending chemical analysis and *in vitro* ruminal degradation. Not all grass species occurred across all three communal grazing areas and, therefore, the grass species did not have equal numbers of replicates. Across all sites, a total of 28 grass species were identified from quadrat samples, but only common and dominant species were considered for analysis.

Laboratory analysis was done at the North-West University experimental farm. The ground samples were kept in air-tight containers until analyzed. Samples were analyzed for dry matter (DM), organic matter (OM), ash, crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin ADL.

### *5.2.3 Chemical analysis of grasses*

The determination of DM was done according to AOAC, 1990 (967.03) where approximately one gram sample of grass was weighed into pre-weighed crucibles and placed in a 100ºC oven for 24 hours. After the 24 hours, samples were removed from the oven, placed in a desiccator to cool and re-weighed. The loss in weight was measured as moisture content and DM was calculated as the difference between initial sample weight and moisture weight. Organic matter content and ash were determined according to AOAC (1990, 942.05) by ashing grass samples for 6 hours using furnace set at 600ºC. After ashing, crucibles were removed, placed in a desiccator to cool and weighed. The loss in weight was measured as the OM content. Micro-Kjedahl method was used to determine the nitrogen content (AOAC 1999, 984.13), while crude protein (CP) was calculated by multiplying nitrogen (N) value with a factor 6.25. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were analyzed following the procedure of Van Soest *et al*. (1991) by refluxing samples (0.45 g) with neutral detergent fibre (NDF) and acid detergent fibre (ADF) solutions (NDS and ADS), respectively for an hour using ANKOM$^{2000}$ fibre analyser. Heat-stable bacterial α-amylase was used for NDF analysis. Acid detergent lignin (ADL) was determined by placing dried ADF bags/samples into sufficient quantity of 72% $H_2SO_4$.

### *5.2.4 In vitro ruminal dry matter degradability*

Dry matter ruminal degradability of grass species was determined using the ANKOM Daisy$^{II}$ incubator. The incubator consists of a thermostatic chamber set at 39ºC with four rotating jars. Samples (0.45 - 0.5 g) were weighed into F57 filter bags (0.45 -0.5 g), heat-sealed and placed in the digestion jars. Two buffer solutions (at a ratio of 1:5) were prepared in advance and combined and 1600mL of the combined buffer together with samples were transferred to each of the jars and warmed.

Rumen fluid (400mL) was collected from the ruminally cannulated Bonsmara cow in the morning before feeding. Two pre-warmed thermos flasks were used to collect rumen fluid. The rumen fluid was used to inoculate each Daisy jar containing the F57 bags in 1600 mL of ANKOM buffer. Carbon dioxide gas cylinder was used to purge the strained rumen fluid, which was kept at 39 ºC. Each jar was purged with $CO_2$ before closing it and placed in the incubation chamber. ANKOM F57 bags were withdrawn at 0, 24, 48 hours after inoculation and washed with cold water for 20 minutes. All washed samples were dried at 105ºC for 12 hours. The *in vitro* dry matter degradability was determined using the following formula:

$$\%IVTD(DM\ basis) = \frac{100 - (W3 - (W1\ x\ C1))}{W2xDM} x100$$

Where: W1:bag tare weight, W2: sample weight, W3: final weight after inoculation and C1: correctional factor (final oven dried weight divide by original blank bag weight).

### *5.2.5 Statistical analysis*

Analysis of variance was used to test the effect of plant species on chemical composition for each communal area and *in vitro* ruminal DM degradability separately for each soil type using General Linear Model (GLM) procedures of SAS (2010) within completely randomized design. All data were analyzed by using a one-way analysis of variance according to the following linear model:-

$$Yij = \mu + PSi + \varepsilon ij$$

Where $\mu$ is overall mean, *PS* is the effect of plant species and $\varepsilon$ was the error term associated with observation *ij*, assumed to be normally and independently distributed. The probability of difference in the lsmeans statement of SAS was used to separate the means (SAS, 2010). Significant differences were declared at the $P < 0.05$.

## 5.3 Results

### *5.3.1 Chemical composition of grasses*

The results for chemical composition (DM, OM and CP) of grass species found in the Tsetse communal area are presented in Table 5.1.

Table 5.1: The dry matter (DM), organic matter (OM), and crude protein (CP) content (g/kg DM unless otherwise stated) of grass species found in the Tsetse communal area

| Grass species | DM (g/kg) | SE | OM | SE | CP | SE |
|---|---|---|---|---|---|---|
| *A. congesta* | $933.1^{bc}$ | 7.3 | $812.3^{g}$ | 9.8 | $55^{cd}$ | 4.07 |
| *E. bicolor* | $928.0^{bc}$ | 4.7 | $872.1^{abc}$ | 6.4 | $58^{c}$ | 6.23 |
| *C. dactylon* | $939.2^{ab}$ | 4.7 | $850.9^{cde}$ | 6.4 | $85^{ab}$ | 4.40 |
| *E. echinochlodea* | $935.4^{abc}$ | 6.3 | $847.7^{cde}$ | 8.5 | $71^{bc}$ | 6.23 |
| *E. trichopora* | $934.5^{abc}$ | 7.3 | $815.3^{fg}$ | 9.8 | $100^{a}$ | 6.23 |
| *C. pospischilii* | $914.1^{c}$ | 3.8 | $842.8^{def}$ | 5.1 | $54^{cd}$ | 3.41 |
| *T. triandra* | $924.4^{bc}$ | 7.3 | $866.3^{abcd}$ | 9.8 | $33^{f}$ | 6.23 |
| *M. repens* | $924.5^{bc}$ | 7.3 | $855.7^{bcde}$ | 9.8 | $65^{c}$ | 6.23 |
| *S. fimbriatus* | $941.8^{ab}$ | 7.3 | $835.5^{efg}$ | 9.8 | $53^{cde}$ | 6.23 |
| *A. diffusa* | $945.8^{ab}$ | 7.3 | $887.6^{a}$ | 9.8 | $36^{ef}$ | 6.23 |
| *A. adscensionis* | $955.0^{a}$ | 7.3 | $883.4^{ab}$ | 9.8 | $37^{def}$ | 6.23 |
| *E. rigidior* | $942.5^{ab}$ | 7.3 | $876.2^{abc}$ | 9.8 | $69^{bc}$ | 6.23 |
| *B. insculpta* | $932.4^{bc}$ | 7.3 | $840.9^{def}$ | 9.8 | $31^{f}$ | 6.23 |

$^{abcd}$:Means with common superscripts in the same column do not differ ($P > 0.05$)
SE: standard error

*Aristida adscensionis* had the highest ($P<0.05$) DM content (955 g/kg) while *Cymbopogon pospischilii* had the lowest ($P<0.05$) DM content (914.1 g/kg). *Aristida diffusa* had the highest

($P<0.05$) OM content and *A. congesta* had the lowest ($P<0.05$) OM content. *Cynodon dactylon* had the same crude protein content as *E. trichopora, E. echinochlodea* and *E. rigidior*. *Aristida adscensionis* had similar crude protein content as *A. congesta,A diffusa, S. fimbriatus, C. pospischilii, B. insculpta* and *T. triandra*.

The results for fibre fractions of all grass species found in Tsetse communal area are presented in Table 5.2.

Table 5.2: The neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) (g/kg DM) of grass species found in the Tsetse communal area

| Grass species | NDF | SE | ADF | SE | ADL | SE |
|---|---|---|---|---|---|---|
| *A. congesta* | $767.2^{abcd}$ | 29.2 | $461.1^{cd}$ | 13.9 | $79.2^{def}$ | 7.4 |
| *E. bicolor* | $723.5^{cd}$ | 19.1 | $420.1^{e}$ | 9.1 | $82.0^{def}$ | 4.9 |
| *C. dactylon* | $728.3^{cd}$ | 20.6 | $400.7^{e}$ | 9.9 | $87.3^{cde}$ | 5.3 |
| *E. echinochlodea* | $728.0^{cd}$ | 29.2 | $401.6^{e}$ | 13.9 | $63.9^{f}$ | 7.4 |
| *E. trichopora* | $743.9^{cd}$ | 29.2 | $326.1^{f}$ | 13.9 | $63.2^{f}$ | 7.4 |
| *C. pospischilii* | $696.8^{d}$ | 15.9 | $400.9^{e}$ | 7.3 | $66.6^{ef}$ | 3.9 |
| *T. triandra* | $772.5^{abcd}$ | 29.2 | $472.7^{bc}$ | 13.9 | $71.2^{ef}$ | 7.4 |
| *M. repens* | $743.7^{cd}$ | 29.2 | $428.8^{de}$ | 13.9 | $77.0^{def}$ | 7.4 |
| *S. fimbriatus* | $770.4^{abcd}$ | 29.2 | $402.8^{e}$ | 13.9 | $84.9^{def}$ | 7.4 |
| *A. diffusa* | $851.1^{a}$ | 29.2 | $574.6^{a}$ | 13.9 | $117.9^{ab}$ | 7.4 |
| *A. adscensionis* | $834.6^{ab}$ | 29.2 | $568.6^{a}$ | 13.9 | $107.3^{bc}$ | 7.4 |
| *E. rigidior* | $806.4^{abc}$ | 29.2 | $501.0^{b}$ | 13.9 | $99.1^{bcd}$ | 7.4 |
| *B. insculpta* | $756.8^{bcd}$ | 29.2 | $544.0^{a}$ | 13.9 | $132.8^{a}$ | 7.4 |

$^{abcd}$:Means with common superscripts in the same column do not differ ($P > 0.05$)
SE: standard error

*Aristida diffusa* had the highest (P<0.05) NDF content (851.1 g/kg DM) while *Cymbopogon pospischilii* had the lowest (P<0.05) NDF content (696.8 g/kg DM). *Aristida diffusa*, *A. adscensionis* and *B. insculpta* had the highest (P<0.05) ADF content (574.6 g/kg DM, 568.6 g/kg DM, 544.0 g/kg DM, respectively). *Melenis repens* had simlar (P>0.05) ADF value as *A. congesta*, *E. bicolor*, *C. dactylon* and *E. echinochlodea*. *Eragrostis trichopora* had lowest (P<0.05) ADF content (326.1 g/kg DM). *Aristida diffusa* had the same ADL value as *B. insculpta*, *A. adscensionis* and *E. rigidior*. *Eragrostis echinochlodea* and *E. trichopora* had lower ADL values, which did not differ significantly from those of *A. congesta, E. bicolor, C. pospischilii, T. triandra*, *M. repens* and *S. fimbriatus*.

The results for DM, OM and CP of grass species found in the Six-hundred communal area are presented in Table 5.3. *Aristida adscensionis* had the highest (P<0.05) DM content (952.6 g/kg), whereas *C. pospischilii* had the least (P<0.05) DM content (910.8 g/kg). *Aristida adscensionis* had the highest (P<0.05) OM content (900.3 g/kg). *B. insculpta* had the lowest OM content (772.3 g/kg). *Eragrostis echinochlodea* had the same (P>0.05) CP value as *F. africana, A. congesta, E. bicolor, C. pospischilii, C. dactylon, P. maximum, E. superba, A. diffusa, H. contortus* and *C. virgata*. *Aristida adscensionis, T. triandra* and *B. insculpta* had the lowest (P<0.05) CP values.

Table 5.3: The dry matter (DM), organic matter (OM), and crude protein (CP) content (g/kg DM unless otherwise stated) of grass species found in the Six-hundred communal area

| Grass species | DM | SE | OM | SE | CP | SE |
|---|---|---|---|---|---|---|
| *A. congesta* | $932.1^{ab}$ | 4.5 | $849.0^{cde}$ | 6.6 | $57^{abc}$ | 2.46 |
| *E. bicolor* | $933.3^{ab}$ | 4.9 | $866.9^{bc}$ | 7.1 | $55^{abc}$ | 2.63 |
| *C. dactylon* | $937.6^{ab}$ | 7.4 | $819.5^{e}$ | 10.8 | $62^{a}$ | 4.01 |
| *E. echinochlodea* | $940.4^{ab}$ | 7.4 | $863.6^{bc}$ | 10.8 | $55^{abcd}$ | 4.01 |
| *F. africana* | $932.6^{ab}$ | 3.7 | $867.2^{bc}$ | 5.4 | $54^{abcd}$ | 2.20 |
| *C. pospischilii* | $910.8^{c}$ | 4.5 | $826.7^{de}$ | 6.6 | $53^{abcd}$ | 2.63 |
| *T. triandra* | $935.6^{ab}$ | 7.4 | $856.5^{cd}$ | 10.8 | $35^{e}$ | 4.01 |
| *P. maximum* | $936.9^{ab}$ | 7.4 | $830.1^{de}$ | 10.8 | $48^{cd}$ | 4.01 |
| *E. superba* | $938.2^{ab}$ | 5.2 | $888.6^{ab}$ | 7.6 | $43^{de}$ | 3.47 |
| *A. diffusa* | $946.3^{ab}$ | 7.4 | $862.0^{bc}$ | 10.8 | $50^{bcd}$ | 4.01 |
| *A. adscensionis* | $952.6^{a}$ | 7.4 | $900.3^{a}$ | 10.8 | $34^{e}$ | 4.01 |
| *H. contortus* | $929.2^{bc}$ | 7.4 | $862.8^{bc}$ | 10.8 | $49^{bcd}$ | 4.01 |
| *B. insculpta* | $939.4^{ab}$ | 7.4 | $772.3^{f}$ | 10.8 | $37^{e}$ | 4.01 |
| *C. virgata* | $937.7^{ab}$ | 7.4 | $829.0^{de}$ | 10.8 | $60^{ab}$ | 4.01 |

$^{abcd}$:Means with common superscripts in the same column do not differ ($P > 0.05$)

SE: standard error

The results for fibre fraction of all grass species found in Six-hundred communal area are presented in Table 5.4. *Aristida adscensionis* had the highest ($P<0.05$) NDF content (826.4 g/kg DM). *Cymbopogon pospischilii* had the least ($P<0.05$) NDF content (685.9 g/kg DM). *Aristida adscensionis*, *A.diffusa* and *Bothriochloa insculpta* (547.8 g/kg DM) had the highest ($P<0.05$) ADF values (559.0 g/kg DM, 530.6 g/kg DM and 547.8 g/kg DM, respectively). *Cynodon dactylon*

(376.4 g/kg DM) and *C. pospischilii* (356.6 g/kg DM) had the lowest ($P<0.05$) ADF values. *Bothriochloa insculpta* had the same ($P>0.05$) ADL value as *C. virgata, A. adscensionis, A. Diffusa* and *P. maximum*. *Aristida congesta* had the same ($P>0.05$) ADL value as *E. bicolor, C.dactylon, E. echinochlodea*, *F. africana*, *T. Triandra* and *C. pospischilii*.

Table 5.4: The neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) (g/kg DM) of grass species found in the Six-hundred communal area

| Grass species | NDF | SE | ADF | SE | ADL | SE |
|---|---|---|---|---|---|---|
| *A. congesta* | $759.2^{def}$ | 7.8 | $446.9^{b}$ | 8.0 | $70.6^{fg}$ | 3.2 |
| *E. bicolor* | $771.6^{cdef}$ | 8.4 | $445.7^{b}$ | 9.0 | $86.4^{def}$ | 3.7 |
| *C. dactylon* | $794.6^{abcd}$ | 12.8 | $376.4^{c}$ | 13.8 | $79.9^{ef}$ | 5.6 |
| *E. echinochlodea* | $769.6^{cdef}$ | 12.7 | $450.7^{b}$ | 13.8 | $70.5^{fg}$ | 5.6 |
| *F. africana* | $801.7^{abc}$ | 7.4 | $469.7^{b}$ | 7.2 | $83.0^{ef}$ | 2.9 |
| *C. pospischilii* | $685.9^{g}$ | 9.9 | $356.6^{c}$ | 9.0 | $58.4^{g}$ | 3.7 |
| *T. triandra* | $752.5^{ef}$ | 12.8 | $447.3^{b}$ | 13.8 | $73.5^{fg}$ | 5.6 |
| *P. maximum* | $751.3^{ef}$ | 12.8 | $469.6^{b}$ | 13.8 | $115.1^{a}$ | 5.6 |
| *E. superba* | $796.1^{abcd}$ | 11.1 | $451.7^{b}$ | 9.8 | $78.6^{ef}$ | 4.0 |
| *A. diffusa* | $814.3^{ab}$ | 12.8 | $530.6^{a}$ | 13.8 | $112.3^{ab}$ | 5.6 |
| *A. adscensionis* | $826.4^{a}$ | 12.8 | $559.0^{a}$ | 13.8 | $91.1^{cde}$ | 5.6 |
| *h. contortus* | $741.0^{f}$ | 12.8 | $444.2^{b}$ | 12.0 | $80.3^{ef}$ | 4.9 |
| *B. insculpta* | $781.2^{bcde}$ | 12.8 | $547.8^{a}$ | 13.8 | $103.7^{abc}$ | 5.6 |
| *C. virgata* | $776.0^{cdef}$ | 12.8 | $481.2^{b}$ | 13.8 | $98.5^{bcd}$ | 5.6 |

$^{abcd}$: Means with common superscripts in the same column do not differ ($P > 0.05$)
SE: standard error

The results for DM, OM and CP of grass species found in the Makgobistadt communal area are presented in Table 5.5. All grass species had the same ($P>0.05$) DM and OM content in the communal area. *Cynodon dactylon* and *C. pospischilii* had the lowest ($P<0.05$) OM values. *Cynodon dactylon* (66 g/kg DM) had the highest ($P<0.05$) CP content while *A. adscensionis, A. congesta, A. stipitata P. patens* and *E. bicolor* CP values did not differ significantly from each other.

Table 5.5: The dry matter (DM), organic matter (OM), and crude protein (CP) content (g/kg DM unless otherwise stated) of grass species found in the Makgobistadt communal area

| Grass species | DM | OM | CP |
|---|---|---|---|
| *E. bicolor* | 953.1 | $863.1^{ab}$ | $53^{b}$ |
| *A. congesta* | 947.7 | $862.7^{ab}$ | $41^{c}$ |
| *C. dactylon* | 947.0 | $826.2^{b}$ | $66^{a}$ |
| *P. patens* | 946.4 | $879.6^{a}$ | $53^{b}$ |
| *A. stipitata* | 936.6 | $855.1^{ab}$ | $49^{bc}$ |
| *A. adscensionis* | 935.9 | $855.7^{ab}$ | $48^{bc}$ |
| *SE* | 12.54 | 13.1298 | 2.63 |

$^{abcd}$:Means with common superscripts in the same column do not differ ($P > 0.05$)

SE: standard error

The results for fibre fraction of all grass species found in Makgobistadt communal area are presented in Table 5.6. All grass species had the same ($P>0.05$) NDF content in the communal area. *Aristida congesta* had the same ($P>0.05$) ADL value as *E. bicolor, A. Stipitata, A. adscensionis* and *P. patents*. *Cynodon dactylon* had the least ($P<0.05$) ADF value (418.9 g/kg DM). All grass species had the same ($P>0.05$) ADL content in the communal area.

Table 5.6: The neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) of grass species found in the Makgobitadt communal area

| Grass species | NDF | ADF | ADL |
|---|---|---|---|
| *E. bicolor* | $764.0^{b}$ | $496.2^{b}$ | 148.0 |
| *A. congesta* | $835.6^{a}$ | $532.2^{ab}$ | 163.8 |
| *C. dactylon* | $754.8^{b}$ | $418.9^{c}$ | 142.2 |
| *P. patens* | $794.4^{ab}$ | $490.5^{b}$ | 154.9 |
| *A. stipitata* | $769.9^{ab}$ | $496.6^{b}$ | 148.7 |
| *A. adscensionis* | $803.2^{ab}$ | $571.3^{a}$ | 180.7 |
| *SE* | 20.8 | 19.1 | 13.5 |

$^{abc}$:Means with common superscripts in the same column do not differ (P > 0.05)
SE: standard error

The results for DM, OM and CP of grass species found in the Loporung communal area are presented in Table 5.7. All grass species had the same (P>0.05) DM content in the communal area. *Aristida adscensionis* had the lowest (P<0.05) OM content (730.0 g/kg) than all other grass species. *Melenis repens* had the highest (P<0.05) CP value (70 g/kg DM) and *E. echinochlodea* had the least CP value (36 g/kg DM).

Table 5.7: The dry matter (DM), organic matter (OM), and crude protein (CP) content (g/kg DM unless otherwise stated) of grass species found in the Loporung communal area

| Grass species | DM | OM | CP |
|---|---|---|---|
| *E. bicolor* | 928.01 | $888.4^{a}$ | $62^{ab}$ |
| *A. congesta* | 947.5 | $850.5^{a}$ | $66^{ab}$ |
| *C. dactylon* | 948.3 | $856.8^{a}$ | $56^{bc}$ |
| *A. diffusa* | 936.7 | $845.4^{a}$ | $54^{bc}$ |
| *C. glauca* | 932.4 | $884.6^{a}$ | $53^{bc}$ |
| *M. repens* | 953.6 | $859.0^{a}$ | $70^{a}$ |
| *P. patens* | 957.2 | $865.1^{a}$ | $49^{c}$ |
| *A. stipitata* | 951.2 | $905.4^{a}$ | $54^{bc}$ |
| *E. echinochlodea* | 945.4 | $851.6^{a}$ | $36^{d}$ |
| *A. adscensionis* | 927.8 | $730.0^{b}$ | $46^{cd}$ |
| *SE* | 9.31 | 18.4 | 3.76 |

$^{abcd}$:Means with common superscripts in the same column do not differ (P > 0.05)
SE: standard error

The results for fibre fraction of all grass species found in the Loporung communal area are presented in Table 5.8. *Aristida stipitata* had the same (P>0.05) NDF content value as *A. adscensionis*, *E. echinochlodea* and *P. patens*. *Eragrostis bicolor* (746.2 g/kg DM)' *A. congesta* (759.8 g/kg DM), *M. repens* (759.1 g/kg DM), *C. dactylon* (754.1 g/kg DM), *A. diffusa* (757.1 g/kg DM), and *C. glauca* (738.4 g/kg DM) had the lowest (P<0.05) NDF content than all other grass species. *Aristida congesta* had the same (P>0.05) ADF value as *A. diffusa*, *M. repens, P. patens, E. echinochlodea* and *A. adscensionis. Eragrostis bicolor* (406.2 g/kg DM), *C. dactylon* (418.2 g/kg DM) and *C. glauca* (404 g/kg DM) had the least ADF values. *Aristida congesta* had the same (P>0.05) ADL value as *C. dactylon, A. diffusa, M. repens, P. patens, A. stipitata A. adscensionis*. *Eragrostis bicolor* and *C. glauca* had the least ADL values (72.6 g/kg DM and 70.6 g/kg DM, respectively).

Table 5.8: The neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) of grass species found in the Loporung communal area

| Grass species | NDF | ADF | ADL |
|---|---|---|---|
| *E. bicolor* | $746.2^{c}$ | $406.2^{d}$ | $72.6^{d}$ |
| *A. congesta* | $759.8^{c}$ | $498.0^{abc}$ | $145.8^{ab}$ |
| *C. dactylon* | $754.1^{c}$ | $418.2^{d}$ | $130.1^{bc}$ |
| *A. diffusa* | $757.1^{c}$ | $525.9^{a}$ | $165.5^{a}$ |
| *C. glauca* | $738.4^{c}$ | $404.7^{d}$ | $70.6^{d}$ |
| *M. repens* | $759.1^{c}$ | $484.1^{bc}$ | $132.4^{b}$ |
| *P. patens* | $792.4^{b}$ | $474.7^{c}$ | $166.4^{a}$ |
| *A. stipitata* | $809.1^{ab}$ | $503.8^{abc}$ | $150.6^{ab}$ |
| *E. echinochlodea* | $832.5^{a}$ | $522.5^{ab}$ | $109.7^{c}$ |
| *A. adscensionis* | $799.6^{b}$ | $533.8^{a}$ | $169.0^{a}$ |
| *SE* | 10.3 | 12.4 | 7.2 |

$^{abcd}$: Means with common superscripts in the same column do not differ (P > 0.05)
SE: standard error

### *5.3.2 In vitro ruminal dry matter degradability*

*In vitro* ruminal dry matter degradability (DMD, g/kg DM) values of grass species found in Tsetse and Six-hundred communal areas are presented in Table 5.9. *Cymbopogon pospischilii* (176.1 g/kg DM) and *E. trichopora* (161.9 g/kg DM) had the highest (P<0.05) DM solubility values, which did not differ (P>0.05) significantly from each other at 0h. *Fingerhuthia Africana* had the same 24h DMD as *A. congesta, H. contortus, C. dactylon, B. insculpta, E. rigidior, E. superba, A. adscensionis, E. bicolor, C. virgata, A. diffusa* and *P. maximum. Cymbopogon pospischilii* (415.1 g/kg DM) and *E. trichopora* (428.0 g/kg DM) had the highest (P<0.05) 24h DMD, which did not differ significantly (P>0.05) from each other at 24h. *Aristida diffusa* had the lowest DMD value, which did not differ (P>0.05) significantly from that of *F. africana*. *Cymbopogon pospischilii* (540.6 g/kg DM) and *E. trichopora* (562.0 g/kg DM) had the highest (P<0.05) 48h DMD. *Aristida diffusa* had the lowest DMD, which did not differ (P>0.05) significantly from *A. adscensionis.*

Table 5.9: The *in vitro* ruminal dry matter degradability (g/kg DM) (0, 24 and 48) of grass species found in Tsetse and Six-hundred communal areas (clay-loamy soil type)

| Species | DMD0 | DMD24 | DMD48 |
|---|---|---|---|
| *F. Africana* | $94.2^{cdef}$ | $230.7^{de}$ | $351.9^{cd}$ |
| *A. congesta* | $134.2^{bc}$ | $333.0^{b}$ | $425.7^{b}$ |
| *E. rigidior* | $96.8^{cdef}$ | $249.0^{cd}$ | $340.5^{cd}$ |
| *C. dactylon* | $123.8^{cd}$ | $299.7^{bc}$ | $342.5^{cd}$ |
| *B. insculpta* | $104.5^{cde}$ | $302.2^{bc}$ | $386.3^{bc}$ |
| *H. contortus* | $107.3^{cde}$ | $337.8^{b}$ | $328.2^{cd}$ |
| *E. superba* | $92.7^{def}$ | $291.5^{bc}$ | $393.7^{bc}$ |
| *E. trichopora* | $161.9^{ab}$ | $428.0^{a}$ | $562.0^{a}$ |
| *A. adscensionis* | $71.3^{ef}$ | $252.5^{cd}$ | $300.3^{de}$ |
| *E. bicolor* | $111.6^{cd}$ | $311.1^{bc}$ | $384.5^{bc}$ |
| *C. virgata* | $118.0^{cd}$ | $290.5^{bc}$ | $373.1^{bc}$ |
| *A. diffusa* | $63.5^{f}$ | $191.1^{e}$ | $254.0^{e}$ |
| *P. maximum* | $116.6^{cd}$ | $303.2^{bc}$ | $385.1^{bc}$ |
| *C. pospischilii* | $176.1^{a}$ | $415.1^{a}$ | $540.6^{a}$ |

$^{abcd}$: Means with common superscripts in the same column do not differ ($P > 0.05$)
Parameters: DMD0 = Dry Matter Degradability at 0 hours; DMD24 = Dry Matter Degradability at 24 hours after inoculation; DMD48 = Dry Matter Degradability at 48 hours after inoculation

*In vitro* ruminal dry matter degradability (g/kg DM) values of grass species found in Makgobistadt and Loporung communal areas are presented in Table 5.10. *Eragrostis bicolor* had the same ($P>0.05$) at 0h DMD as *C. dactylon*, *C. glanca*, *M. repens* and *P. patents*. *Aristida adscensionis* (69.8 g/kg DM), *E. echinochlodea* (72.7 g/kg DM), *A. congesta* (80.7 g/kg DM), *A. diffusa* (82.2 g/kg DM) and *A. stipitata* (85.7 g/kg DM) had the lowest ($P<0.05$) 0h DMD. *Cynodon dactylon* had the same 24h DMD as *E. bicolor, A. congesta, A. diffusa, C. glanca, P.*

*patents*, *A. stipitata*, and *E. echinochlodea*. *Aristida adscensionis* (227.4 g/kg DM) had the lowest 24h DMD value, which did not differ significantly from *A. congesta*, *A. diffusa* and *A. stipitata*. All grass species had similar 48h DMD.

Table 5.10: The *in vitro* ruminal dry matter degradability (g/kg DM) of grass species found in Makgobistadt and Loporung communal areas (red-brown soil type)

| Species | DMD0 | DMD24 | DMD48 |
|---|---|---|---|
| *E. bicolor* | $127.2^{ab}$ | $316.5^{ab}$ | 369.7 |
| *A. congesta* | $80.7^{c}$ | $264.8^{cd}$ | 340.9 |
| *C. dactylon* | $118.9^{b}$ | $301.4^{abc}$ | 342.5 |
| *A. diffusa* | $82.2^{c}$ | $273.0^{bcd}$ | 360.3 |
| *C. glanca* | $139.7^{a}$ | $299.1^{abc}$ | 382.9 |
| *M. repens* | $125.7^{ab}$ | $335.0^{a}$ | 409.1 |
| *P. patens* | $116.7^{b}$ | $276.6^{bc}$ | 404.3 |
| *A. stipitata* | $85.7^{c}$ | $254.4^{cd}$ | 275.3 |
| *E. echinochlodea* | $72.7^{c}$ | $277.5^{bc}$ | 366.5 |
| *A. adscensionis* | $69.8^{c}$ | $227.4^{d}$ | 305.2 |

$^{abcd}$: Means with common superscripts in the same column do not differ ($P > 0.05$)
Parameters: DMD0 = Dry Matter Degradability at 0 hours; DMD24 = Dry Matter Degradability at 24 hours after inoculation; DMD48 = Dry Matter Degradability at 48 hours after inoculation

## 5.4 Discussion

### *5.4.1 Chemical composition of grass species*

Most grass species are known to have good grazing value when they are still at the vegetative stage of growth. Their supply of nutrients to meet animal demand is limited during the dry season due to a shortage of rain and harsh climatic conditions. *Cynodon dactylon* and *E. trichopora* had higher crude protein content than other grass species. This was in line with the findings by several authors (Hanna, 1992; Ataide-Junior *et al.,* 2001; Matlebyane *et al*., 2010). Findings from other authors are that *C. dactylon* is considered as medium quality forage that has chemical composition of 9 - 16% protein and is ranked as most palatable species (Matlebyane *et al*., 2010). *Themeda triandra* had the lowest crude protein content in all communal areas. This grass is regarded as a palatable species, thus its low protein content might be due to the stage of growth (Ekaya, 2001) when it was harvested. Nutritional quality of pastures is related to the reproductive of the forage when harvested. With the exeption of *C. pospischilii*, all grass species had average NDF values above 700 g/kg DM. These values are within the range reported by Ekaya (2001) and Mitsuru *et al*. (1999) on *T. triandra, E. superba, Aristida spp.* and *P. purpureum* at reproductive stage. During the early growing season, nutritional value (crude protein, rumen degradable protein, non-fibre carbohydrates, and net energy) of grasses tend to be higher, while fibre content (NDF) is lower. The reverse happens late in the growing season, when growth rates decline, fibre increases and CP declines (Rayburn, 1991; Fales *et al*., 1995; Ekaya, 2001). The same grass species (*C. dactylon* and *E. trichopora*) that had higher CP content also had lower ADF and ADL content than other grass species. But these grass species were not dominating in the communal areas as compared to *Aristida spp*. *Cymbopogon pospischilii* had lower CP, lower NDF and lower lignin content. Values of NDF, ADF and ADL on grass species are associated with intake, digestibility and degradability of grass as influenced by stages of growth of grass. Since grass species were harvested at reproductive stage, as the grass grows, grass leaves have a midrib made of lignin for further structural aid for the leaves which put more structural carbohydrates and increasingly lower digestibility of the leaves (Buxton & Redfearn, 1997). Ruminants, especially cattle have high concentration of microorganisms in their stomachs that are capable of digesting high fibre diet.

### *5.4.2 In vitro ruminal dry matter degradability of grass species*

*In vitro* ruminal DM degradability values of *C. pospischilii* and *E. trichophora* were higher than other grasses after 24 and 48 hours of incubation. However, species like *C. pospischilii* are known to have poor grazing value due to some volatile oils, which give the grass a bitter taste and if under-utilized due to its unpalatability, this species can become moribund (Smit & Rethman, 1990; Snyman, 1999; van Oudtshoorn, 2014). Tshabalala *et al*. (2010) stressed that this is one of the species that can be neglected during the rainy season but became a prime dietary item in drought. These values of *C. pospischilii* are similar to the ones reported by Fourie *et al*. (1985) who found that the average digestibility rate of *C. pospischilii* is 54.3%. This is the species that can be treated with protein source supplement to increase its acceptability to livestock. Low ADL amount in the *C. pospischilii* grass species might be the reason why this substrate had high degradability. Factors associated with the composition of the cell wall have been found to be responsible for the lower forage intake and animal productivity in the world. van Soest (1994) highlighted that within the components of the cell wall, lignin is considered the main limiting factor of the degradation of fibrous polysaccharides in the rumen. Lignin interferes with gut microbes that do have the necessary enzymes to digest cellulose, because it both acts as a physical barrier to digestion, and contains chemical bonds that cannot be broken down by normal rumen microbial flora (Buxton & Redfearn, 1997). Degradation of the cell wall requires an active microbial population that is capable of utilizing its components. Therefore, it depends on a complex interaction of microbial enzymes and substrates, which will determine the effectiveness of the degradation process (Detmann *et al*., 2009). So the lower the lignin content (in line with high concentration of acid soluble lignin) the higher the digestibility and more animal productivity.

*Fingerhuthia africana, A. congesta E. superba, C. glanca* and *E. bicolor* had the 48 h DMD values ranging from 351.9 - 425.67 g/kg. Though *A. congesta* had 425 g/kg DMD disappearance value at 48h, the species is considered not palatable due to its low leafy yield and is only grazed during the early growth stage. The 48h DMD of *Fingerhuthia africana* grass (352 g/kg) was lower than the one reported by Fourie *et al*. (1985) who reported 530 DMD for the fully mature species. Ekaya (2001) also reported higher value of DM degradability for *Eragrotis* (470 g/kg) and a lower value for *Aristida spp* (370 g/kg) harvested during inactive growth.

*Heteropogon contortus* is known to have low nutritional content and degradability resulting in inadequate rumen microbial protein synthesis (Morrison *et al*., 1990). Indeed, in this study *Heteropogon contortus* had the lowest DMD (328.18 g/kg). Minson & Mcleod (2006) stressed that the production of animals grazing tropical pasture species is generally low, because of the low DM degradability of the grasses. This is because the time for high nutritive value in grass is always limited to a short period of rapid growth. This is in agreement with Cherney *et al*. (1993) and Ximena & Rene (2011) who found that the ruminal dry-matter degradability declined in all grasses with advance in reproductive. Low dry matter degradability normally influences the productivity of livestock in a negative way.

The relationship between degradability and chemical composition of forages has been described in the literature several times (Morrison *et al*., 1990; Broderick, 1995; von Keyserlingk *et al*., 1996; Oh *et al*., 2008; Mlambo *et al*., 2009; Mnisi & Mlambo, 2016). These authors found that when there is a high concentration of CP, especially degradable CP, rumen degradability tends to increase up to 650 g/kg and on contrary, the increasing amount of fibre fraction has a negative influence. Plant species with higher nutritional values especially CP and lower fibre fraction are known to have higher ruminal degradability. When dietary CP is in the rumen, it is exposed to microbial attack and extensive degradation into peptides, amino acids and ammonia (Oh *et al*., 2008), fermentation products that are then used for microbial protein synthesis.

## 5.5 Conclusion

More grasses had higher fibre (NDF and ADF) and low CP content because they were harvested towards the end of their growth cycle. Most of the grass species were found to be of low nutritive content due to the fact that they were at maturity/reproductive stage. The grazing areas need to be properly managed to avoid overgrazing, especially those species of high feed values. Timing in the utilisation of grass species is important so that livestock can benefit in nutrient availability during growing stage. Those grass species with higher CP (*E. trichopora* and *C. dactylon*) and degradability (*E. trichopora*, *C. dactylon*, *C. pospischilii*) values can complement each other with forage supplements in improving livestock productivity when these grasses are fed as basal diet. Therefore, supplementation with by-products or high protein content diet is necessary for low quality roughage especially at their reproductive stage to sustain animal productivity and to avoid impairing growth. The understanding of the nutritional values of these grasses at later stages of growth or reproductive stage in communal areas can be considered as one of the keys to the efficient and sustainable mechanisms to the production of animals. This will help farmers to know when to supplement the forage.

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# 6 CHAPTER SIX - CHEMICAL COMPOSITION AND *IN VITRO* RUMINAL DRY MATTER AND NITROGEN DEGRADABILITY OF LEAVES FROM SOME TREE SPECIES FOUND IN FOUR COMMUNAL AREAS IN SELECTED LOCALITIES

## Abstract

The study was designed to assess the chemical composition, soluble phenolics, condensed tannins, and *in vitro* rumunal dry matter and nitrogen degradability of leaves from different browse species (*G. flava*, *A. erioloba*, *A. nilotica*, *S. lancea*, *Z. mucronata*, *A. caffra*, *G. monticola*, *D. cinerea*, and *A. mellifera*) harvested at three designated distances from the homesteads in four communal grazing lands. Browse leaves were collected from Tsetse, Six-hundred, Makgobistadt and Loporung communal areas and analysed for dry matter (DM), organic matter (OM), neutral detergent fibre (NDF), acid detergent fibre (ADF), acid detergent lignin (ADL), crude protein (CP), soluble phenolics (SPh), soluble condensed tannins (CT), *in vitro* rumunal dry matter degradability (DMD) and nitrogen degradability (ND). Generally, the highest crude protein content ($P < 0.05$) was recorded in *G. flava*, *A. erioloba* and *Z. mucronata* leaves (143.8, 166.9 and 148.9 g/kg DM, respectively) in Tsetse, *A. caffra* (173.1 g/kg DM) in Six-hundred; *G. monticola* (190.4 g/kg DM) in Makgobistadt; and *A. mellifera* (170 g/kg DM) in Loporung communal area. Generally, there was a spatial variation ($P<0.05$) in SPh and CT content. In Tsetse and Six-hundred grazing areas, the highest ($P<0.05$) CT content (0.975 and 0.98 $AU_{550}$/200 mg, respectively) was found in *A. nilotica* leaves. However, in Makgobistadt and Loporung grazing areas it was *D. cinerea* leaves that had the highest CT content (0.993 and 1.044 $AU_{550}$/200 mg, respectively). *Acacia mellifera* from Loporung had the lowest ($P<0.05$) CT content (0.298 $AU_{550}$/200 mg) of all tree species. The SPh content of browse species ranged from 639.53 to 741.08 µg TAE/g DM. *Ziziphus mucronata, G. monticola,* and *A. mellifera* leaves had the highest ($P<0.05$) 48h DMD values (670.98, 643.90 and 590.04 g/kg DM, respectively) compared to all other browse species. *Acacia nilotica*, *A. erioloba*, *S. lancea* and *D. cinerea* leaves had the lowest ($P<0.05$) DMD digestibility values (353.43, 368.16, 333.15 and 289.58 g/kg DM, respectively). *Acacia mellifera* and *G. monticola* leaves had the highest ($P<0.05$) 48 h ND values (740.8 and 715.1 g/kg N, respectively) than all other browse species. *Acacia caffra, D. cinerea, A. nilotica, S. lancea* leaves had the lowest ($P<0.05$) 48 h ND degradability values. *Acacia nilotica* and *S. lancea* leaves had lower potential as supplementary protein sources due to lower crude protein content, higher levels of condensed tannins, and lower N degradability. *Dichrostachys cinerea* leaves had higher crude protein content, but their potential as protein sources may be low due to the presence of high levels of condensed tannins and the associated low N degradability. *Ziziphus mucronata, G. monticola, A. mellifera*, and *A. erioloba* leaves have the greatest potential as protein supplements due to higher crude protein content, and higher *in vitro* ruminal N degradability.

Key words: browse species, tannins, phenols, nutritional composition, *in vitro* degradation.

## 6.1 Introduction

Establishment of the nutrient concentration and other nutritive value indicators of herbage from natural browse plants is essential for the efficient and sustainable production of animals off the veld (Tefera *et al*., 2008). Tree fodders are important in providing nutrients to ruminants in arid and semi-arid environments such as the North West province, where feed quality and quantity are major constraints to livestock production. Trees have appropriate agronomic characteristics and their browse products have high nutritional value to be useful as animal feed. They are known to maintain high crude protein and mineral contents during growth better than grasses, which decline rapidly in quality with maturity (Shelton, 2004). As a result, tree fodders can serve as supplements to improve the productivity of herbivores fed on low quality grasses.

Several indigenous and exotic browse species have been investigated and evaluated for inclusion in ruminant feeding systems in most parts of South Africa (Mokoboki *et al.,* 2005; Motubatse *et al.,* 2008; Mnisi & Mlambo, 2016). Unfortunately, the utilization of these species in most areas by livestock has been low despite the known benefits such as reduction of bush encroachment and improving animal performance in semi-arid areas like North West province. Furthermore, the presence of anti-nutritional factors in tree foliage has been known to contribute to the low intake of these browse species. Anti-nutritional factors are those substances that when present in animal feeds or water reduce nutrient availability by interfering with feed utilisation and affect the health and production of animals. Information on the nutritive value of browse species that were identified in Chapter 4, is required for long-term monitoring and management in the context of rangeland ecology and sustainable utilisation. There is, therefore, a need for continuous screening of browse trees to identify those with potential for animal feeding in order to increase the productivity of ruminants. An attempt to understand the potential nutritive value of browse products in communal areas should be done to ensure that local farmers can contribute to animal protein production in the country in a sustainable manner. This will also assist in assessing the sustainability of livestock production from existing rangeland resources in different communities. The objective of the study was, therefore, to assess the spatial variation in the chemical composition and *in vitro* ruminal degradability of some leaves from some tree species found in four selected localities in Ngaka Modiri Molema district, North West province, South Africa.

## 6.2 Material and methods

### 6.2.1 *Study sites*

The study was conducted in Tsetse, Six-hundred, Makgobistadt and Loporung communal areas. The geographical coordinates as well as climatic conditions of these areas have already been described in Chapter 3.

### 6.2.2 *Harvesting and processing of leaves*

As decsribed in 4.2.2, three 2.2 km transects, which served as replicates were established at each of the selected grazing areas. The three transects were placed at least 200 m from each other. Along each transect, points were marked within 500–700 metres (considered as near sites), >0.70–1.4 kilometres (middle site) and >1.4–2.2 kilometres (far sites) from the homesteads to form 9 sampling sub-transects (geo-referenced using a GPS). Three 10 x 10 metre homogenous vegetation units (HVU) were marked at each sub-transect and spaced 20 metres from each other making a total of 27 HVU. Leaves from different tree species were harvested separately from the species found in the HVU between February and March 2015. The leaf samples from each tree species were bulked within each HVU but the final number of replicates per species depended on the availability of each species in the HVU. Not all tree species were represented in HVU samples across all sites resulting in unequal numbers of replicates. In all sites, 5–7 browse tree species were identified from each HVU per communal area. Samples were oven dried at 60°C for 24 h to avoid destroying heat-labile components such as phenolics, after which they were ground to pass through a 2 mm sieve and kept in air-tight plastic bags pending chemical analysis and *in vitro* ruminal degradation.

### *6.2.3 Chemical analysis of browse species*

The browse species samples were analysed following the procedure described in Section 5.2.3, Chapter 5.

### *6.2.4 Soluble phenolics (SPh)*

Folin-Ciocalteau method was used to estimate soluble phenolics (Makkar, 2003) after extracting sample (200mg) three times for 5 min at a time with 10 mL of aqueous acetone (7.3 v/v acetone water). Folin and Ciocalteau reagent (2N) (0.25mL) was mixed with 0.02mL of acetone in a test tube after extraction and 1.25 mL of sodium carbonate (anhydrous) was added to the mixture and vortexed vigorously using the Vortex mixer. The mixture was allowed to stand for 40 minutes so that it can be able to react. The absorbance was measured at 725 wavelength using a spectrophotometer (T60 UV-visible, PG Instruments) (Makkar, 2003). The standard calibration curve was developed using tannic acid so as to determine the soluble phenolics concentration in leaf samples. After the assay was performed, results for soluble phenols were expressed as tannic acid equivalents (TAE).

### *6.2.5 Condensed tannins*

The modified butanol-HCl reagent was used on the same aqueous acetone (acetone:water (7:3, v/v) leaf extract sample to assess the soluble condensed tannins (Porter *et al*., 1986). The soluble CT fraction was determined using the butanol-HCl assay (Porter *et al*., 1986), by adding 0.5mL of the aqueous extract to 3mL of butanol-HCl (95:5, v/v). The mixture in the test tubes was vortexed vigorously and the closed test tubes were heated at 100ºC using the metal block for an hour and allowed to cool at room temperature after heating. The absorbance for soluble condensed tannins was measured at 550nm wavelength using spectrophotometer (T60 UV-visible, PG instruments). The soluble condensed tannins concentration results were reported as AU (absorbance units) per 200 mg sample according to Makkar (2003).

### *6.2.6 In vitro ruminal DM and N degradation*

The dry matter and nitrogen ruminal degradability (*in vitro*) of browse species leaves was determined using the ANKOM Daisy$^{II}$ incubator (ANKOM technology Corp, Fairport, NY). The incubator consists of a thermostatic chamber set at 39ºC with four rotating jars. milled browse or tree leaf samples (0.45 - 0.5 g) were weighed into F57 filter bags (0.45 -0.5 g), heat-sealed and placed in the digestion jars. Two buffer solutions (at a ratio of 1:5) were prepared in advance and mixed together and 1600mL of the mixed buffers with samples were transferred to each of the jars and warmed. Rumen fluid (400mL) was collected from the ruminally cannulated Bonsmara cow in the morning before feeding. Two pre-warmed thermos flasks were used to collect rumen fluid. The rumen fluid was used to inoculate each Daisy jar containing the F57 bags in 1600 mL of ANKOM buffer. Carbon dioxide gas cylinder was used to purge the strained rumen fluid kept at 39 ºC. Each jar was purged with $CO_2$ before closing it and placed in the incubation chamber. ANKOM F57 bags were withdrawn at 0, 24, 36 48 hours after inoculation and washed with cold water for 20 minutes. All washed samples were dried at 105ºC for 12 hours. The *in vitro* dry matter degradability was determined using the following formula:

$$\%IVTD(DM\ basis) = \frac{100 - (W3 - (W1\ x\ C1))}{W2xDM} x100$$

Where: W1 = bag tare weight, W2 = sample weight, W3 = final weight after inoculation and C1 = correctional factor (final oven dried weight divide by original blank bag weight).

Kjedahl method (AOAC, 1999) was used to determine the nitrogen content on dried residue. The degradability of nitrogen at 0, 24, 36, 48 hours of inoculation (ND0, ND24, ND36, ND48, respectively) was estimated as the loss in total nitrogen upon inoculation.

## 6.3 Statistical analysis

Statistical analysis of all data was done separately for the four communal grazing areas as per distance from homesteads. Chemical composition was analysed using a two-way analysis of variance in general linear models (GLM) procedure of SAS (SAS, 2010) in a completely randomised design to test differences between species and distance intervals (near, middle and far from homesteads) within each communal areas. *In vitro* ruminal degradability data for the tree species were analysed using one way analysis of variance due to lack of significance difference in chemical composition in browse leaves as influenced by distance from homesteads. Some of the tree browse species did not have enough replicates for statistical comparison and, therefore, simple descriptive statistics were employed to present their data on phenols and tannins.

The following general linear model was used for chemical composition data:-

$$Yijk = \mu + Si + Dj + (SxD)ij + \varepsilon ijk$$

Where; $Y_{ijk}$= dependant variable, $\mu$ = overall mean, $Si$ = effect of tree species, $Dj$ = effect of distance from homesteads within each grazing area, $(S \times D)ij$ = interaction effect of species and distance, and $\varepsilon ijk$ was the error term associated with observation $ijk$, assumed to be normally and independently distributed. The probability of difference in the lsmeans statement of SAS was used to separate the means (SAS, 2010). Significant differences were declared at the $P \leq 0.05$.

The following general linear model was used on *in vitro* ruminal DM and N degradability:-

$$Yij = \mu + Si + \varepsilon ij$$

Where; $Y_{ij}$ = dependant variable, $\mu$ = overall mean, *Si* = effect of species, and $\varepsilon ij$ was the error term associated with observation *ij*, assumed to be normally and independently distributed. The probability of difference in the lsmeans statement of SAS was used to separate the means (SAS, 2010). Significant differences were declared at the $P < 0.05$.

## 6.4 Results

### *6.4.1 Chemical composition of browse leaves – Tsetse communal area*

The results for chemical composition of browse leaves harvested in Tsetse communal area are presented in Table 6.1. There were no spatial differences in terms of chemical composition of leaves in Tsetse communal area. *Ziziphus mucronata, G. flava, A. erioloba* and *S. lancea* leaves had similar ($P>0.05$) DM values. *Acacia nilotica* leaves had the lowest ($P<0.05$) DM content (900.4 g/kg) compared to all the other species. *Searsia lancea* leaves had the highest OM content compared with other tree species. *Grewia flava* leaves had the same ($P>0.05$) OM value as *A. nilotica* and *A. erioloba.* The lowest ($P<0.05$) OM value (821.1 g/kg DM) was obtained from *Z. mucronata*. *Ziziphus mucronata*, *A. erioloba* and *G. flava* leaves had higher ($P<0.05$) CP content (143.8 g/kg DM, 166.9 g/kg DM and 148.9 g/kg DM, respectively) compared to *S. lancea* and *A. nilotica* leaves.

Neutral detergent fibre content was highest in *G. flava* and *A. erioloba* than all other browse species leaves. *Acacia nilotica* and *Z. mucronata* leaves had the least NDF values (275.2 and 416.8 g/kg DM, respectively). Acid detergent fibre content (201.8 g/kg DM) of *Z. mucronata* leaves was lower ($P<0.05$) than all the other browse species. *Acacia nilotica*, *G. flava*, *A. erioloba* and *S. lancea* had similar ($P>0.05$) amounts of ADF content. *Grewia flava* and *Z. mucronata* leaves had lower ($P<0.05$) ADL content (129.4 g/kg DM and 78.1 g/kg DM, respectively) than those of *S. lancea, A. nilotica* and *A. erioloba* (234.8 g/kg DM, 226.9 g/kg DM and 240.2 g/kg DM, respectively).

Table 6.1: The chemical composition (g/kg DM, unless otherwise stated) of tree leaves found in Tsetse communal area

| | Parameters[1] | | | | | |
|---|---|---|---|---|---|---|
| Tree species | DM (g/kg) | OM | CP | NDF | ADF | ADL |
| *G. flava* | $916.6^{a}$ | $859.1^{bc}$ | $143.8^{a}$ | $535.7^{a}$ | $334.4^{a}$ | $129.4^{b}$ |
| *A. erioloba* | $921.8^{a}$ | $864.1^{b}$ | $166.9^{a}$ | $530.6^{a}$ | $405.9^{a}$ | $240.2^{a}$ |
| *S. lancea* | $921.0^{a}$ | $887.4^{a}$ | $97.4^{b}$ | $476.7^{b}$ | $404.7^{a}$ | $234.8^{a}$ |
| *A. nilotica* | $900.4^{b}$ | $845.3^{c}$ | $104.0^{b}$ | $375.2^{c}$ | $351.4^{a}$ | $226.9^{a}$ |
| *Z. mucronata* | $901.8^{a}$ | $821.1^{d}$ | $148.9^{a}$ | $416.8^{c}$ | $201.8^{b}$ | $78.1^{b}$ |

$^{abcd}$:Means with common superscripts in the same column do not differ ($P > 0.05$)
[1] Parameters: DM = dry matter; OM = organic matter; CP = crude protein; NDF = neutral detergent fibre; ADF = acid detergent fibre; ADL = acid detergent lignin

### *6.4.2 Chemical composition of browse leaves – Six-hundred communal area*

Results for chemical composition of browse species found in Six-hundred communal area are presented in Table 6.2. With the exception of CP, there was no spatial difference in terms of chemical composition of leaves in Six-hundred communal area. Statistical differences were observed across tree species. Browse leaves had similar DM content in the communal grazing area. *Acacia caffra* leaves had higher OM content compared to *Z. mucronata* leaves. *Acacia caffra* had highest ($P<0.05$) CP content (173.1 g/kg DM). *Acacia nilotica* had the lowest

($P<0.05$) CP content (104.6 g/kg DM). *Acacia erioloba* had the highest ($P<0.05$) NDF content (575.5 g/kg DM). *Acacia nilotica* had the least ($P<0.05$) NDF value (373.8 g/kg DM).

*Grewia flava, A. erioloba, A. caffra* and *A. nilotica* had similar ($P>0.05$) amount of ADF content. *Ziziphus mucronata* had the lowest ($P<0.05$) ADF content (199.2 g/kg DM). *A. erioloba, A. caffra, A. nilotica* had higher ($P<0.05$) ADL content (236.7 g/kg DM, 241.3 g/kg DM and 233.6 g/kg DM) than *G. flava* and *Z. mucronata* (137.4 g/kg DM and 79.64 g/kg DM).

Table 6.2: The chemical composition (g/kg DM, unless otherwise stated) of tree leaves found in Six-hundred communal area

| | Parameters[1] | | | | | |
|---|---|---|---|---|---|---|
| Tree species | DM (g/kg) | OM | CP | NDF | ADF | ADL |
| *G. flava* | 921.1 | $858.1^{ab}$ | $147.2^{b}$ | $501.8^{b}$ | $335.4^{a}$ | $137.4^{b}$ |
| *A. erioloba* | 908.5 | $843.0^{ab}$ | $131.8^{c}$ | $575.5^{a}$ | $430.7^{a}$ | $236.7^{a}$ |
| *A. caffra* | 912.4 | $868.8^{a}$ | $173.1^{a}$ | $535.8^{ab}$ | $411.9^{a}$ | $241.3^{a}$ |
| *A. nilotica* | 902.9 | $856.3^{ab}$ | $104.6^{d}$ | $373.83^{d}$ | $362.3^{a}$ | $233.6^{a}$ |
| *Z. mucronata* | 904.9 | $820.2^{b}$ | $156.7^{b}$ | $466.6^{c}$ | $199.2^{b}$ | $79.64^{b}$ |

$^{abcd:}$Means with common superscripts in the same column do not differ ($P > 0.05$)
[1] Parameters: DM = dry matter; OM = organic matter; CP = crude protein; NDF = neutral detergent fibre; ADF = acid detergent fibre; ADL = acid detergent lignin

There were spatial differences in terms of CP content in browse species found in Six-hundred communal area (Table 6.3). *Grewia flava* leaves harvested from trees growing at the middle site of grazing area had lower ($P<0.05$) crude protein content (132.6 g/kg DM) than those harvested from near and far sites, which did not show spatial differences from each other. *Acacia erioloba* leaves harvested from trees growing furthest from homesteads had lower ($P<0.05$) CP content

(111.1 g/kg DM) than those harvested from near and middle sites. Crude protein content of *A. nilotica* leaves did not show any spatial differences in this communal area.

Table 6.3: Spatial differences in the crude protein content (g/kg DM) of browse tree leaves in Six-hundred communal area

| | Distance from homesteadss | | |
|---|---|---|---|
| Tree species | Near | Middle | Far |
| *G. flava* | $152.3^a$ | $132.6^b$ | $151.9^a$ |
| *A. erioloba* | $141.5^a$ | $142.8^a$ | $111.1^b$ |
| *A. nilotica* | 104.1 | 105.4 | 103.0 |

$^{ab}$:Means with common superscripts in the same row do not differ ($P > 0.05$)

### 6.4.3 *Chemical composition of browse leaves – Makgobistadt communal area*

Results for chemical composition of browse species found in Makgobistadt communal area are presented in Table 6.4. There were no spatial differences in terms of chemical composition of leaves in Makgobistadt communal area. Statistical differences were observed across tree species. *Grewia flava*, *A. erioloba, A. mellifera, G. monticola, S. lancea,* and *D. cinerea* leaves had similar ($P>0.05$) DM values in the communal area. *Ziziphus mucronata* had lower ($P<0.05$) DM value (899.1 g/kg) than all other species. All the browse species had the same ($P>0.05$) amount of OM.

*Grewia monticola* leaves had the highest ($P<0.05$) CP content than all other browse leaves. Leaves of *G. flava*, *A. mellifera*, *D. cinerea*, *A. erioloba* and *Z. mucronata* did not differ significantly from each other on CP content.. The least ($P<0.05$) CP value was obtained on *S. lancea* leaves. *Acacia mellifera* and *D. cinerea* had the same ($P>0.05$) NDF values as all other browse species leaves. *Acacia mellifera* and *G. monticola* had the same (P>0.05) ADF values as all other browse species. *Searisia lancea* had the highest (P<0.05) ADL value. *Grewia flava* had the same (P>0.05) ADL value as *A. erioloba, A. mellifera*, *G. monticola*, *D. cinerea* and *Z. mucronata.*

Table 6.4: The chemical composition (g/kg DM, unless otherwise stated) of tree leaves found in Makgobistadt communal area

| | Parameters[1] | | | | | |
|---|---|---|---|---|---|---|
| Tree species | DM (g/kg) | OM | CP | NDF | ADF | ADL |
| *G. flava* | 917.2$^{a}$ | 850.8 | 132.9$^{bc}$ | 528.42$^{a}$ | 332.3$^{a}$ | 156.3$^{bc}$ |
| *A. erioloba* | 929.2$^{a}$ | 869.9 | 123.4$^{c}$ | 519.5$^{a}$ | 339.1$^{a}$ | 198.1$^{b}$ |
| *A. mellifera* | 912.2$^{a}$ | 827.6 | 130.7$^{bc}$ | 475.2$^{ab}$ | 265.3$^{ab}$ | 112.1$^{c}$ |
| *G. monticola* | 915.4$^{a}$ | 841.5 | 190.4$^{a}$ | 511.9$^{a}$ | 255.7$^{ab}$ | 101.0$^{c}$ |
| *S. lancea* | 926.$^{a}$ | 893.8 | 100.4$^{d}$ | 389.1$^{b}$ | 316.7$^{a}$ | 279.0$^{a}$ |
| *D. cinerea* | 915.2$^{a}$ | 854.9 | 130.7$^{bc}$ | 470.8$^{ab}$ | 316.5$^{a}$ | 199.0$^{b}$ |
| *Z. mucronata* | 899.1$^{b}$ | 823.7 | 145.5$^{b}$ | 508.9$^{a}$ | 219.9$^{b}$ | 103.5$^{c}$ |

$^{abcd}$:Means with common superscripts in the same column do not differ (P > 0.05).

[1] Parameters: DM = dry matter; OM = organic matter; CP = crude protein; NDF = neutral detergent fibre; ADF = acid detergent fibre; ADL = acid detergent lignin

### *6.4.4 Chemical composition of browse leaves – Loporung communal area*

Results for chemical composition of browse species found in Loporung communal area are presented in Table 6.5. There were no spatial differences in terms of chemical composition of leaves in Loporung communal area. Statistical differences were observed across tree species. *Acacia erioloba* leaves had a higher (929.7 g/kg) DM value than all other species. *Ziziphus* *mucronata, G. flava, A. mellifera* and *D. cinerea* leaves had the least (P<0.05) DM values (916.5 g/kg DM, 914.4 g/kg DM, 916.3 g/kg DM, and 912.3 g/kg DM, respectively). *Acacia erioloba* leaves had higher (P<0.05) OM value (866.2 g/kg DM) compared with *A. mellifera* (823.1 g/kg DM) leaves. *Ziziphus mucronata, G. flava, A. mellifera* and *A.erioloba* and *D. cinerea* leaves OM values did not differ significantly from each other.

Table 6.5: The chemical composition (g/kg DM, unless otherwise stated) of tree leaves found in Loporung communal area

| | Parameters[1] | | | | | |
|---|---|---|---|---|---|---|
| Tree species | DM (g/kg) | OM | CP | NDF | ADF | ADL |
| *G. flava* | $916.5^{b}$ | $857.4^{ab}$ | $138.3^{ab}$ | 486.8 | $349.5^{ab}$ | $171.2^{a}$ |
| *A. erioloba* | $929.7^{a}$ | $866.2^{a}$ | $125.2^{b}$ | 483.1 | $378.9^{a}$ | $223.1^{a}$ |
| *A. mellifera* | $914.4^{b}$ | $823.1^{b}$ | $169.6^{a}$ | 429.9 | $242.0^{c}$ | $106.1^{b}$ |
| *D. cinerea* | $916.3^{b}$ | $858.7^{ab}$ | $155.2^{ab}$ | 452.7 | $306.3^{b}$ | $172.0^{a}$ |
| *Z. mucronata* | $912.3^{b}$ | $855.4^{ab}$ | $165.8^{a}$ | 427.2 | $206.4^{c}$ | $99.8^{b}$ |

$^{abc}$:Means with common superscripts in the same column do not differ (P > 0.05).
[1]Parameters: DM = dry matter; OM = organic matter; CP = crude protein; NDF = neutral detergent fibre; ADF = acid detergent fibre; ADL = acid detergent lignin

*Acacia mellifera* (169.6 /kg DM) and *Z. mucronata* (165.8 g/kg DM) CP values were higher (P<0.05) when compared with *A. erioloba* (125.2 g/kg DM). *Ziziphus mucronata, G. flava, D. cinerea, A.erioloba A. Mellifera* leaves DM values did not differ significanlty from each other. All browse species' leaves had the same (P>0.05) NDF content. *Grewia flava* had the same (P>0.05) ADF value as *A. erioloba* and *D. cinerea. Ziziphus mucronata* and *A. mellifera* leaves had the lowest ADF values (206.4 g/kg DM and 242.0 g/kg DM, respectively). *Grewia flava*, and *D. cinerea* had higher (P<0.05) ADL content (171.2 g/kg DM, 223.1 g/g DM 172.0 g/kg DM) than *A. mellifera* and *Ziziphus mucronata* which had 106 g/kg DM and 99.8 g/kg DM, respectively.

### *6.4.5 Phenolic content of browse leaves in Tsetse communal area*

Results on spatial variation in soluble phenolics and condensed tannin content of common browse species found in Tsetse communal area are presented in Table 6.6. There were spatial differences in terms of soluble phenolics and condensed tannins of leaves in Tsetse communal area. Statistical differences were also observed across tree species. *Grewia flava* leaves harvested from trees located furthest from homesteads had higher ($P<0.05$) soluble phenolics (729.1 µg TAE/g DM) than those located near the homesteads (719.2 µg TAE/g DM). *Grewia flava* leaves harvested far from homesteads also had higher ($P<0.05$) condensed tannins (0.822 $AU_{550}$/200 mg) than those harvested near the homesteads. Leaves from *A. erioloba* harvested near the homesteads had the highest ($P<0.05$) soluble phenolics value (720.8 µg/g DM), followed by far site (713.2 µg/g DM) and then middle site (705.4 µg/g DM) of the grazing area. The furthest site of grazing area from homesteads had highest ($P<0.05$) condensed tannins amount (0.535 $AU_{550}$/200 mg), whereas those *A. erioloba* species located near the homesteads had lowest ($P<0.05$) amount 0.380$AU_{550}$/200 mg) of condensed tannins.

Table 6.6: Spatial variation of soluble phenolics (µg $TAE^1$/g DM) and total condensed tannin ($AU_{550}$/200 mg) content of leaves of common browse species found in Tsetse communal area

| Tree species | Soluble phenolics | | | Condensed tannins | | |
|---|---|---|---|---|---|---|
| | Near | Middle | Far | Near | Middle | Far |
| *G. flava* | $719.2^{b}$ | | $729.1^{a}$ | $0.681^{b}$ | - | $0.822^{a}$ |
| *A. erioloba* | $720.8^{a}$ | $705.4^{c}$ | $713.2^{b}$ | $0.380^{c}$ | $0.453^{b}$ | $0.535^{a}$ |
| *S. lancea* | 705.4 | 707.3 | - | 0.921 | 0.917 | - |
| *A. nilotica* | $706.3^{b}$ | $708.1^{a}$ | $701.1^{c}$ | $0.997^{a}$ | $0.937^{c}$ | $0.975^{b}$ |
| *Z. mucronata* | - | - | 695.0 | - | - | 0.901 |

[1] TAE: tannic acid equivalents

[abc] :Means with common superscripts in the same row do not differ ($P > 0.05$)

- : no species found in the site

Leaves harvested from *A. nilotica* trees located in the middle of the grazing area had higher ($P<0.05$) soluble phenolics content (708.1 µg $TAE^1$/g DM) than near (706.3 µg $TAE^1$/g DM) and far (701.1 µg $TAE^1$/g DM) sites. Leaves harvested from the grazing area near the homesteads had the highest ($P<0.05$) concentration of total condensed tannins (0.997 $AU_{550}$/200 mg), whereas the middle site had the least ($P<0.05$) amount of condensed tannins (0.937 $AU_{550}$/200 mg).

### *6.4.6 Phenolic content of browse leaves in Six-hundred communal area*

Spatial variation of soluble phenolics and condensed tannins of common browse species found in Six-hundred communal area are presented in Table 6.7. There were spatial differences in terms of soluble phenolics and condensed tannin content of leaves from Six-hundred communal area. Statistical differences were also observed across tree species. *Grewia flava* leaves harvested far from homesteads had highest ($P<0.05$) amount (733.3 µg $TAE^1$/g DM) of soluble phenolics, followed by middle (729.7 µg $TAE^1$/g DM) and the near site with the lowest amount (720.1 µg/g

DM) of soluble phenolics. *Grewia flava* leaves from the furthest site from homesteads had higher ($P<0.05$) condensed tannin content (0.82 $AU_{550}$/200 mg) than middle (0.79 $AU_{550}$/200 mg) and near sites (0.68 $AU_{550}$/200 mg). *Acacia erioloba* harvested near the homesteads had lower ($P<0.05$) concentration of soluble phenolics (712.8 µg $TAE^1$/g DM) than that harvested from the middle site of grazing area and far sites, which did not differ ($P>0.05$) from each other. *Acacia erioloba* leaves from the furthest site from homesteads had the highest ($P<0.05$) amount (0.951 $AU_{550}$/200 mg) of condensed tannin content, whereas the middle site had the lowest condensed tannin value (0.793 $AU_{550}$/200 mg).

Table 6.7: Spatial variation of soluble phenolics (µg $TAE^1$/g DM) and condensed tannins content ($AU_{550}$/200 mg) of leaves from common browse species found in Six-hundred communal area

| Species | Soluble phenolics | | | Condensed tannins | | |
|---|---|---|---|---|---|---|
| | Near | Middle | Far | Near | Middle | Far |
| *G. flava* | $720.1^c$ | $729.7^b$ | $733.3^a$ | $0.68^c$ | $0.790^b$ | $0.820^a$ |
| *A. erioloba* | $712.8^b$ | $740.4^a$ | $741.1^a$ | $0.898^b$ | $0.793^c$ | $0.951^a$ |
| *A. nilotica* | $710.4^a$ | $693.5^c$ | $698.9^b$ | $0.965^b$ | $0.962^b$ | $0.980^a$ |
| *Z. mucronata* | 692.7 | - | - | 0.910 | - | - |

[1]TAE: tannic acid equivalents

$^{abc}$: Means with common superscripts in the same row do not differ ($P > 0.05$)

- : no species found in the site

*Acacia nilotica* leaves harvested from near the homesteads had the highest ($P<0.05$) soluble phenol content (710.35 µg $TAE^1$/g DM), followed by furthest site (698.88 µg $TAE^1$/g DM and middle area of grazing site (693.52 µg $TAE^1$/g DM). *Acacia nilotica* leaves harvested from furthest site from homesteads had higher ($P<0.05$) amount (0.98 µg $TAE^1$/g DM) of soluble phenols than those leaves harvested from near and middle areas of grazing sites which did not differ ($P>0.05$) from each other.

### 6.4.7 *Phenolic content of leaves in Makgobistadt communal area*

Spatial variation of soluble phenolics and condensed tannins of common browse species found in Makgobistadt communal area are presented in Table 6.8. There were spatial differences in terms of soluble phenolics and condensed tannin content of leaves in Makgobistadt communal area. Statistical differences were also observed across tree species. *Grewia flava* found near homesteads had the highest ($P<0.05$) amount (736.7 µg TAE$^1$/g DM) of soluble phenol content, while middle site of the grazing area had the least ($P<0.05$) amount (711.11 µg TAE$^1$/g DM). *Grewia flava* from the middle site of the grazing area had the highest ($P<0.05$) amount (0.92 AU$_{550}$/200 mg) of condensed tannins whereas the furthest site from homesteads had the least concentration (0.69 AU$_{550}$/200 mg) of condensed tannins.

*Acacia erioloba* species harvested from the furthest site had higher ($P<0.05$) soluble phenol content (725.30 µg TAE$^1$/g DM) than near and middle. *Acacia erioloba* species harvested near the homesteads and middle area of the grazing site had the same ($P>0.05$) soluble phenol content. Tree leaves harvested from the middle area of the grazing site had the highest ($P<0.05$) amount (0.66 AU$_{550}$/200 mg) of condensed tannins, while those from the furthest site had the least ($P<0.05$) amount (0.56 AU$_{550}$/200 mg).

*Acacia mellifera* leaves harvested far from the homesteads had the highest ($P<0.05$) soluble phenolic content (691.9 µg TAE$^1$/g DM), followed by near (684.14 µg TAE$^1$/g DM) and middle area of the grazing site (677.47 µg TAE$^1$/g DM). *Acacia mellifera* leaves harvested far from homesteads had lower condensed tannins than near and middle sites. *Acacia mellifera* species harvested near the homesteads and middle area of the grazing site had the same (P>0.05) soluble phenol content.

Table 6.8: Spatial variation of soluble phenolics (µg TAE[1]/g DM) and condensed tannins content ($AU_{550}$/200 mg) of leaves from common browse species found in Makgobistadt communal area

| | Soluble phenolics | | | Condensed tannins | | |
|---|---|---|---|---|---|---|
| Species | Near | Middle | Far | Near | Middle | Far |
| *G. flava* | $736.7^{a}$ | $711.1^{c}$ | $730.5^{b}$ | $0.84^{b}$ | $0.92^{a}$ | $0.69^{c}$ |
| *A. erioloba* | $721.6^{b}$ | $721.1^{b}$ | $725.3^{a}$ | $0.62^{a}$ | $0.66^{a}$ | $0.56^{c}$ |
| *A. mellifera* | $684.1^{b}$ | $677.5^{c}$ | $692.0^{a}$ | $0.48^{a}$ | $0.46^{a}$ | $0.43^{b}$ |
| *G. monticola* | - | 724.9 | - | - | 1.039 | - |
| *S. lancea* | - | - | 714.0 | - | - | 0.914 |
| *D. cinerea* | 726.8 | 726.1 | 728.3 | 1.05 | 1.05 | 0.993 |
| *Z. mucronata* | - | $701.7^{a}$ | $693.0^{b}$ | - | $0.977^{a}$ | $0.809^{b}$ |

[1]TAE: tannic acid equivalents
$^{abc}$: Means with common superscripts in the same row do not differ (P > 0.05)
- : no species found in the site

*Dichrostahys cinerea* species leaves harvested in the communal area did not show any spatial variation (P>0.05) in terms of soluble phenolics content. However, *D. cinerea* leaves harvested from the far site from homesteads had higher (P<0.05) condensed tannin content (728.28 µg TAE[1]/g DM) compared to near and middle sites, which did not differ (P>0.05) from each other. *Ziziphus mucronata* species harvested in the middle area of grazing site had higher (P<0.05) soluble phenolics concentration (701.7 µg TAE[1]/g DM) than that located far (693 µg TAE[1]/g DM) from homesteads. *Ziziphus mucronata* harvested in the middle of the grazing areas had higher ($P<0.05$) condensed tannin content (0.977 $AU_{550}$/200 mg) than leaves harvested from far site (0.809 $AU_{550}$/200 mg) from homesteads.

### *6.4.8 Phenolic content of browse leaves in Loporung communal area*

Results on spatial variation in soluble phenolics and condensed tannin content of common browse species found in Loporung communal area are presented in Table 6.9. There were spatial differences in terms of soluble phenolics and condensed tannins of leaves in Loporung communal area. Statistical differences were also observed across tree species. *Grewia flava* species harvested near homesteads and middle area of grazing sites had higher ($P<0.05$) amounts (718.1 and 713.10 µg $TAE^1$/g DM, respectively) of soluble phenolics than from the furthest site (707.07 µg $TAE^1$/g DM). Leaves from *G. flava* species harvested in the near grazing site had the highest ($P<0.05$) amount (0.997 $AU_{550/}$200 mg) of condensed tannins, whereas the middle site had least ($P<0.05$) concentration (0.833 $AU_{550/}$200 mg) of condensed tannins.

Table 6.9: Spatial variation in terms of soluble phenolics (µg $TAE^1$/g DM) and condensed tannins content ($AU_{550}$/200 mg) of leaves from common browse species found in Loporung communal area

| | Soluble phenolics | | | Condensed tannins | | |
|---|---|---|---|---|---|---|
| Species | Near | Middle | Far | Near | Middle | Far |
| *G. flava* | $718.1^a$ | $713.1^a$ | $707.1^b$ | $0.997^a$ | $0.833^c$ | $0.884^b$ |
| *A. erioloba* | $729.7^b$ | $733.0^b$ | $740.4^a$ | $0.716^a$ | $0.714^a$ | $0.508^b$ |
| *A. mellifera* | $679.6^b$ | $693.6^a$ | $639.5^c$ | $0.278^b$ | $0.354^a$ | $0.261^c$ |
| *D. cinerea* | 724.8 | | 730.0 | 1.044 | | 1.045 |
| *Z. mucronata* | 707.1 | - | - | 0.913 | - | - |

TAE: tannic acid equivalents

$^{abc}$: Means with common superscripts in the same row do not differ ($P > 0.05$)

- : no species found in the site

*Acacia erioloba* leaves harvested from the furthest site had higher ($P<0.05$) soluble phenolics (740.35 µg $TAE^1$/g DM) compared to those from near and middle grazing sites, which did not differ ($P>0.05$) from each other. *Acacia erioloba* species harvested near homesteads and middle area of grazing site had higher ($P<0.05$) concentration of condensed tannins (0.716 $AU_{550/}$200 mg and 0.714 $AU_{550/}$200 mg), than those from the furthest site (0.508 $AU_{550/}$200 mg). *Acacia mellifera* species from the middle of the grazing site had higher ($P<0.05$) soluble phenolics content (693.56 µg $TAE^1$/g DM) than near (679.57 µg $TAE^1$/g DM) and furthest (639.53 µg $TAE^1$/g DM) sites. *Acacia mellifera* species growing in the middle of the grazing site had higher ($P<0.05$) condensed tannins content (0.354 $AU_{550/}$200 mg) than in near (0.278 $AU_{550/}$200 mg) and furthest (0.261 $AU_{550/}$200 mg) sites. *Dichrostahys cinerea* species leaves harvested in the communal area did not differ ($P>0.05$) from each other on phenol content and condensed tannins.

### *6.4.9 In vitro ruminal dry matter degradability of browse leaves*

The *in vitro* ruminal dry matter degradability (g/kg DM) values of leaves harvested from some common browse species growing in selected communal areas are presented in Table 6.10. Statistical differences were observed across tree species on DM degradability. *Grewia monticola* and *A. mellifera* leaves had the highest ($P<0.05$) 24 hour DM degradability values (DMD24) (494.1 and 545.7 g/kg DM, respectively) compared to those from *A. nilotica, A. erioloba, G. flava, S. lancea, D. cinerea* and *A. caffra*. *Ziziphus mucronata, A. mellifera, G. monticola,* and *A. caffra* leaves had the same ($P<0.05$) DMD24 values. *Acacia nilotica, A. erioloba, G. flava, S. lancea*, and *D. cinerea* leaves had the lowest ($P>0.05$) DMD24 values. *Grewia flava,* and *A.mellifera leaves* had the highest ($P<0.05$) DMD36 values than *A. erioloba, A. nilotica, G. flava, S. lancea* and *A. caffra.*

Table 6.10: The *in vitro* ruminal dry matter degradability (g/kg DM) of browse leaves found in the four communal areas

| | Parameters[1] | | | |
|---|---|---|---|---|
| Tree species | DMD0 | DMD24 | DMD36 | DMD48 |
| *A. nilotica* | $85.7^{c}$ | $297.9^{c}$ | $324.4^{b}$ | $353.4^{b}$ |
| *A. erioloba* | $149.4^{bc}$ | $299.2^{c}$ | $377.0^{b}$ | $368.2^{b}$ |
| *G. flava* | $117.2^{bc}$ | $298.0^{c}$ | $348.3^{b}$ | $403.2^{b}$ |
| *S. lancea* | $197.9^{b}$ | $306.5^{c}$ | $353.2^{b}$ | $333.2^{b}$ |
| *Z.mucronata* | $78.8^{c}$ | $426.0^{ab}$ | $456.0^{ab}$ | $671.0^{a}$ |
| *G. monticola* | $69.3^{c}$ | $494.1^{a}$ | $534.1^{a}$ | $643.9^{a}$ |
| *D. cinerea* | $189.6^{b}$ | $314.8^{c}$ | $344.1^{b}$ | $289.6^{b}$ |
| *A. mellifera* | $343.9^{a}$ | $545.7^{a}$ | $527.8^{a}$ | $590.0^{a}$ |
| *A. caffra* | $101.2^{c}$ | $370.7^{b}$ | $383.8^{b}$ | $401.9^{b}$ |
| *SE* | 25.2 | 25.9 | 39.9 | 52.7 |

[1] Parameters: DMD0 = Dry Matter Degradability at 0 hours; DMD24 = Dry Matter Degradability at 24 hours after inoculation; DMD36 = Dry Matter Degradability at 36 hours after inoculation; DMD48 = Dry Matter Degradability at 48 hours after inoculation

[abc]:Means with common superscripts in the same column do not differ ($P > 0.05$)

SE: standard error

*Ziziphus mucronata, G. monticola,* and *A. mellifera* leaves had the highest DMD48 values than any other browse species. *Dichrostachys cinerea, A. nilotica, A. erioloba, G. flava, S. lancea* and *A. caffra* had the lowest ($P<0.05$) DMD48.

### *6.4.10 In vitro ruminal nitrogen degradability of browse species*

The results for the *in vitro* ruminal nitrogen degradability (kg/DM) of browse species leaves found in the communal areas are presented in Table 6.11. *Acacia mellifera* had higher ($P<0.05$)

N degradability value (631.98 g/kg N) than all other browse species leaves at 24 h. *G. monticola* had higher ($P<0.05$) ND24 value (434.08 g/kg N) compared to *A. nilotica, S. lancea, Z. mucronata, D. cinerea* and *A. Caffra.* Both *A. erioloba* and *G. flava* leaves had the same ($P>0.05$) ND24 content as *A. nilotica, S. lancea, Z. mucronata, D. cinerea, G. monticola* and *A. caffra.*

Table 6.11: The *in vitro* ruminal nitrogen degradability (g/kg DM) of browse leaves found in the four communal areas

| | Parameters[1] | | | |
|---|---|---|---|---|
| Species | ND0 | ND24 | ND36 | ND48 |
| *A. nilotica* | $62.5^{bc}$ | $217.4^{c}$ | $248.3^{d}$ | $203.5^{c}$ |
| *A. erioloba* | $172.1^{bc}$ | $299.7^{bc}$ | $450.0^{bc}$ | $359.9^{bc}$ |
| *G. flava* | $196.6^{b}$ | $292.2^{bc}$ | $350.3^{cd}$ | $375.8^{bc}$ |
| *S. lancea* | $87.5^{bc}$ | $227.9^{c}$ | $265.2^{d}$ | $233.7^{cd}$ |
| *Z. Mucronata* | $139.4^{bc}$ | $191.6^{c}$ | $260.9^{d}$ | $440.9^{b}$ |
| *G. monticola* | $174.7^{bc}$ | $434.1^{b}$ | $531.9^{b}$ | $740.8^{a}$ |
| *D. cinerea* | $47.6^{c}$ | $160.6^{c}$ | $187.8^{d}$ | $153.9^{d}$ |
| *A. mellifera* | $396.2^{a}$ | $632.0^{a}$ | $658.2^{a}$ | $715.1^{a}$ |
| *A Caffra* | $109.0^{bc}$ | $204.4^{c}$ | $313.8^{cd}$ | $178.9^{d}$ |
| *SE* | 39.04 | 44.95 | 52.95 | 61.46 |

[1] Parameters: ND 0= Nitrogen Degradability at 0 hours; ND 24= Nitrogen Degradability at 24 hours; ND 36 = Nitrogen Degradability at 36 hours; ND 48 = Nitrogen Degradability at 48 hours after inoculation

[abcd]:Means with common superscripts in the same column do not differ ($P > 0.05$)

SE: standard error

*Acacia mellifera* leaves had higher ND36 value (631.98 g/kg N) than all other browse species. *Grewia monticola* and *A.erioloba* leaves had the same ND 36 values. Both *G. flava* and *A. caffra* leaves had similar ($P>0.05$) ND36 as *A. nilotica, A. erioloba, S. lancea, Z. mucronata* and *D. cinerea* leaves. *Acacia mellifera* and *G. monticola* leaves had highest ($P<0.05$) ND values (740.8

and 715.1 g/kg N, respectively) at 48 h. Both *S. lancea* and *A. caffra* had the lowest (P>0.05) ND48 values.

## 6.5 Discussion

### *6.5.1 Chemical composition of browse leaves*

Most of tree browse species in the study area are palatable and have a potential sources of nutrients to ruminants (Rubanza *et al*., 2006; Dambe *et al*., 2015). In all communal areas, *G. flava* had a narrow range of CP values of 132.9 g/kg DM to 147.2 g/kg DM. These crude protein values are within the range reported by Dambe *et al.* (2015) and Mohammed Elhassan & Yagi (2010) for *Grewia spp*. These results are contrary to the findings of Aganga *et al*. (2000) and Le Houérou (1980), who reported lower CP values (11.1-12% DM). However, CP values from this study are lower than the ones reported by Mtengeti & Mhelela (2006) and Osuga *et al*. (2006) for this browse species. These authors found that *G. flava* leaves had CP content ranging from 192 to 201.9 g/kg DM. Rubanza *et al.* (2006) also recorded a higher value of CP content (150 g/kg DM) for *Grewia spp* leaves. The differences in CP content between browse species can be explained by essential attributes of each tree species' capability to extract and accumulate nutrients from the soil (Njidda, 2010). *Acacia erioloba* leaves had CP values ranging from 125 to 166.9 g/kg DM across all the communal areas. These values of crude protein for *A. erioloba* in this study encompass the CP value of 150 g/kg DM reported by Mnisi (2015). These values obtained in this study are comparable to the CP value (142.1 g/kg DM) reported by Kamupingene & Abate (2004) on the same browse species.

The results from study displayed 145.5 g/kg DM to 165.8 g/kg DM crude protein content in *Z. mucronata* from all the communal areas. Similar to the findings from this study, *Z. mucronata* forage is known to have medium to high protein content (10-20% DM) (Aganga, 1999; Hassen *et al.,* 2009; Njidda & Olatunji, 2012; Mnisi, 2015). Makkar & Becker (1998) also reported value of 15.7% on DM basis. The CP concentration of *S. lancea* in two communal areas (Tsetse and Makgobistadt) was in close range (97.4 g/kg DM and 100.4 g/kg DM). These values are higher than the ones recorded by Monegi *et al*. (2016) and lower than those reported by Naumann *et al*. (2016) on dry leaves. The high concentration of CP in this browse species is an indication that this plant can play a vital role in livestock production as a protein supplement. The leaves of *S. lancea* can provide valuable fodder for livestock but can taint the flavour of milk if consumed in large quantities by dairy cattle as a result of the resin contained in them (Stern, 2002). *Acacia nilotica* had the lowest values of CP content in both Tsetse and Six-hundred communal areas (104.0 g/kg DM and 104.6 g/kg DM). The *A. nilotica* values are lower than those reported by Tefera *et al.* (2008) (108 g/kg DM) and Azim *et al*. (2011) (122 g/kg DM). Contrary to this study, Mokoboki *et al*. (2005) found that *A. nilotica* had CP content of 151.7 g/kg DM and Makkar & Becker (1998) found 187 g/kg DM. *Acacia nilotica* as of acacia group is known as a useful source of protein, especially during dry seasons (Orwa *et al.,* 2009). *Acacia caffra* leaves harvested from Six-hundred communal areas had CP content of 173 g/kg DM. There are no reports on the chemical composition of *A. caffra* leaves in South Africa. This is despite the tree providing edible leaves and dominating also in Limpopo, Gauteng, Mpumalanga, Kwazulu Natal and Eastern Cape provinces (Smit, 2008), little or no research has been conducted on the species, and therefore, more assessments are reqiured on this species on its potential source of nutrients to livestock.

The CP content of leaves from *A. mellifera* growing in Makgobistadt and Loporung communal areas ranged from 130.7 to 169.6 g/kg DM. These values are comparable to the ones reported by Osuga *et al.* (2008) (149.5 g kg DM) and Dambe *et al*. (2015) (14.5 g/kg DM), but lower than the ones reported by Ondiek *et al*. (2010) and Nassoro *et al.* (2015) for the same *A. mellifera* species. *Dichrostachys cinerea* leaves had CP content ranging from 127.6-133.72 g.kg DM. Choongo *et al*. (2008) also found that this species has a relatively high protein content (90-190 g/kg DM) and may be an alternative source of crude protein for ruminants. The same CP range was reported by Tefera *et al*. (2008) and Aganga *et al.* (2005). Makkar & Becker (1998) recorded lower CP content figures when compared with the ones in this study. On the other hand, Mokoboki (2011) reported higher CP content to the one recorded in this study (192 g/kg DM). Beside their ability to extract nutrients from the soil, the preceding variations in nutritional characteristics of tree species forages may be attributed to numerous factors that include edaphic and environmental, the plant part (leaf, stem and pod), stage of growth and season (Simons & Stewart 1998; Abdullah *et al*., 2013). However, the low concentration of nutrients in plants as well as seasonal variation in the biomass yields and in the nutritional quality of the browse trees can, therefore, strongly limit the growth and production of ruminant animals (Dickhoefer *et al*., 2010; Mnisi, 2015).

Neutral detergent fibre is known as structural carbohydrate (SC) complex compounds that form parts of the cell wall e.g. cellulose, hemicellulose and lignin. It is also known as the predictor of voluntary intake because of the provision of bulk. There is an increment on feed intake when NDF is low, and when NDF increases, intake is suppressed (Rasby & Martin, 2016). The concentration of NDF in feeds is negatively correlated with energy concentration. Neutral detergent fibre values in this study were high (>500 g/kg DM) in *G. flava*, *A. erioloba*, and *A.*

*caffra*. These higher figures might have been influenced by age of the leaves when harvested for analysis. Most of the leaves for this study were harvested at maturity stage. Rasby & Martin (2016) stressed that forages vary widely in the concentration of nutrients due to area, harvest date in relation to age of leaves, year, and other management practices put in place. With advancing maturity in leaves, plants develop xylem tissue for transpiration, accumulate more structural carbohydrates (complex carbohydrates), and these tissues become bound together by lignification (Min, 2016). Lignin in cell wall is harder for rumen bacteria to digest than cellulose and hemicellulose. Pascual *et al*. (2000) also mentioned that the increased level of NDF content in some of the browse species can be due to the harsh climatic conditions prevailing in the semi-arid region like North west province, as high temperature and low rainfall tend to accelerate fibre fraction and to reduce the soluble contents of the plants. As browse plants are exposed to this environment, the proportion of fibre increases and the soluble carbohydrate content decreases and, therefore, the nutritional value is reduced (Mahala *et al*., 2009). *Dichrostachys cinerea* had an average NDF values of above 450 g/kg DM. INFIC (1978) also reported the values above 400 on the same species. *Ziziphus mucronata* and *A. nilotica* had the lowest NDF values. *Ziziphus mucronata* NDF values are within the range reported by Tefera *et al*. (2008), and higher than the ones reported by Hassen *et al*. (2009) for leaves harvested in spring (328 g/kg DM) and summer (372 g/kg DM). The growth environment on the species from this study might have influenced NDF concentration when compared to the one reported in the literature. *Acacia nilotica* NDF values are lower than the ones reported by Mokoboki *et al*. (2005) and Mnisi (2015). Carter (1998) recorded a lower NDF value of 200.2 g/kg DM on *A. nilotica* leaves than ones reported in this study.

*Grewia flava*, *A. erioloba*, *A. nilotica* and *A. caffra* leaves had ADF content values ranging from 306-430.7 g/kg DM. Similar values were also reported by Ondiek *et al*. (2010) and Mnisi (2015) on *A. erioloba* and *G. flava*, respectively. Mokoboki *et al*. (2005) reported higher ADF content (472.2 g/kg DM) for *A. nilotica* leaves than observed in this study. *Ziziphus mucronata*, *A. mellifera* and *G. monticola* leaves had lower (<300 g/kg DM) ADF content when compared with other species. Osuga *et al*. (2008); Hassen *et al*. (2009) as well as Ondiek *et al*. (2010) reported similar results for the *Ziziphus mucronata*. *Ziziphus mucronata* forage is known to have moderate ADF content (Njidda 2012). Tefera *et al*. (2008) reported higher values on *A. mellifera* than one in this study. The ADF content values for *D. cinerea* were lower than ones reported by Mokoboki (2011).

Although the discrepancy in the chemical concentration compositions evaluated may be due to several factors such as species, soil, stage of maturity and harvesting (Singh *et al.,* 2005), one of the reasons for unchanged nutritional composition from different communal areas might be because these woody species are mostly depending on the subsurface water instead of topsoil nutrients as occurred in herbs and shrubs. The concentration of the various chemicals in different plant parts varies with the stage of growth of the plant.

The concentration of nutrients in plants as influenced by harvesting or browsing interval have been reported before (Wigley *et al*., 2015). Du toit (1990) found that trees that are browsed tend to have lower N concentration in plant leaves. Opposite to that, Suksombat & Buakeeree (2006) and Azuhnwi *et al.* (2011) highlighted that the increasing harvesting interval or period can also increase dry matter and nutrient concentration including fibre fraction and ADL percentage and also having a significant effect on digestibility of forage. The variability of chemical attributes can also come through because of the avoidance mechanism, in which factors such as plant morphology and distance (3.2 km) from village, watering points and resting sites contributed to the fact that some plants tend to develop grazing avoidance mechanisms through morphological attributes that lower their accesibility and the chance of that plant to be browsed by animals (Lyons & Hanselka, 2001).

### *6.5.2 Soluble phenolics and total condensed tannin content of browse leaves*

There was inconsistent variation of phenolic content with distance from homesteads. The inconsistent variation of phenolics on tree plants have been known to come from chemical composition and palatability of plants and how plants respond to browsing intervals. Plants that are highly palatable and contain high concentration of N can be heavily browsed when compared with those with low browsing value, and as a result the plant tends to increase production of secondary metabolites to ward-off herbivores (Scogings *et al*., 2013). All the browse species across all communal areas had soluble phenolic concentration of less than 750 µg TAE[1]/g DM. Browse products contain variable quantities of tannins, whose nutritional effects on the animal can be positive or negative (Mlambo & Mapiye, 2015). The tannin content for this study is low and may not be harmful to herbivores, especially ruminants. Filippich *et al.* (1991) and Mlambo *et al*. (2009) stressed that the highest amounts of tannins (3-6%) can have a negative impact (toxic) on the efficiency and activities of microbes. Tannins are known to reduce the amount of total protein digested in the rumen and also enhance the amount of protein available for digestion in the intestine (Wang *et al*., 1996). Mueller-Harvey *et al*. (2007) stressed that tannin-containing plants such as *Acacia Spp*. and *D. cinerea* can yield useful benefits in herbivores, such as high productivity of animal.

During droughts, crude protein concentration and energy value of low quality grasses are below animal requirements during much of the year and browses have been incorporated in the feeding systems to improve the nutritional status of ruminants (Kaitho *et al*., 1998). The degradability of the protein in the rumen becomes the main factor that defines protein quality for ruminant animals. For an animal to meet the N requirements of microbes when poor-quality fibrous diets are fed, a protein supplement must be able to supply a large proportion of rumen-degradable protein (Cudjoe & Mlambo, 2013). Microbial protein production is influenced by the proportion of feedstuffs N that is soluble and degradable in the rumen, in addition to the digestible energy available to fuel incorporation of ammonia and degradable protein into microbial protein (Kaitho *et al*., 1998).

### *6.5.3 Dry matter and nitrogen degradability of browse leaves*

*Ziziphus mucronata, A. mellifera* and *G. monticola* leaves had highest DM and nitrogen degradability compared to all the species at 36 and 48 h. These findings are also similar to the ones reported by Mnisi & Mlambo (2016) on *Z. mucronata* species after 24 h of incubation. Mabeza *et al.* (2015) also found that 70% of *Acacia spp* DM was digested after 36 hours of incubation. Low lignin in *A. mellifera* (101–121 g/kg DM), *Z. mucronata* (78.1-103 g/kg DM) and *G. monticola* (101 g/kg DM*)* compared to all other species might have been the contributing factor to higher degradability. Lignin is known as a complex organic polymer found in the tissues of plants. Most biological activities in ruminant animals are controlled by the amount of lignin a plant has. Even though high amounts of lignin can contribute to the strength of the plants function and survival, it may contribute negatively to the nutritional value of the plant for herbivores. The availability of N for the breakdown of lignocellulose in the rumen is affected by both feed and physiological factors. Lignin is known as an anti-quality component in forages because of its negative impact on the nutritional availability to ruminant animals (Williams, 1959; Minson & Pigden, 1961; Mnisi & Mlambo, 2016). The authors stressed that in cases where low N forages, such as wheat straw and oat straw, do not respond to N supplementation, lignification is likely to be the limiting factor. Moore *et al*. (2001), highlighted that lignin interferes with the digestion of cell-wall polysaccharides by acting as a physical barrier to microbial enzymes.

*Acacia nilotica*, *S. lancea* and *D. cinerea* had low DM and N degradability compared to other species after 36 and 48 h of incubation. These findings on *Acacia* spp. are similar to a report by Aganga & Adogla-Bessa (1999). Again Mnisi & Mlambo (2016) reported similar results for *A. nilotica* species. The presence of phenolic compounds in these tree species might be the contributing factor (Williams, 1959; Minson & Pigden, 1961; Moore *et al.*, 2001; Cudjoe & Mlambo, 2013; Mnisi & Mlambo, 2016). Indeed, the tree species, which had lower degradability values (*A. nilotica*, *S. lancea* and *D. cinerea*) also had higher levels of tannins. Tannins are known to be polyphenolic compounds, which bind to protein and can be used as chemical additives for protecting and reducing ruminal fermentation of proteins in ruminant feeds (Goromela *et al.*, 1997; Frutos *et al*., 2002; Makkar, 2003). Tannins from different plants exhibit variation in their biological effects at the same concentration (Guglielmelli *et al.*, 2011). In this study, *Z. mucronata* leaves had higher tannin content than other browse species, yet they had high N degradability. This indicates that, even at similar concentrations, tannins from different plants might have different effects on degradability of nitrogen (Gemeda & Hassen, 2015).

## 6.6 Conclusion

All the browse species contained more than 10% crude protein content. Therefore, they can be used as protein supplements in basal diets with low protein content. *Ziziphus mucronata, G. monticola,* and *A. mellifera* leaves have greater potential to be used as supplements due to higher crude protein content and high ruminal DM and N degradability. Compared to other browse species, *A. nilotica* and *S. lancea* had lower DM and N degradabilities and higher levels of condensed tannins that might reduce their chances to be used as CP source in grazing areas. Although *Dichrostachys cinerea* leaves had higher crude protein content, their potential as protein supplements may be suppressed by high condensed tannin level, which might have led to low N degradability. *Acacia erioloba* leaves also have the potential to be used as protein sources due to higher crude protein content and lower condensed tannin levels. All the browse species contain lower amounts of tannins in their leaves. Low amounts of condensed tannins may have positive effects on the productivity of ruminants.

## 6.7 References

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# 7 CHAPTER SEVEN - MORPHOLOGY, NUTRITIONAL COMPOSITION AND *IN VITRO* RUMINAL DEGRADATION OF ECOTYPES OF SOME NATIVE GRASS SPECIES GROWN UNDER A CONTROLLED ENVIRONMENT

## Abstract

The study was designed to assess the morphology, nutritional composition and *in vitro* ruminal fermentation of ecotypes of some grass species under controlled growing conditions. Grass species used were *U. mosambicensis***,** *C. pospischilii, E. superba, F africana* and *E. bicolor*. Clay-loamy soil collected from Six-hundred and Tsetse communal areas was mixed, sieved, and homogenized, and approximately 10 kg was then transferred to deep 12 L plastic pots (36 cm diameter and 29 cm depth) in the greenhouse. Twenty pots were randomly allocated to each of the 5 grass species with each pot containing nongerminated (not less than 20) seeds as an experimental unit replicated four times. Soil sample was taken for laboratory analysis using the procedure described in section 3.2.5. Upon germination, seedlings were further thinned to ten plants per pot. All species were analyzed for morphology (Tiller height, leaf width, stem diameter and number of leaves per tiller) (on different stages of growth, vegetative, elongation, maturity/reproductive). Number of tillers was assessed after every three months, while nutritional composition and ruminal fermentation at the maturity stage. Differences ($P<0.05$) were observed on morphological characteristics across grass species and growth stages. *Eragrostis superba* was taller ($P<0.05$) at reproductive stage than all other grass species. *Urochloa mosambicensis* leaves had the highest value ($P<0.05$) of leaf width (7.27 mm) than all other grass species at the maturity stage. *Eragrostis bicolor* had higher ($P<0.05$) number of tiller developed at maturity stage. *Fingerthuhia africana* (1.903 mm), *E. superba* (1.761 mm) and *U. mosambicensis* (1.824 mm) had higher ($P<0.05$) stem diameter values than *C. pospischilii* and *E. bicolor* at maturity stage. All the grass species had the highest (P<0.05) fibre fraction (NDF and ADF) and lowest CP content at maturity stage. *Cymbopogon pospischilii* and *U. mosambicensis* had the highest (P<0.05) DM degradability values at 0h (DMD0) (210.1 and 204.7 g/kg DM) compared to all other grass species. There were no differences (P>0.05) in DM degradability values in all grasses at 36 h (DMD36) and 48 h (DMD48). Due to different morphological characteristics, these species could complement each other in rehabilitating the communal areas affected by heavy grazing. The grass species showed high potential in feeding value based on their *in vitro* ruminal degradability values. However, the grasses need to be further evaluated *in vivo* to confirm whether this potential could be translated into animal performance. Again, more research is needed to assess the nutritional values of these grass species at different stages of growth.

Key words: grass species, controlled enviroment, grass morphology, nutrition, restoration.

## 7.1 Introduction

Vegetation changes largely occur erratically in the short-term in response to rainfall, and episodically in the long-term (decades) in response to rare events, or due to grazing pressure, climatic change, altered disturbance regimes, or a combination of these factors (Darkoh, 1996). According to Snyman (1999), in some rangeland areas of South Africa, natural vegetations are degraded to such an extent that the application of management practices or even total withdrawal of grazing, will not have the desired effect on the recovery and density of vegetation. Sustainable pasture production and restoration of degraded rangelands are the two most important components of rangeland management and utilization. Both studies of rangeland degradation and the potential for increasing soil organic carbon (SOC) sequestration when degraded soils and ecosystems are restored have recently gained increasing interest. Finding long-term C storage in terrestrial ecosystems is being promoted as a key part to climate stabilization as greenhouse gases (GHG) continue to accumulate in the atmosphere. Major emphasis could be placed on the adoption of best management practices and restoration using indigenous plant species that are adapted to the local environment (Smith *et al*., 2008). This, in turn, requires profound knowledge of the germination, phenology and physiology of the desirable plants, and their connections as well as interaction with the environment (Kwesiga *et al*., 2003). Plant establishment up to reproductive are critical stages in the life history of grasses and determine their density as well as their contribution to community composition (Zimmermann *et al*., 2008; Fay & Schultz, 2009) and biomass. Disturbances in any of these stages may alter community composition. In South Africa, the propagation from seed and vegetative parts using indigenous plant species could be an inexpensive and effective means to restore degraded rangelands, conserving and enhancing the seed banks of valuable forage species for future use. Although numerous studies have addressed germination characteristics of perennial herbaceous plants elsewhere, little is known about specific growth, morphological, and tiller development of important native grass species of South African rangelands. In addition, growth, phenological patterns, reproductive cycles and morphological characteristics of these species are poorly understood.

As mentioned in Chapter 5, assessment of the chemical composition of different grass species and varieties has been carried out extensively. Factors that cause variation in grass chemical composition and ruminal fermentation were outlined by Särkijärvi *et al*. (2012). These include growing conditions as influenced by climate, soil type, water and nutrient availability. The determination of nutritional characteristics of these grasses is of paramount importance. This study, therefore, sought to determine key characteristics of prioritized (selected) grass species under controlled environmental conditions, including their morphologic characterictics, relative growth rates, as well as their chemical composition, and *in vitro* ruminal fermentation. This study will integrate scientific information on forage distribution and farmers' local ecological knowledge to get a strong foundation for a prioritization and selection of plant species.

## 7.2 Material and methods

### *7.2.1 Study site*

The study was conducted at Molelwane University Farm, about 10 km north of the North-West University, Mafikeng campus. The experimental site is situated in a semi-arid area with average annual rainfall of between 300 to 450 mm. Summer temperatures range between 22 and 34ºC. The average winter (from May to July) temperature is 16ºC but can range from 2 to 20ºC in a single day. The seeds were collected from two communal areas (Six-hundred and Tsetse communal areas) as most of the species were found to be common in those areas. The harvesting was done mid-January 2016. The harvesting of seeds from each grass species was done by hand and dried at room temperature and placed in a tight containers before planting. The vegetation type in the two communal areas is described as perennial or self-seeding annual forage species (which may persist indefinite species like *acacia species*, grasses, grass-like plants, forbs or shrubs that have the potential to be grazed) and which is used as a natural ecosystem for the productivity of grazing livestock.

### *7.2.2 Green house experiment*

This experiment was carried out in a greenhouse at the North-West University, Molelwane farm. The greenhouse had light reflective roofing and mantained the temperature between 20 and 30$^{o}$C. Seeds of grass species (*Urochloa mosambicensis*, *Cymbopogon pospischilii, Eragrostis superba, Fingerhuthia africana* and *Eragrostis bicolor*) selected on the basis of being common species in most parts of the Northwest semi-arid communal lands, were planted in deep 12-litre plastic pots (36 cm diameter and 29 cm depth). Clay-loamy soil collected from Six-hundred and Tsetse communal areas was sieved and homogenized, and approximately 10 kg was then transferred to the pots in the greenhouse. Twenty pots were randomly allocated to each of the 5 grass species with each pot containing nongerminated (not less than 20) seeds as an experimental unit replicated four times (each species was planted in four pots). Soil sample was taken for laboratory analysis using the procedure described in section 3.2.5. Upon germination, seedlings were further thinned to ten plants per pot. Plants were watered regularly. Several morphological characteristics were recorded for each grass species on different stages of growth (vegetative, elongation, maturity/reproductive stages). Plant measurements included plant height (PH), leaf width (LW), leaves numbers (LN), tiller number (TN), and stem diameter (SD). The LW and SD were measured with an electronic caliper on five mature leaves per plant or tillers randomly selected within each pot. The data for morphologic characteristics were collected from end of February to the end of April 2016 and plants were allowed to grow till October 2016 for tiller development. Number of tillers was assessed after every three months. Nutritional composition and ruminal DM degradation of grass species were also analysed only at the maturity stage using one way analysis of variance focusing on the effects of species on chemical composition.

### *7.2.3 Harvesting and preparation of samples*

The harvesting and preparation of samples was done as described in section 5.2.2

### *7.2.4 Chemical analysis*

Chemical analyses (DM, OM, CP, NDF, ADF and ADL) were done as described in section 5.2.3.

### 7.2.5 In vitro ruminal degradation

*In vitro* ruminal degradation was done as described in section 5.2.4.

### 7.2.6 Statistical analysis

Data on morphological characteristics were analysed using a two-way analysis of variance to determine the variation due to plant species and growth stage SAS (2010). The following statistical model was used for morphological characteristics data on different species:-

$$Yijk = \mu + Si + Gj + (SxG)ij + \varepsilon ijk$$

Where $\mu$ is overall mean, *Si* is the effect of grass species and $Gj$ is the effect of growth stage and $(SxG)ij$ is the interation between plant species and growth stage and $\varepsilon ijk$ is the error term associated with observation *ijk*, assumed to be normally and independently distributed.

The data on chemical composition of grass species were analysed using one-way analysis of variance. Least significant differences (LSD) were calculated at 5% level. The following model was used for chemical composition data on different species:-

$$Yij = \mu + SSi + \varepsilon ij$$

Where $\mu$ is overall mean, $SSi$ is the effect of species and $\varepsilon$ is the random error associated with observation *ijk*.

## 7.3 Results

### *7.3.1 Soil parameters*

Results on pH, organic carbon, nitrogen, macro and micro mineral content of soil used as a potting medium are presented in Table 7.1. The soil had a pH of 4.3, the N content was 1.76 mg/kg while P and K contents were 1.47 and 169 mg/kg, respectively.

Table 7.1: The pH, organic carbon (%), nitrogen and mineral content (mg/kg) of potting media used in the greenhouse growth trial

| Chemical constituents | Values |
|---|---|
| pH (KCl) 1:2.5 | 4.32 |
| %C | 0.65 |
| N(mg/kg) | 1.76 |
| *Macro minerals* | |
| P (Bray1) | 1.47 |
| K | 169 |
| Ca | 328 |
| Mg | 86 |
| Na | 0.002 |
| *Micro minerals* | |
| Fe | 4.02 |
| Cu | 0.55 |
| Zn | 0.38 |
| Mn | 14.92 |

### *7.3.2 Morphology*

Results on statistical significance (*P* value) of the effects of the main factors on the morphological characteristics (PH, TD, LN, SD, LW) of different grass species planted in greenhouse are tabulated in Table 7.2. Differences (P<0.05) were observed on morphological characteristics across grass species, growth stage and their interaction.

Table 7.2: Statistical significance (P value) of the effects of main factors on the plant height (PH), tiller number (TN), stem diameter (SD), number of leaves (NL) and leaves width (LW) from five different selected grass species.

| Main factors | PH | TN | LN | SD | LW |
|---|---|---|---|---|---|
| Grass species | ** | ** | ** | ** | ** |
| Growth stage | ** | ** | ** | ** | ** |
| Grass species x Growth stage | ** | ** | ** | ** | ** |

**: Significant at P<0.05
PH: plant height, TN: tiller number; NL: leaves number; SD: stem diameter; LW: leaves diameters

Results on plant height at different developmental stages of some selected grass species under greenhouse experiment are presented in Table 7.3. *Urochloa mosambicensis* plants were taller (P<0.05) at vegetative stage than all other grass species. *Fingerhuthia africana* and *E. bicolor* were the shortest (P<0.05) (15.43 cm and 14.68 cm). *Cymbopogon pospischilii* plants had the same (P<0.05) height as *U. mosambicensis* and *E. bicolor* at elongated stage. *Fingerhuthia africana* and *E. bicolor* plants were the shortest (P<0.05) plants (25.83 cm and 26.5 cm) at elongated stage. *Eragrostis superba* was taller (P<0.05) at reproductive stage than all the other grass species. *Cymbopogon pospischilii* and *E. bicolor* plants had similar height at reproductive stage. *Fingerhuthia africana* plants were shorter (P<0.05) (50.5 cm) than all other species at reproductive elongated stage.

Table 7.3: Plant height (cm) of selected grass species at different stages of growth.

| Grass species | Vegetative stage | Elongated stage | Reproductive stage |
|---|---|---|---|
| *U. mosambicensis* | $29.15^{aC}$ | $44.80^{aB}$ | $57.85^{cA}$ |
| *C. pospischilii* | $24.15^{bC}$ | $42.50^{abB}$ | $70.95^{bA}$ |
| *E. superba* | $18.98^{cC}$ | $39.00^{bB}$ | $78.20^{aA}$ |
| *F. africana* | $15.43^{dC}$ | $25.83^{cB}$ | $50.50^{dA}$ |
| *E. bicolor* | $14.68^{dC}$ | $26.50^{cB}$ | $67.65^{bA}$ |
| SE | 1.180 | 1.49 | 2.47 |

$^{ABC}$: In a row, different upper case superscripts denote significant (P<0.05) differences between the growth stages
$^{abcd}$: In a column, different lower case superscripts denote significant (P<0.05) differences between the grass species
SE: standard error

The width (cm) of leaves of grass species at different development stages are presented in Table 7.4. *Urochloa mosambicensis* had higher leaf width than *E. superba* at vegetative stage. *Cymbopogon pospischilii*, *E. bicolor* and *F. africana* had similar (P>0.05) leaf width values at vegetative stage. *Urochloa mosambicensis* leaves had higher (P<0.05) leaf width (5.93 mm) than *E. superba* (3.26 mm) at elongated stage. *Cymbopogon pospischilii* leaves had the same width values as *E. bicolor* and *F. africana* at elongated stage. *Urochloa mosambicensis* leaves had the highest value (P<0.05) of leaf width (7.27 mm) compared to all other grass species at the reproductive stage. *Cymbopogon pospischilii* and *E. bicolor* had the lowest (P<0.05) values of leaf width (2.74 mm and 2.97 mm) when compared with other grass species. Within the species growth stage, *Urochloa mosambicensis*, *E. superba* and *F. africana* had the lowest (P<0.05) leaf width values at vegetative stage and highest at the reproductive stage, but for the remaining grass species leaf width for the vegetative and elongated stages were similar and lower than the reproductive stage.

Table 7.4: Leaf width (mm) of selected grass species at different stages of growth.

| Grass species | Vegetative stage | Elongated stage | Reproductive stage |
|---|---|---|---|
| *U. mosambicensis* | $3.63^{aC}$ | $5.93^{aB}$ | $7.27^{aA}$ |
| *C. pospischilii* | $1.45^{cB}$ | $1.92^{cdB}$ | $2.74^{dA}$ |
| *E. superba* | $1.99^{bC}$ | $3.26^{bB}$ | $5.10^{bA}$ |
| *F. africana* | $1.39^{cC}$ | $2.19^{cB}$ | $4.23^{cA}$ |
| *E. bicolor* | $1.24^{cB}$ | $1.62^{dB}$ | $2.97^{dA}$ |
| SE | 0.129 | 0.177 | 0.179 |

$^{ABC}$: In a row, different upper case superscripts denote significant ($P<0.05$) differences between the growth stages
$^{abcd}$ : In a column, different lower case superscripts denote significant ($P<0.05$) differences between the grass species
SE: standard error

The number of tillers at different developmental stages of growth of the grass species are presented in Table 7.5. All grass species had one tiller during 0-3 months of age. *Urochloa mosambicensis* had the same ($P>0.05$) number of tillers as all other grass species at >3-6 months age.

Table 7.5: Average tiller number of selected grass species at different stages of growth.

| | Months | | |
|---|---|---|---|
| Grass species | 0-3 | >3-6 | >6-9 |
| *U. mosambicensis* | $1^{B}$ | $1.4^{abB}$ | $3.0^{cA}$ |
| *C. pospischilii* | $1^{B}$ | $2.0^{aB}$ | $9.3^{abA}$ |
| *E. superba* | $1^{B}$ | $1.0^{bB}$ | $7.4^{bA}$ |
| *F. africana* | $1^{B}$ | $1.0^{bB}$ | $7.0^{bA}$ |
| *E. bicolor* | $1^{B}$ | $1.3^{bB}$ | $11.1^{aA}$ |
| SE | 0.0001 | 0.038 | 0.043 |

$^{ABC}$: In a row, different upper case superscripts denote significant ($P<0.05$) differences between the months
$^{abc}$: In a column, different lower case superscripts denote significant ($P<0.05$) differences between the grass species
SE: standard error

*Eragrostis bicolor* had higher (P<0.05) number of tillers developed at >6-9 months stage. *Cymbopogon pospischilii* had same (P>0.05) tiller number as *E. bicolor, F. african* and *E. superba. Urochloa mosambicensis* had the lowest (P<0.05) number of tillers (3 tillers) at at >6-9 months of age. Within each species growth, >6-9 month stage had highest (P<0.05) average number of tillers when compared to both >3-6 and 0-3 month stages which did not differ significantly from each other within each species.

The stem diameters (mm) of some grass species grown under greenhouse conditions are presented in Table 7.6. *Urochloa mosambicensis* had thicker (1.199 mm) stems (P<0.05) than all other grass species at vegetative stage. *Cymbopogon pospischilii* and *E. superba* had similar (P>0.05) stem diameters at vegetative stage. *Eragrostis bicolor* had the lowest (P<0.05) value (0.575 mm) for stem diameter at vegetative stage. *Urochloa mosambicensis* had the thickest stem diameter (P<0.05) (1.461 mm) at elongated stage while *E. bicolor, C. pospischilii* and *F africana* had the lowest (P<0.05) values of the stem diameter at elongated stage. *Urochloa mosambicensis* (1.824 mm)*, E. superba* (1.761 mm) and *F africana* (1.903 mm) had higher (P<0.05) stem diameter values than *C. pospischilii and E. bicolor* at reproductive stage. *Eragrostis bicolor* had lowest (P<0.05) stem diameter value (1.264 mm) at reproductive stage. Within growth stages of each species, both elongated and reproductive stages had the higher (P<0.05) stem diameter values compared to vegetative stages in *U. mosambicensis species.* Reproductive stage of *C. pospischilii and E. superba* had the highest (P<0.05) stem diameters when compared to to other corresponding growth stages of the same grass species.

Table 7.6: Stem diameter (mm) of selected grass species at different stages of growth.

| Grass species | Vegetative stage | Elongated stage | Reproductive stage |
|---|---|---|---|
| *U. mosambicensis* | $1.199^{aB}$ | $1.461^{aA}$ | $1.824^{aA}$ |
| *C. pospischilii* | $0.740^{cC}$ | $1.176^{bB}$ | $1.534^{bA}$ |
| *E. superba* | $0.704^{cC}$ | $1.317^{abB}$ | $1.761^{aA}$ |
| *F. africana* | $0.883^{bB}$ | $1.064^{bB}$ | $1.903^{aA}$ |
| *E. bicolor* | $0.575^{dB}$ | $0.964^{bB}$ | $1.264^{cA}$ |
| SE | 0.043 | 0.054 | 0.079 |

$^{ABC}$: In a row, different upper case superscripts denote significant ($P<0.05$) differences between the growth stages
$^{abcd}$: In a column, different lower case superscripts denote significant ($P<0.05$) differences between the grass species
SE: standard error

The number of leaves per tiller at different developmental stages of growth of grass species are presented in Table 7.7. *Urochloa mosambicensis* and *C. pospischilii* had the highest ($P<0.05$) number of leaves than *E. superba*, *E. bicolor* and *F. africana* at vegetative and elongated stages.

Table 7.7: Average number of leaves per tiller (log$^{10}$ (Number)) of selected grass species at different stages of growth.

| Grass species | Vegetative stage | Elongated stage | Reproductive stage |
|---|---|---|---|
| *U. mosambicensis* | $0.621^{aB}$ | $0.767^{aA}$ | $0.789^{aA}$ |
| *C. pospischilii* | $0.587^{aC}$ | $0.791^{aA}$ | $0.712^{bB}$ |
| *E. superba* | $0.483^{bC}$ | $0.708^{bB}$ | $0.790^{aA}$ |
| *F. africana* | $0.503^{bC}$ | $0.698^{bA}$ | $0.641^{cB}$ |
| *E. bicolor* | $0.495^{bC}$ | $0.691^{bB}$ | $0.732^{bA}$ |
| SE | 0.015 | 0.014 | 0.016 |

$^{ABC}$: In a row, different upper case superscripts denote significant ($P<0.05$) differences between the growth stages
$^{abc}$: In a column, different lower case superscripts denote significant ($P<0.05$) differences between the grass species
SE: standard error

*Urochloa mosambicensis* and *E. superba* had higher ($P<0.05$) number of leaves (6.0 leaves/tiller) than all other grass species at reproductive stage. *Cymbopogon pospischilii* and *E. bicolor* had the same ($P>0.05$) average number of leaves per tiller at reproductive stage. *Fingerhuthia africana* had the lowest ($P<0.05$) average number (4 leaves/tiller) of leaves per tiller at reproductive stage.

Within growth stages of each species, both elongated and reproductive stages of *U. mosambicensis species* had the highest ($P<0.05$) number of leaves when compared to vegetative stage of the same species. Elongated stage of *C. pospischilii and F. africana* produced high ($P<0.05$) number of leaves when compared to other corresponding growth stages of the same grass species. Reproductive stage of *E. bicolor* had higher ($P<0.05$) number of leaves whereas vegetative stage of the same species had lowest ($P<0.05$) number of leaves.

### *7.3.3 Chemical composition of grass species harvested from greenhouse*

The results for chemical composition (DM, OM and ash) of grass species harvested from the greenhouse are presented in Table 7.8. *Eragrostis superba* had the highest ($P<0.05$) amount (983.6 g/kg) of DM compared to all other grass species. *Eragrostis bicolor* had same ($P>0.05$) amount of dry matter content as *F. africana, C. pospischilii* and *U. mosambicensis*. *Urochloa mosambicensis* had higher ($P<0.05$) ash content (162.0 g/kg) than all other grass species. *Eragrostis superba* (93 g/kg), *E. bicolor* (95 g/kg) and *C. pospischilii* (90.2 g/kg) had the lowest ($P<0.05$) ash amount. *Eragrostis spp* had higher ($P<0.05$) OM content (890.7 g/kg DM and 872.8 g/kg DM) than other grass species.

Table 7.8: Dry matter (DM), ash, organic matter (OM), and crude protein (CP) (g/kg DM, unless otherwise stated) of grass species

| Species | DM (g/kg) | ASH | OM | CP |
|---|---|---|---|---|
| *F. africana* | $956.1^{c}$ | $108.6^{b}$ | $847.5^{b}$ | $102^{a}$ |
| *E. superba* | $983.6^{a}$ | $93.0^{c}$ | $890.7^{a}$ | $50^{d}$ |
| *E. bicolor* | $967.7^{bc}$ | $95.0^{c}$ | $872.8^{a}$ | $61^{c}$ |
| *C. pospischilii* | $964.6^{bc}$ | $90.2^{c}$ | $690.9^{c}$ | $71^{b}$ |
| *U. mosambicensis* | $971.8^{ab}$ | $162.0^{a}$ | $709.1^{c}$ | $42^{e}$ |
| SE | 4.62 | 1.75 | 5.26 | 2.30 |

$^{abcde}$:Means with common superscripts in the same column do not differ ($P > 0.05$)

SE. standard error

*Cymbopogon pospischilii* (690.9 g/kg DM) and *U. mosambicensis* (709 g/kg DM) had the lowest ($P<0.05$) values of organic matter. *Fingerhuthia africana* had the highest ($P<0.05$) CP content (102 g/kg) than all other grass species. *Urochloa mosambicensis* had lowest ($P<0.05$) CP value (42 g/kg). Fibre fractions of all grass species harvested from the greenhouse are presented in Table 7.9. *Fingerhuthia africana* and *E. superba* did not differ ($P > 0.05$) in terms of NDF content. *Eragrostis bicolor, C. pospischilii* and *U. mosambicensis* also had the same ($P>0.05$) amount of NDF. *Fingerhuthia africana*, *E. bicolor, U. mosambicensis* and *E. superba* had the highest ($P<0.05$) ADF content than *C. pospischilii*. *Urochloa mosambicensis* had the same value of ADL content as *E. bicolor, C. pospischilii* and *E. superba*. *Fingerhuthia africana* had the lowest value of ADL content. *Eragrostis bicolor* had the same ($P>0.05$) amount cellulose content as *F. africana, U. mosambicensis* and *E. superba*. *Cymbopogon pospischilii* had the lowest ($P<0.05$) amount (282.8 g/kg DM) of cellulose. All grass species had the same ($P>0.05$) amount of hemicellulose.

Table 7.9: The fibre and lignin content (g/kg DM) of grass species grown under greenhouse conditions

| Species | NDF | ADF | ADL | Cellulose | Hemicellulose |
|---|---|---|---|---|---|
| *F. africana* | $797.0^{a}$ | $419.66^{a}$ | $67.7^{c}$ | $351.9^{a}$ | $377.4^{a}$ |
| *E. superba* | $801.0^{a}$ | $433.7^{a}$ | $82.9^{b}$ | $350.8^{a}$ | $367.4^{a}$ |
| *E. bicolor* | $681.7^{b}$ | $436.1^{a}$ | $96.7^{a}$ | $339.4^{ab}$ | $245.7^{b}$ |
| *C. pospischilii* | $690.9^{b}$ | $378.3^{b}$ | $95.5^{a}$ | $282.8^{c}$ | $312.6^{ab}$ |
| *U. mosambicensis* | $709.1^{b}$ | $416.2^{a}$ | $86.2^{ab}$ | $330.1^{b}$ | $292.8^{b}$ |
| SE | 25.3 | 6.0 | 3.4 | 4.3 | 22.6 |

$^{abcd}$:Means with common superscripts in the same column do not differ ($P > 0.05$)NDF: neutral detergent fibre; ADF: acid detergent fibre; ADL: acid detergent lignin
SE. standard error

### *7.3.4 In vitro ruminal dry matter degradability*

*Cymbopogon pospischilii* and *U. mosambicensis* had the highest ($P<0.05$) DM degradability values at 0h (DMD0) (210.1 and 204.7 g/kg DM) compared to all other grass species (Table 7.10). *Eragrostis bicolor*, *E. superba* and *F. africana* had the lowest ($P<0.05$) DM degradability values (151.5 g/kg DM, 147.7 g/kg DM and 132.3 g/kg DM) at 0h. *Cymbopogon pospischilii* and *U. mosambicensis* had the highest ($P<0.05$) DM degradability value at 24h (DMD24) (238.5 and 240.1 g/kg DM) than all other grass species. *Eragrostis bicolor, E. superba* and *F. africana* also did not differ significantly in DM degradability values at 24 h. There were no differences ($P>0.05$) in DM degradability values in all grasses at 36 h (DMD36). *Urochloa mosambicensis* had the same ($P>0.05$) DM degradability value at 48h (DMD48) as all other grass species.

Table 7.10: *In vitro* ruminal dry matter degradability (g/kg DM) of grass species grown under greenhouse conditions

| Grass species | DMD0 | DMD24 | DMD36 | DMD48 |
|---|---|---|---|---|
| *U. mosambicensis* | $210.1^{a}$ | $238.5^{a}$ | $377.0^{ab}$ | $474.4^{ab}$ |
| *C. pospischilii* | $204.7^{a}$ | $240.1^{a}$ | $425.6^{ab}$ | $526.6^{a}$ |
| *E. bicolor* | $151.5^{b}$ | $183.9^{b}$ | $341.0^{b}$ | $424.2^{b}$ |
| *E. superba* | $147.7^{b}$ | $212.1^{b}$ | $441.3^{a}$ | $407.4^{b}$ |
| *F. africana* | $132.3^{b}$ | $208.7^{b}$ | $403.9^{ab}$ | $562.7^{a}$ |
| SE | 7.8 | 14.9 | 26.5 | 27.6 |

$^{abcd}$:Means with common superscripts in the same column do not differ ($P > 0.05$)

$^{1}$Parameters: DMD 0= Dry Matter Degradability at 0 hours; DMD 24 = Dry matter degradability at 24 hours, DMD 36 = Dry matter degradability at 36 hours, DMD 48 = Dry matter degradability at 48 hours

SE: standard error

## 7.4 Discussion

### *7.4.1 Morphological structure of grass*

The need to restore rangelands in semi-arid areas that are exposed to uncontrolled heavy grazing has been recognized as a strategy to improve grass species composition, carrying capacity and environmental functions (Parrotta, 2000; Lamb *et al*., 2005; Shono *et al*., 2007). This study shows that among the grass species, *E. superba* had the highest tiller height value compared to other grass species at the reproductive stage. This height value is comparable to the one reported by van Oudtshoorn (2014). Within the limits set by genotype, Laude (1972) stressed that growth of the tiller is responsive to the environment. When a plant is growing, Dahl (1995) indicated that there is a quantitative change in plant dimensions that may lead to high biomass productions and also prevent leaching of important nutrients from the topsoil. Plant growth occurs normally through an increase in the number of cells by cell division in meristematic tissue and through cell enlargement and elongation (Alberts *et al*., 2002). *Urochloa mosambicensis* had higher leaf width value than all the other grass species in all different stages of growth. This value is within the range reported by Chippindall & Crook (1976); Gibbs-Russell *et al.* (1990) and McIvor (1992). Though grasses might show similar shoot anatomy and morphology, different sizes of leaves will always be observed (Kellogg & Birchler, 1993; Watson & Dallwitz, 1999). And this particular grass species can be used in the prevention of moisture evaporation from soil due to its broad leaves that can create shade on the surface. *Cymbopogon pospischilii* had same tiller number as *E. bicolor, F. africana* and *E. superba* at >6-9 month stage. Planting date, reproductive stages and some environmental factors can greatly affect tillers by influencing the development and survival of tillers (Thiry *et al*., 2002). Laude (1972) highlighted that a decline in rate of tillering or in tiller numbers is noted near the elongation, heading or anthesis stages with an increase in tillering observed soon thereafter that might be the response to environmental factors. High number of tillers per shoot play an important role in the increment of biomass, soil erosion reduction, suppressing weeds and reducing number of weeds and also preventing bush encroachment (Sun & Liddle, 1993). When tillers are many, there is an increase in soil fertility especially after their life cycle end thereby adding organic matter into the soil. Moreover, the crown in which stems are attached to, is the most important grass part that gives rise to leaf development, secondary roots, and other tillers. Once there is soil cover due to many tillers available, root development will be stimulated, that may transform soil structure and allow more water to soak into the soil and reduce runoff.

Leaf appearance and elongation rate, number of live leaves, basal and total tiller appearance rate had been reported as some of the positive factors influencing development of mass tillers (Rodrigues *et al.*, 2011). Though *C. pospischilii* is known as a poor quality grass species (van Oudtshoorn, 2014) due to the essential oils, which give the grass a bitter taste, it is known to accumulate many tillers and is rarely part of moribund material (Smit & Rethman, 1990) when compared with other grass species used in this study.

*Fingerhuthia africana* had the highest stem diameter at reproductive stage though not statistically different from other grass species (*E. superba* and *U. mosambicensis* ) tillers. The plant stem is a component of the shoot system, the portion of the plant body of the angiosperms having phototropic response (Jung, 2012). It is known as a “central axis” to which all other parts are attached and it contributes to the morphological structure and resilience in the overall plant function (Raven *et al.*, 2005), thereby providing the mechanical support for stems and leaves and supplies the strength and rigidity of plant walls. In addition to the effects of lignin, physical and structural barriers may limit fibre digestibility (Jung, 2012) because the middle lamella and primary wall of thick-walled cells are so highly lignified, many cells can be digested only from the interior of the cell (Buxton & Redfearn, 1997).

*Urochloa mosambicensis* and *E. superba* had higher number of leaves compared to other grass species at reproductive stage of growth. On average, six leaves per tiller were observed on these grass species. Initiation and development of grass leaves and internode often have interrelationships among each other (Skinner & Nelson, 1994). When the leaf blade emerges, it is often accompanied by internode that will increase the length of the grass height. Number of leaves per tiller also play an important role in the accumulation of biomass that may be required by livestock to enhance their productivity. Groups of new cells in the apical meristem form growth centres and develop into leaf blade primordia, which develop into phytomers (Langer, 1972). The first cells of a leaf are at the tip, and the freshest cells are at the base (Dahl, 1995). Leaves are plant parts primarily adapted for photosynthesis (Raven *et al*., 1999). This is the area in the grass part where photosynthates are produced or where food for the plant is made. The green plant substance chlorophyll captures light energy and uses it to convert water and carbon dioxide into plant food and oxygen back to the atmosphere (CFAC, 2013). The Amount of leaves must be adequate for continuing photosynthesis in order to get significant re-growth after grazing.

### *7.4.2 Chemical composition of grass species harvested at reproductive stage*

*Fingerhuthia africana* had higher crude protein content (102 g/kg) than all the other grass species. This figure is higher than the one reported in section 5.3.1 Table 5.3 and also the one reported by Fourie *et al*. (1985). The authors found that the average crude protein content of the species was 90 g/kg for fresh material and 40 g/kg for hay. Compared to the results of Fourie *et al*. (1985) and in section 5.3.1 Table 5.3, the growth environment might have contributed to the high concentration of CP on this grass species at reproductive stage since it was grown in a controlled green house enviroment. *Urochloa mosambicensis* had the lowest CP value (42 g/kg). This value is lower than the one reported by Beyene & Mlambo (2012). The average CP content found was 63.7 g/kg. This value from the study was expected since the species was the first to reach the maturity/reproductive stage than all the other species, which might have contributed to nutritional corrosion before harversting them simultaneously.

*Fingerhuthia africana* (797 g/kg DM) and *E. superba* (801 g/kg DM) had the highest value of NDF content. The NDF value of *E. superba* in this study was higher than the one reported by Kirwa *et al*. (2015). The highest NDF value was also expected as the species were harveted at maturity stage. Neutral detergent fibre values of all grass species in this experiement are similar to the ones reported by Van Soest *et al.* (1991), Mandebvu *et al*. (1999), Aregheore (2000) as well as Heuze *et al*. (2015) on diversity of grass species. NDF is the insoluble fibre fraction that remains after boiling in a neutral detergent solution. It is regarded as the necessary part of the diet in ruminant animals by acting on stimulating the rumen function. Grass fibre concentration can increase with the stage of growth. During the vegetative stage, grass fibre content is usually at its lowest when the grass is most digestible. These higher NDF values were expected because these grasses were harvested at reproductive stage whereby the NDF content was expected to be above 70%. Ball *et al*. (2001), Hoffman *et al*. (2001) and Van Saun (2016) highlighted that for grazing, the maximum NDF content of grass species should range between 30 to 40% of total dry matter.

*Eragrostis bicolor* and *C. pospischilii* had the highest values of ADL. Animals can easily digest the contents of plant cells, but not their lignin. All plant cells have an outer cell wall composed of cellulose or lignin. In general, older grass plants have higher levels of cellulose and lignin (Wilson, 1994; Buxton & Redfearn, 1997) than those at vegetative stage. Grasses have thick-walled parenchyma bundle-sheath cells around the vascular bundles found in the temperate or C4 grass species associated with the deposition of lignin polymers in cell walls (Giordano *et al*., 2014). High lignin content normally correlates negatively with digestibility (Wilson, 1993). Lignin interferes with gut microbes that do have the necessary enzymes to digest cellulose, limiting the achievable degradation of cellulose and hemicellulose and limiting the digestible energy available to ruminants because of chemical bonds that cannot be broken down by rumen microbial flora (Jung & Allen, 1995). *Fingerhuthia africana* had higher crude protein content than all other grass species. There is no relationship between CP and fibre fraction for *F. africana*. Higher CP within the species is always associated with lower NDF and ADF. As the plant advances in growth to vegetative stage, crude protein and digestibility are highest, as compared to maturity or reproductive stage, when stem growth advances, there will be more deposition of fibrous components (Adesogan *et al*., 2006; 2009).

### *7.4.3 Degradability of grass species*

Degradation of the complex compounds that form parts of the cell wall requires an active microbial population that is capable of utilizing its components. Detmann *et al*. (2009) highlighted that complex interactions of microbial enzymes and substrate, which will determine the effectiveness of the degradation processes, is of paramount importance. *Fingerhuthia africana* and *C. pospischilii* had the highest DM degradability values than other grass species at 48 h (DMD48). Plants having higher lignin content are known to have lower degradability values (Wilson, 1993; Buxton & Redfearn, 1997), but the opposite was true with *C. pospischilii* species. Although the species had higher concentration of lignin, which would have made this species harder to digest, but appeared to have been easily degraded at all intervals measured. Normally, lignin is considered as an anti-quality component in forage due to its negative impact on the nutritional availability of plant fibre (Moore & Jung, 2001).

## 7.5 Conclusion

*Eragrostis superba*, *E. bicolor* and *F. africana* due to high number of tillers and regarded as palatable species can have quantity of biomass that can play an ecological role. *Urochloa mosambicensis* had higher leaf width value than all other grass species in all different stages of growth but less tillers and it cannot be suitable in restoring the degraded land in communal areas. High CP, Lower ADL and higher value of DMD at 48h content was found on *F. africana* which makes it a better grass species that could increase productivity of animals grazing in most communal areas. Due to its unpalatability at reproductive, caused by the essential oils, *Cymbopogon pospischilii* can be recommended as long as it will be grazed at vegetative stages of growth and it could be useful during winter or scarcity times. Knowledge on the nutritional values of these grasses at later stages of growth or reproductive stage in communal areas can be considered as one of the keys to the efficient and sustainable production of animals. Due to their different morphological and nutritional characteristics, these species could complement each other in rehabilitating the communal areas affected by heavy grazing. The grass species showed potential feeding value based on their *in vitro* degradability values. However, the results need to be further confirmed in animal experiments whether the potential could be translated into animal performance. Again more research is needed to assess the nutritional values of these grass species on different stages of growth.

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# 8 CHAPTER EIGHT - GENERAL DISCUSSION AND CONCLUSIONS

For communal farmers to have a better returns to address food security status, it is important to enhance the livestock productivity. Livestock farming contributes to economic growth of South Africa and other developing countries in communal areas. their contribution in the provinsion of cash, and other socio-economics part would not go unnoticed. To meet these various functions, cattle productivity has to be increased through improvement of rangeland. Rangeland health is one of the most important determinants of livestock productivity. as it influences growth and health of those animals that depend on natural veld.

Overgrazing seems to be common in all the communal areas that were studied. The challenge of over grazing in communal areas needs identification of the policies, institutional capacity and easily utilized technologies which can contribute positively in mitigating the undesirable effects of grazing. Kotze (2015) also stressed that rangelands can self-rehabilitate, if managed appropriately, however scientists still have much to learn about how grazing affects soil properties. The ecological exploitation of the rangeland ecosystem is based on the appropriate application of rangeland management principles that will secure the long-term food security and cost-effectiveness of the production system at the lowest possible risk. Due to the high number of farmers in the studied areas who do not apply proper management practices in communal grazing lands, there should be an implementation of community-based training in the utilization and management of communal rangelands. The livestock management systems that are employed in these areas are a product of indigenous knowledge, farmer objectives, economic pressures, and affordability. The community-based training will assist improve farmers' skills in veld management to prevent land degradation through appropriate conservation and management of natural resources. The programmes may be made available in order to analyze data available to identify existing challenges experienced by farmers in communal areas. Government authorities and other stakeholders can collaborate for discussions and support and also consultation with the community to create awareness and to capture their willingness and views. There can be a selection of the target groups; especially cattle pastoralists to serve as a model for pasture evaluation, fodder conservation and skills intervention.

The soil chemical constituents data indicated that over-grazing and the shortage of plants can contribute negatively to soil quality as assessed by these parameters especially organic carbon. Failure to estimate the carrying capacity can also lead to soil compaction and erosion, reduced fertility of the soil and water holding capacity and infiltration, due to lack of organic matter (Haan *et al*., 1998). Though all communal study areas were deteriorated, soil nutrient status (N, P, and K) was high at top soil (0–20 cm) in Tsetse and Six-hundred communal areas than Loporung and Makgobistadt communal areas. Soil properties like micro minerals differed across communal areas as influenced by the type of soil (clay-loamy to red-brown sand soil). The results of this study could be used to make recommendations of best management and modelling of soil and plant relationships in future studies. The studied communal areas need more attention to avoid overgrazing and more years of lying fallow (2-3 years) are required to rehabilitate the areas to attain the ecological niche.

In all communal areas, there was a reduction in the occurrence of most palatable species, (especially *T. Triandra* which was observed furthest from the homesteads and *D. eriantha* which was very rare in all communal areas) and a general increase in grass species that cannot be used by livestock especially *Aristida spp* which were common and more dominant in all areas. Lower biomass accumulation was found in the site near the homesteads from both soiltype areas which had resulted in variation in species ditribution and composition along with distance. Forage availability is always reduced to low near the resting areas and this can bring a unimodal relationship between distance from certain location and utilization.

The biomass and diversity of grazing high grazing value plants would decrease with increasing proximity to the homesteads.

In semi arid areas where rainfall is unpredictable, most unpalatable grasses are expected to dominate when compared with palatable annual plants. This threatens livestock production and most rural people's livelihood. Extended heavy grazing contributes to the disappearance of palatable species and the subsequent dominance by other, less palatable, herbaceous plants or bushes (Lesoli, 2011). On the other hand changes in vegetation structure can be induced by reducing the density of woody plants (e.g. *A. mellifera* and *A. nilotica*) thus creating a conducive environment for open grasslands to occupy the communal areas and create biodiversity within the grass species. This prevention of bush encroachment, if sustained will stabilize vegetation and enhance animal productivity.

*Eragrostis superba*, *E. bicolor*, and *F. africana* had high number of tillers and regarded as semi palatable species can have quantity of biomass that can play an ecological niche in most communal areas. *Urochloa mosambicensis* had higher leaf width value than all other grass species in all different stages of growth but fewer tillers, and it cannot be suitable in restoring the degraded land in communal areas. Better CP was obtained from *F. africana* in the greenhouse experiment which had 10 % CP g/kg. More grasses had the expected higher neutral detergent fibre (NDF) content as influenced by the stage of harvesting for chemical analysis for both field and greenhouse trials. Lower ADL and higher value of DMD at 48h content was found on *F. africana* which makes it a better grass species that could increase productivity of animals grazing in most communal areas. *Cymbopogon pospischilii* had high ADL content and DMD. But due to its low grazing value at reproductive, caused by the essential oils that bring bitter taste, this species can be recommended as long as it will be grazed at vegetative stage of growth. Due to different morphological characteristics, these species could complement each other in rehabilitating the communal areas affected by heavy grazing. The understanding of the nutritional values of these grasses at later stages of growth or reproductive in communal areas can be considered as one of the keys to the efficient and sustainable production of animals. The grass species showed the potential feeding value based on their *in vitro* degradability values. However, the results need to be further confirmed in animal experiments whether the potential could be translated into animal performance. Again more research is needed to assess the nutritional values of these grass species on different stages of growth. This can be of paramount importance to farmers in knowing when to supplement the forage which had deteriorated in nutritional content.

Compared to grass species, browse leaves contained higher levels of crude protein with an average 100 g/kg CP content. Therefore, they can be used as protein supplements when basal diet has low protein content. These browse species can supply livestock with crude protein and energy when grasses are mature and of low nutritive value. *Ziziphus mucronata, G. monticola,* and *A. mellifera* leaves have greater potential to be used as supplements due to higher crude protein content and high DM and N degradability. Compared to other browse species, *A. nilotica* and *S. lancea* had lower DM and N degradabilities and higher levels of condensed tannins, that might reduce their chances to be used as CP supplements. Although *D. cinerea* leaves had higher crude protein content, their potential as protein supplements may be suppressed by high condensed tannin level, which might have led to low N degradability. *Acacia erioloba* leaves also have the potential to be used as protein sources due to higher crude protein content and lower condensed tannins level.

Although most tree leaves are generally rich in tannins, their effects on animals range from beneficial to toxicity and death (Makkar, 2003). In general, the browse species from this study contain lower amounts of tannins in their leaves that may have positive effects on the productivity of ruminants. Although grass species in this study seem to have moderate potential based on their *in vitro* ruminal degradability values, the results need to be further confirmed in animal experiments whether the potential could be translated into animal performance as suggested by Abebe *et al*. (2012).

## 8.1 References

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# 9 APPENDICES

**Appendix 1.** Template for grass data collection

**Date:...............................................................................**

**Plot:...............................................................................**

**MEASUREMENTS (1m$^2$)**

| **Species** | **Density** | **Height** | **DM** |
|---|---|---|---|

**Appendix 2.** Template for tree data collection

**Date:..............................................................................**

**Plot...............................................................................**

**MEASUREMENTS**

| **Species** | **0-1** | **1-1.5** | **>1.5-2** | **>2-3** | **>3** | $D_1$ | $D_2$ |
|---|---|---|---|---|---|---|---|

**Appendix 3.** Ingredients for the *in vitro* ruminal degradation buffer

| **Buffer A:** | **gram/litre** |
|---|---|
| $KH_2PO_4$ | 10.0 |
| $MgSO_4.7H_2O$ | 0.5 |
| NaCl | 0.5 |
| $CaCl_2.2H_2O$ | 0.1 |

| **Buffer B:** | **gram/litre** |
|---|---|
| $Na_2CO_3$ | 15.0 |
| $Na_2S.9H_2O$ | 1.0 |

Buffer A & B were mixed using a ratio 1:5 and the final pH 6.8 was obtained.