VEGETATION AND SOIL CONDITIONS AROUND WATER POINTS IN RANCHING AND COMMUNIAL GRAZING SYSTEMS IN THE HARDVELD AND SANDVELD OF BOTSWANA

Master of Science Degree in Animal Science(Animal Management Systems)

By

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VEGETATION AND SOIL CONDITIONS AROUND WATER POINTS IN RANCHING AND COMMUNAL GRAZING SYSTEMS IN THE HARDVELD AND SANDVELD OF BOTSWANA

A dissertation submitted in partial fulfillment of the requirements for the award of degree of Master of Science Degree in Animal Science (Animal Management Systems)

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May 2017

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CERTIFICATION

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STATEMENT OF ORIGINALITY

The work documented in this dissertation was compiled by the author at the Botswana University of Agriculture and Natural Resources (BUAN), Botswana, during the period of May 2014 to May 2016. It is original work except where reference was made. This work has not been submitted and shall not be submitted for the award of any degree or diploma to any institution of higher learning.

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DEDICATION

This work is dedicated to my husband Richard B. Seletlo and late daughter Azariah K. Seletlo. Richard, you were my source of strength throughout this time. I thank you for your love.

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ACRONYMS

%	Percent
APRU	Animal Production Research Unit
BUAN	Botswana University of Agriculture and Natural Resources
Ca	Calcium
Cu	Copper
FAO	Food and Agriculture Organization
Fe	Iron
FMD	Foot and Mouth Disease
Ha	Hectare
K	Potassium
LSU	Livestock Unit
Mg	Magnesium
Mn	Manganese
N	Nitrogen
Na	Sodium
NRC	Nutrient Requirements of livestock
OM	Organic Matter
P	Phosphorus
SAS	Statistical Analysis System
SASSCAL	Southern Africa Science Service Centre for Climate Change and Adaptive Land Use
Spp	Species
Zn	Zinc

DECLARATION

The research described in this thesis was carried out in the Department of Animal Science and Production, BUAN under the supervision of Drs K. Tshireletso, S. W. Makhabu, M. Nsinamwa and M. R. Setlalekgomo.

This is to declare that this thesis is a product of my own investigation and has not been submitted for any degree in any academic institution. All sources of information shown in text and listed in the references and all assistance have been duly acknowledged.

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GENERAL ABSTRACT

Artificial water sources or boreholes were introduced in Botswana to mitigate surface water scarcity in rangelands and aid livestock production. Gradually piospheres were observed, areas close to water points experience high grazing pressure, trampling and excreta deposition as animals congregate at a reduced area for water, causing changes in vegetation and soil conditions. The magnitude of grazing and animal movements reduces as animals move away from water points as area of impact increases. Nonetheless, whether the above phenomenon takes place in different grazing management systems and ecological zones is poorly understood. Therefore the objective of this study was to investigate the effects of distance around water points, grazing management systems (ranches and communal grazing areas) and ecological zones (hardveld and sandveld) on vegetation and soil conditions. Vegetation conditions included grass species abundance, woody plant density, and plant diversity (grass and woody) and soil conditions included soil pH and mineral status. In each zone, 2 ranches and 2 adjacent communal grazing areas were used for this study. One water point was used as a reference point for 4 randomly placed transects of 1000m in length radiating in different directions from the water source at each site. Four plots measuring 50mx20m were placed at intervals of 250 m along each transect. Within the 50mx20m plot, grass species abundance was estimated in a 10mx10m plot while woody plant density was estimated in the 50mx20m plots. Shannon-Wiener Index was used to calculate plant species diversity. For soil conditions, soil samples were collected in the first and last 50mx20m plots along each transect. At each sample plot, a soil sample was collected as composite sample from 5 randomly collected samples that were mixed together in a bucket. From the mixture a composite soil sample was collected so as to avoid small spatial variations. All soil samples were analyzed for soil pH, macro (Mg, Ca, K, Na, P and N) and micro (Fe, Mn, Zn and Cu) minerals. Total grass species abundance, woody plant density and plant diversity were not affected by distance from water points ($P>0.05$). Ranching and communal grazing management systems also did not affect total grass species abundance and woody plant density ($P>0.05$). However, strong perennials, decreaser, increaser I, good and poor palatable grass species abundances were significantly higher in ranches compared to communal grazing areas ($P<0.05$). Grass and woody species diversities were higher in ranches than in communal grazing areas ($P<0.05$). Woody plant density, total grass species, strong and weak perennial, decreaser, increaser I, increaser II, high, moderate and poor palatable grass species abundance differed between the hardveld and sandveld ecological zones of Botswana ($P<0.05$). Woody plant diversity differed ($P<0.05$) between ecological zones whereas grass species diversity did not vary between ecological zones ($P=0.32$). Woody plant diversity in the sandveld (1.78 ± 0.06) was higher than in the hardveld (1.29 ± 0.06; $P<0.0001$). Soils further away from water points were acidic compared to those close to water points. Ranches (5.10 ± 0.13) had less acidic soils than those in communal grazing areas (4.71 ± 0.13; $P=0.03$). The hardveld (4.94 ± 0.13) and sandveld (4.88 ± 0.13) had similar soil pH ($P=0.73$). Macro and micro minerals were not affected by distances from water point except for calcium which was highest further from water sources. Generally, soil mineral status was higher in ranches than communal grazing areas. Variations between the two grazing management systems were found in Mg, Na, P and Zn contents. Soils in the hardveld had higher soil mineral status than the sandveld. This study did not find evidence that distance from water points causes changes in vegetation and soil conditions. However, grazing managements systems and ecological zones did influence some variations in vegetation and soil conditions. Ranching grazing management system showed

higher good grass species abundance, plant diversity and soil mineral status than communal grazing systems. The hardveld also was higher in good grass species abundances and soil mineral status than the sandveld. For livestock production to be sustainable in the sandveld mineral supplementation is required to argument low mineral status of the soil. It is recommended that the following may be considered for future studies; 1) observe more (2-4) communal and ranching grazing management systems in each ecological zone, 2) have longer transects (preferably longer than a kilometer) with shorter sampling intervals, 3) measure soil physical and mineral properties of a complete soil profile so as to measure grazing effects over time and 4) measure vegetation growth (above and belowground biomass, cover and height) of grasses.

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background

Savanna ecosystems cover about 20% of the Earth's land surface (Bond and Midgley, 2000; Sankaran *et al.*, 2005) and 50% of Africa (Wang *et al.*, 2010) of which Botswana is inclusive (Setshwaelo, 2001). Rangelands found in the savanna ecosystem play an important role in the delivery of ecosystem goods and services for livelihoods worldwide. The provision of livestock is one of the most important services in arid and semi-arid savannas (Sandhage-Hofmann *et al.*, 2015). Rangelands are the largest resource based upon the extensive area covered and that a significant portion of Botswana's population depends on livestock production, veld products, wildlife and tourism (Setswaelo, 2001; Eriksen and Watson, 2009; Muhumuza and Byarugaba, 2009). Grazing lands comprise the largest land use (Liebig *et al.*, 2006) estimated to cover 25% of the Earth surface (Asner *et al.*, 2004). About forty million hectares or 76% of Botswana's total land surface area is used for grazing by domestic and wild animals (Setswaelo, 2001; Asner *et al.*, 2004). Approximately 37 million hectares of the total land in Botswana is held in tribal grazing areas under communal rights (Setswaelo, 2001), while 8% of the land area is covered by commercial cattle ranches (Frenken, 2005). The extensive area covered by rangelands makes them an essential resource for biodiversity maintenance (O'Connor, 2005) and a source of livelihood particularly rural communities (Eriksen and Watson, 2009; Muhumuza and Byarugaba, 2009).

1.2 Rangeland management systems in Botswana

There are three rangeland management systems in Botswana namely communal/traditional, ranching/commercial and game farming management systems. However, the latter is growing but not yet popular. The communal grazing management system is the most practiced of them all (Statistics Botswana, 2014).Communal livestock producers in Botswana far exceed ranchers in number and livestock population. In the years 2011, 2012 and 2013 communal grazed cattle population percentages were at 88.48%, 88.33% and 88.53% respectively (Statistics Botswana, 2013). Grazing management systems vary in management structure, animal diversity and products (Smet and Ward, 2005). Ranching systems comprise of a single manager, single animal species depending on farmer's interests (Smet and Ward, 2005) and have adopted rotational grazing systems (Sandhage-Hofmann *et al.*, 2015). In contrast, communal grazing systems have multiple managers (Smet and Ward, 2005), where the land is used collectively by members of surrounding villages with multiple animal species of cattle, goats, sheep, donkeys and/or horses. Continuous grazing is employed in communal grazing areas due to lack of fencing (Sandhage-Hofmann *et al.*, 2015).

Generally, rangelands are said to be degraded due to overgrazing by livestock (Fernandez-Gimenez, 2000), which threaten their sustainability (Vetter, 2005; Darkoh, 2009) and rural communities whose livelihoods depends on livestock production (Kgosikoma *et al.*, 2013; Sandhage-Hofmann *et al.*, 2015). Communal grazing management systems have faced criticism for their observed rangeland degradation (Smet and Ward, 2005). The Botswana Government in 1975 introduced privately owned ranches (fencing of rangelands) through the Tribal Grazing Land Policy (TGLP) (Botswana Government, 1975; Tsimako, 1991) so as to curb rangeland degradation. However, studies have shown that ranches are similarly as degraded as communal grazing areas (Kgosikoma *et al.*, 2012a). Nonetheless, some studies have shown that rangelands are complex and dynamic (Li and Li, 2012) and those in arid and semi-arid environments are mostly driven by rainfall variability rather than grazing pressure (Westoby *et al.*, 1989).

1.3 The Piosphere Effect

A piosphere is an indicator of localized impact of grazing on vegetation and soil conditions (Egeru *et al.*, 2015b). It has a radiating zone of attenuating animal impact away from a concentrator such as water, feeding stations and kraals (Washington-Allen *et al.*, 2004). These results in herbaceous species composition changes (Tefera *et al.*, 2007) through reduction of palatable herbaceous plant species and increases in unpalatable species (Makhabu *et al.*, 2002; Smet and Ward, 2005) and woody vegetation cover (van Vegten *et al.*, 1984) toward the foci. The establishment of woody plants increases due to access to limited resources such as soil nutrients and moisture (Yanoff and Muldavin, 2008; van Auken, 2009) as herbaceous species are weakened by grazing. High grazing pressure towards concentrators also destroys soil structure and promotes soil compaction through trampling and reduced vegetation cover (Castellano and Valone, 2007; Geissen *et al.*, 2009).

Proper management of rangelands is essential to sustain ecosystem services, and livelihood of pastoral communities. This depends on understanding the effects of different land uses and environmental factors on rangeland dynamics. In Botswana, though communal rangelands are considered degraded, there is limited evidence to suggest that ranches are ecologically sustainable (Kgosikoma *et al.*, 2012a). Comparative analysis of the impact of communal and ranching on rangelands have been widely conducted (Smet and Ward, 2005; Terefa *et al.*, 2010; Kgosikoma *et al.*, 2012a; Kgosikoma *et al.*, 2015). Relationship between land use, soil characteristics and vegetation dynamics are complex and are not fully understood especially around water points. It is unclear whether grazing management systems currently practiced in

Botswana are sustainable (Kgosikoma *et al.*, 2015). There is a need for analysis of relationships between indicators of degradation such as soil, vegetation and distance from water point, management systems and ecological zone effects, to improve our knowledge of rangeland dynamics (van der Heijden and Phillips, 2009). In the present study, the focus was on indicators of long-term degradation in vegetation change due to herbivore activity which vary from vegetation composition to soil quality. The focus specifically was on grass species abundance (decreaser, increaser and invader species), woody species density and soil mineral status due to distance from water sources, grazing management systems and ecological sites. The abundance of the groups gives an idea of the effect of grazing on the rangeland (Smet and Ward, 2005). Woody species density was used as an indicator of bush encroachment (Tolsma *et al.*, 1987; Moleele and Perkins, 1998; Dougill *et al.*, 1999).

1.4 Objective

The objective of the study was to determine vegetation and soil conditions around water points in ranches and communal grazing management systems in the hardveld and sandveld.

1.4.1 Specific Objectives

1.4.1.1 Vegetation conditions

- To determine how grass species abundance and diversity changes with increasing distance from water points.
- To determine whether there is a difference in grass species abundance and diversity under ranching and communal grazing management systems.

- To establish whether grass species abundance and diversity vary between the hardveld and sandveld.
- To determine whether the area around water points are encroached by woody species or not.
- To establish whether woody species density and diversity vary between ranching and communal grazing management systems.
- To determine whether there is a difference in woody species density and diversity between the hardveld and sandveld ecological zones.

1.4.1.2 Soil conditions

- To determine soil pH and minerals at different distances from water points.
- To determine whether there are differences in soil and minerals under ranches and communal grazing systems.
- To establish whether soil pH and minerals vary between the hardveld and sandveld ecological zones.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Rangelands provide many services such as producing forage to feed livestock, improving soil structure (McCallum *et al.*, 2004), controlling runoff and pollution (Dorioz *et al.*, 2006) and maintaining high biodiversity (Ockinger and Smith, 2007; Nawaz *et al.*, 2014). They make up 20% of the world's vegetation cover (Arabaci and Yildiz, 2004). Rangelands play an important role in the delivery of ecosystem goods and services for livelihoods worldwide, with the provisioning of livestock feed being one of the most important services in arid and semiarid savannas (Sandhage-Hofmann *et al.*, 2015).

2.2 Causes of livestock overgrazing

In livestock farming it is vital not to exceed the carrying capacity of rangelands. There must be a balance between number of livestock and area of grazing land. Most studies report overgrazing to be a consequence of overstocking which implies that the carrying capacity of the land was surpassed (Kinlund, 1996). Overstocking can be due to dwindling grazing areas caused by changing the land to arable areas, infrastructure and human settlements due to population increase. Some of the reasons livestock farmers, particularly cattle farmers keep livestock beyond carry capacity are; for prestige, security and cultural obligations, to meet growing meat demand and availability of water resources. Traditionally, cattle are reared as a source of income for the household, to pay for lobola when a male child marries, for security and as measure of wealth. The larger a herd size the more one would be considered wealthy in the community.

However, for others particularly less educated and permanent residents of an area perceive keeping large herds as maximizing the amount of food in the house (Falk, 2008). They pay attention to the fact that kept cows give up to 30L/day of milk, pensioners share the same opinion while employed people do not (Falk, 2008). The narrative is changing as farmers are shifting to keeping cattle for selling however still beyond carrying capacity so as to increase profits. The current increase in human population, urbanization and income growth augment the demand for livestock products (Thornton, 2010). Urbanization has considerable impact on patterns of food consumption in general and on demand for livestock products in particular: urbanization often stimulates improvements in infrastructure, including cold chains, and this allows perishable goods to be traded more widely (Delgado, 2005). Between 1950 and 2000, there was an annual global per capita income growth rate of 2.1% (Maddison, 2003) thus as income grows, so does expenditure on livestock products (Steinfeld *et al.*, 2006). Overstocking can also be caused by increased water supply to livestock. The Kgatleng Beef Producers Association in Botswana reported that increased boreholes and their close proximity to the capital city of Botswana, Gaborone, has caused overstocking, reduced carrying capacity and overgrazing in their areas (Mokwena, 2016). Livestock diseases such as Foot and Mouth Disease (FMD) lead to implementation of control measures that restrict the movement of livestock in or out of the affected areas and this may cause overstocking. The Botswana Ministry of Agriculture blamed FMD for overstocked areas such as the Ngamiland and Bobirwa areas as farmers have nowhere to sell their cattle (Ontebetse, 2013).

2.3 Effects of grazing pressure on grass species biomass production

Grazing pressure is the relationship between animal live weight and forage mass per unit area of the specific unit of land being grazed at any given time (Allen *et al.*, 2011). Generally, grazing removes significant portions of leaf biomass resulting in great reduction in leaf number and total leaf area per plant (Zhao *et al.*, 2009). Grazing is also associated with some plant morphological and physiological responses such as the regeneration of tillers, shorter shoot internodes, compensatory growth, stimulation of the photosynthetic rate, redistribution of carbohydrates and changes of water use efficiency allowing the plants to adapt to defoliation disturbance and more stressful habitats (Nelson, 1996; Doescher *et al.*, 1997; van Staalduinen and Anten, 2005; Peng *et al.*, 2007; Zhao *et al.*, 2008). Grazed plants use reserves from remnant leaves, shoots and roots to generate new leaves for leaf area enlargement and photosynthetic capacity restoration (Reichman and Smith, 1991; van Staalduinen and Anten, 2005; Liu *et al.*, 2007). However, if conditions exceed their tolerance levels due to overgrazing, the plant fails to regenerate leaves and eventually dies. Thus, livestock overgrazing is considered a main cause of rangeland degradation through lowering both the productivity and resilience of host species and reduction of vegetation cover (Mainguet, 1994; Keya, 1998; El-Keblawy *et al.*, 2009; Zhou *et al.*, 2011; Belgacem *et al.*,2013; Kairis *et al.*, 2015).For example, Zhao *et al.* (2009) reported that shoot biomass of *Leymus chinensis* was considerably reduced by grazing which caused the grazed plants not to produce enough new leaves for compensating leaf removal from grazing, thus explained the contrasting differences in the above-ground biomass between the ungrazed and grazed communities of *Leymus chinensis*. Grazing intensity can also be observed to gradually decrease away from a piosphere as herbaceous plant heights increase away from the piosphere (Egeru *et al.*, 2015a).In agreement, Prakash and Paliwal (2012) found that aboveground primary productivity was significantly higher on ungrazed plot (3082.2 kg ha^{-1}) than grazed plot (2644 kg ha^{-1}). Li *et al.* (2011)'s study demonstrated that the grassland above-ground biomass, vegetation cover and height significantly decreased with increased grazing intensity. Heights of palatable species were observed to increase significantly with distance from watering points in the Iranian piospheres (Shahriary *et al.*, 2012).

A study in the El'Ouara rangelands at southern Tunisia found higher biomass productivity in protected area compared to overgrazed area (Gamoun *et al.*, 2010). In addition, within grazed areas selective grazing can influence the composition and structure of the community mainly by modifying the competitive interactions between plants (Olofsson *et al.*, 2001).Selective grazing of palatable plant species by domestic herbivores lead to dominance of the plant community by relatively few unpalatable species accompanied by reduction in species diversity with increasing grazing intensity (Mligo, 2006). Mphinyane *et al.* (2008) found that herbage production of good grass species increased with decreasing stocking rate and was always highest in the 12 ha $LSU^{-1}$and the control area compared to 2, 4, 6, 8 and 10ha LSU^{-1} at Masiatilodi ranch, Botswana . Nsinamwa *et al.* (2005) reported that most annual forb species that favour fertile sites were found around boreholes probably because they were not palatable to cattle, whilst heavy trampling, grazing and eutrophication around boreholes seemed to be working against the establishment of grasses. Increased grazing pressure may limit the following year's production of annuals in rangelands through the depletion of soil seed banks (Hiernaux and Turner, 1996). Severe grazing may reduce both aerial and basal cover of grassland thus increasing evaporation and runoff.

2.4 Effects of grazing pressure on grass species composition and diversity

The occurrence of high plant species richness is indicative of the level of grazing intensity (Mligo, 2006) as grazing intensity produces shifts in vegetation composition through selective grazing. Grazing intensity therefore maintains proportional species diversity in an area through removal of palatable plant species, trampling by hooves, soil compaction and animal excreta deposition (Gibson and Brown, 1992; Nathan *et al.*, 1993; Saberwal, 1996). Al-Rowaily *et al.* (2015) found that cover and density of annuals, grasses, perennial forbs, shrubs and trees were significantly greater in the enclosure than in the overgrazed site. The study further showed that grasses were the most sensitive growth form to overgrazing as they were absent from the overgrazed sites. Heavy grazing pushes the range condition to a degraded status dominated by weedy or unpalatable grass species typical of disturbed areas (Vetter, 2005).This has been supported by various studies done in various parts of Africa particularly around water points (Lusigi and Glaster, 1984; Parsons *et al.*, 1997; Skarpe, 2000; Mligo, 2006; Hoshino *et al.*, 2009). The studies showed that basal cover, proportion of annuals and proportion of unpalatable species were higher in heavily grazed areas than lightly grazed areas (Lusigi and Glaster, 1984; Parsons *et al.*, 1997; Skarpe, 2000; Mligo, 2006; Hoshino *et al.*, 2009). For example, Abdulatife and Ebro (2015)'s study indicated that communal grazing areas of Chifra District of Afar Regional State, Ethiopia, were invaded by less desirable grass species like *Eragrostis teniufolia, Aristida adoenesis, Aristida somalense, Eleusine multiflora, Sporobolus pyramidalis, Tragus berteronianus* and *Brachiaria* species while a single desirable grass species *Chryspogon plumolosus* dominated in the communal grazing areas.

Around water points, grazing pressure decreases with increasing distance away from water points thus detectable changes can be noted on vegetation conditions. For example, in Karamoja, Uganda it was observed that grazing gradient had a significant effect on species composition and abundance at waterhole piospheres (Egeru *et al.*, 2015b). Herbaceous decreaser species *Cynodon nlemfuensis*, *Hyparrhenia rufa*, *Aristida adscensionis*, *Oxytenanthera abyssinica*, *Hyparrhenia filipendula*, *Echinochloa haploclada*, *Chloris pychnothrix* and *Chloris virgata* significantly increased with distance away from the waterhole piosphere (Egeru *et al.*, 2015b). Meanwhile, increaser grass species *Cynodon dactylon*, *Hyparrhenia newtonii*, *Sporobolus pyrimidalis* and *Sporobolus stapfianus* significantly decreased with an increase in distance from the waterhole (Egeru *et al.*, 2015b). Supported by Rajabov (2009) and Teka *et al.* (2013), they also observed differences in herbaceous species abundance and density in the piospheres of Uzbekistan and Southern Ethiopia, respectively.

2.5 Effects of grazing pressure on soil pH and nutrients

Soil quality is defined as the ability of the soil to function (Larson and Pierce, 1991) or the ability of a specific soil to function for a specific use (Mausbach, 1996). In grasslands, soil quality is measured by the soils ability to provide structural support to vegetation, sustain biological diversity and productivity, store water and regulate water movement, and retain and cycle nutrients (Karlen *et al.*, 1997). Because vegetation is frequently removed in grasslands through grazing, soil is of particular interest since re-growth of vegetation depends primarily on soil nutrient content and plant subsoil structures of an area within a given climate (Barbour *et al.*, 1980; Johnson and Matchett, 2001).

Livestock grazing may, however, change the distribution pattern of nutrients in the soil. Estimates vary, but it has been estimated that 80-95% of nutrients eaten by range animals are excreted and returned into the soil, but, not necessarily at the same place where they were eaten (Mphinyane, 2001). There are areas of concentration around which faecal deposits and urination spots are found (Mphinyane, 2001). These areas include; around water points, bedding grounds, mineral licks and areas of level topography or where preferred plants are growing (Lange, 1969; Hyder, 1969; Washington-Allen *et al.*, 2004). Hilder (1966) found that about one third of sheep faeces were deposited on only five to seven percent of the pasture. Animal excreta contain large amounts of nutrients. Mphinyane (2001) found that the concentration of soil nutrients was significantly higher at the first location (0m) than subsequent locations away from a water point. Soil nutrients at sample points 0 m and 150 m were high where the input of dung and urine typically resulted in high values.

Soil organic matter (SOM) is an important component in ecosystem dynamics because of its ability to exchange ions, interact with clay mineral, form soil aggregates, absorb and release plant nutrients and hold water (Caon *et al.*, 2014). Brady (1974) indicated that SOM has great influence on soil properties such as soil colour, structure, plasticity and water holding capacity, cation absorption capacity and the availability of nutrients. Plant and animal decomposition lead to the formation of soil organic carbon (SOC), which is usually scarce in arid regions due to poor vegetation cover and thus the low litter inputs (Schitzer, 1982; Romanya *et al.*, 2007). It is also affected by grazing. Therefore, SOC is one of the indicators included in determining soil fertility. Livestock excretions can promote SOM mineralization rates (McNaughton *et al.*, 1997). According to Klumpp *et al.* (2009) different grazing intensities lead to alterations in SOM and nutrient cycling through litter quality and decomposition. High grazing intensities reduced soil carbon content because of decline in plant cover leading to reduced organic inputs (Lal, 2004; Rutherford and Powrie, 2010) and increased soil erosion (Kgosikoma *et al.*, 2015). A study by Nsinamwa *et al.* (2005) in the hardveld and sandveld communal grazing areas of Botswana showed that organic carbon (OC) significantly decreased with distance from water points at both study sites. Areas close to the water points were subjected to higher livestock densities. Nsinamwa *et al.* (2005) results were in agreement with Mphinyane (2001) findings that indicated significant decrease in OC along the transect away from the water point. In contrast, Milchunas and Lauenroth (1993) reported that the SOC had positive, negative or no responses to grazing.

The soil pH is also affected by livestock grazing through animal movement and excreta (Sheath and Boom, 1985). Typically soils exhibit pH values that range from 4 to 8, although certain soils may have higher or lower values (Mphinyane, 2001). Grasses tend to use more bases, and grasslands often prevent the soil pH from dropping (Barbour *et al.*, 1980). The effect of soil pH on nutrient availability is of particular importance. The availability of nutrients such as nitrogen and phosphorus and the leacheability or solubility of nutrients such as potassium or phosphorus is strongly influenced by soil pH (Mphinyane, 2001). Kgosikoma *et al.* (2015) found that soil pH narrowly ranged between 4.5 and 5.5 and was not significantly associated with grazing management systems (ranching or communal systems). Nsinamwa *et al.* (2005) study showed an increase in soil pH with distance from water points (from 4 to 6) in communal grazing areas. This indicated that the soil acidity increased in areas of high livestock activity, water points, and decreased with distance away from the water points. In contrast, Sandhage-Hofmann *et al.* (2015) found alkaline soils (8.1 and 8.1) close to water points and decreased in alkalinity (6.4 and 6.9) further away from the water point in commercial ranches and communal grazing areas, respectively.

Nitrogen in soil can be present in organic and inorganic forms and may be available or not available for plants (EPA, 2013). Grazing livestock obtain nitrogen from forage plants in the rangeland and as such nitrogen is affected by grazing and other livestock activities. Nitrogen is highly concentrated in animal urine and made available to plants but easily lost through volatilization (Noah *et al.*, 2001). The urine and dung of livestock may accelerate nitrogen cycling in grassland ecosystems (McNaughton *et al.*, 1997). Therefore, areas of high livestock densities are expected to have significant concentrations of soil nitrogen. Li *et al.* (2011) found that soil total nitrogen concentration and soil available nitrogen significantly increased in the high grazed intensity meadow compared to low grazed intensity meadows. The authors attributed the observation to soil compaction (increased bulk density) which reduces the oxygen content and slows decomposition. Stewart and Frank (2008) explained that increased root allocation increased nitrogen retention within the soil. The depositions of nitrogen in root tissues and closed cycling within the root zone have been suggested as mechanisms that increase nitrogen storage (Stewart and Frank, 2008). Additionally, the soil temperatures increase as grazing decreases the litter cover and plant canopy, thereby accelerating the decomposition rate of litter (Vermeire *et al.*, 2005). These findings were in agreement with Abdullah *et al.* (2008) study's that soil fertility indices (SOM, N, P, K^+, Ca^{2+} and Mg^{2+}) were significantly higher in the canopy area of *Acacia raddiana* compared to open areas. Hence, high soil fertility positively correlates with high grass species density.

Soil macro (P, Mg, Na, Ca and K) and micro (Fe, Cu and Zn) elements are also affected by livestock grazing at different intensities and grazing management systems. Phosphorus is significantly affected by grazing history of a site and stage of plant growth (Belsky *et al.*, 1993;

Turner, 1998) particularly in the late growing season (Mark and McCain, 1994). Potassium is recycled through plant intake, animal consumption and manure deposition (NRC, 1996). Mphinyane (2001) found that the continuously grazed areas tended to be significantly higher in P and Ca than the rotationally grazed areas while Na, Mg, K and OC showed no differences between the treatments. In addition, Li *et al.* (2011) found that soil total P and soil available P significantly increased in the high grazed intensity meadow. Macro and micro element concentrations decreased with distance away from water points in both the communal grazing areas of the hardveld and sandveld of Botswana (Nsinamwa *et al.*, 2005). Sandhage-Hofmann *et al.* (2015) reported that contents of Ca, Mg, K and Zn were elevated near the water points in both commercial ranches and communal grazing areas. Furthermore, they noted that the two management systems showed different patterns for nutrients within the grazing gradients.

2.6Effects of grazing pressure on soil physical properties

Soil quality can also be measured by physical properties such as bulk density, aggregate stability,. soil moisture and soil compaction (Doran and Parkin, 1994). Bulk density is the ratio of mass to bulk (volume) of soil (Black and Hartgate, 1986; Redden, 2014).Soils with lower relative bulk density tend to have greater soil structure, greater plant-available water capacity, and higher infiltration rates (Redden, 2014). Bulk density can change with varied grazing intensities and management practices. Proffitt *et al.* (1995) noted that long term grazing causes an increase in soil bulk density accompanied with a decrease of the soil penetration rate and an increase of soil pH rendered soil water more difficult to be utilized by plants resulting in plant physiological aridity. Heavy grazing may cause compaction, reduce water holding capacity and infiltration while increasing bulk density (Branson *et al.*, 1981; Abdel-Magid *et al.*, 1987; Vallentine, 2001).

In contrast, Kgosikoma *et al.* (2015) comparison of soil bulk density between communal grazing areas and ranches failed to show significant differences at all sites of the study. In addition, increased animal trampling did not alter bulk densities within the grazing gradients of both the commercial ranches and communal grazing areas (Sandhage-Hofmann *et al.*, 2015). Generally, hard-hoofed animals cause a major impact on the generally thin soil of the rangelands, particularly when vegetation cover was cleared or where vegetation was subjected to overgrazing (Earl and Jones, 1996). Once grass is removed and soil loosened, sandy soil is easily eroded by strong winds (Fredrickson *et al.*, 1998). In agreement to this, Gamoun *et al.* (2010) found that hoof action reduced the size of naturally occurring soil aggregates and increased density of the surface soil layer. Livestock trampling compacts soil and significantly reduces water infiltration rate (Gamougoun *et al.*, 1984; Abdel-Magid *et al.*, 1987; Schlesinger *et al.*, 1990; Fleischner, 1994; Perevolotsky, 1994; Evans, 1998; Evans, 2000; Amiri, 2008). However, in sandy soils Sandhage-Hofmann *et al.* (2015) found that lack of soil compaction corresponded to the soil's sandy texture and coincided with an absence of aggregate formation.

CHAPTER THREE

THE EFFECTS OF DISTANCE FROM WATER POINTS AND GRAZING MANAGEMENT SYSTEMS ON GRASS SPECIES ABUNDANCE AND WOODY PLANT DENSITY

Abstract

Studies have found that in piospheres, for example where water points are a foci, the magnitude of animal impact on vegetation condition reduces as animals move away from water points. However, not much is known whether the above scenario takes place in different grazing management systems and ecological zones of Botswana. Therefore the objective of this study was to investigate the effects of distance from water points, grazing management systems (ranches and communal grazing areas) and ecological zones (hardveld and sandveld) on grass species abundance, woody plant density, and plant diversity (grass and woody). The study was conducted in the hardveld and sandveld ecological zone. In each zone, 2 ranches and 2 adjacent communal grazing areas were used for the study. A single water point was used as a reference point for 4 randomly placed transects of 1000m in length radiating in different directions from the water source. Each transect had 4 plots measuring 50mx20m placed at 250m intervals. Within the 50mx20m plot, grass species abundance was estimated in a 10mx10m plot while woody plant density was estimated in the 50mx20m plots. Grass and woody species were estimated by identification, counting and recording of individual species in a total of 16 survey plots at each site. The Shannon-Wiener Index was used to calculate plant species diversity. Total grass species abundance, woody plant density and plant diversity were not affected by distance from water points ($P>0.05$). Grazing management systems also did not affect total grass species abundance and woody plant density ($P>0.05$). However, strong perennials, decreaser, increaser I, good and poor palatable grass species abundances were significantly higher in ranches compared to communal grazing areas ($P<0.05$). Grass and woody species diversities were higher in ranches than in communal grazing areas ($P<0.05$). Woody plant density, total grass species, strong and weak perennial, decreaser, increaser I, increaser II, high, moderate and poor palatable grass species abundances were higher in the hardveld than the sandveld ($P<0.05$). Woody plant diversity differed between ecological zones ($P>0.0001$) whereas grass species diversity did not vary between them ($P=0.32$). Woody plant diversity in the sandveld (1.78±0.06) was higher than in the hardveld (1.29±0.06). The conclusions drawn from this study were, 1) distance from water points as a measure of livestock grazing pressure did not cause any changes in vegetation conditions 2) ranching grazing management system is better than communal grazing system in conserving good grass species abundances and diversity, and 3) the hardveld is better than the sandveld in providing better growing conditions for higher grass species abundances especially those highly preferred by livestock.

3.1 Introduction

Livestock production in arid and semi-arid rangelands relies on the availability of water and forage for sustenance (Awa *et al.*, 2002; Egeru *et al.*, 2015b). Proximity to water sources and feed availability are key determinants of livestock grazing (Ash *et al.*, 2004; Bailey and Provenza, 2008). Livestock grazing is vital in shaping and maintaining grasslands and savannas (van Langevelde *et al.*, 2003), as this can manifest in various ways including altering plant community composition and diversity (Belsky, 1992; Augustine and McNaughton, 1998). These changes have impacts on forage production, soil, hydrologic and carbon cycling (Jackson *et al.*, 2002). Examining grazing effects on the above variables aids in the evaluation of long term sustainability of grazing management systems and estimate the impacts on livestock production (Allred *et al.*, 2012). The investigation of grazing effects is therefore fitting to start at a key determinant such as water.

The scarcity of surface water in rangelands led to the introduction of artificial water sources (boreholes) (Mpinyane, 2001; Nsinamwa, 2005). These water sources introduced focused grazing and activity patterns around them and studies have reported their significant ecological effects (Mpinyane, 2001; Makhabu *et al.*, 2002; Nsinamwa, 2005; Brooks *et al.*, 2006, Egeru *et al.*, 2015b). Lange (1969) termed these activity patterns a piosphere. Areas close to a foci are said to experience high grazing pressure and trampling as animals congregate at a reduced area for water, causing changes in vegetation and soil conditions over time. The magnitude of impact reduces as animals move away from the water point as area of impact increases. Therefore piospheres can be divided into areas showing the intensity of grazing and the effects of different grazing intensities on vegetation can be evident. For example, areas far from water points are in most cases lightly grazed sites. These sites are characterized by high grass species richness dominated by perennial grasses compared with heavily grazed sites that are dominated by annuals (Tesseman *et al.*, 2011). This is so because, heavy grazing reduces the growth and reproductive rate of perennial grasses which influences the competitive relationships among the different species (Bilotta *et al.*, 2007).Heavily grazed perennial grass species loose competitive power compared with the lightly grazed species, and subsequently unpalatable and grazing tolerant annual species become dominant in heavily grazed areas. Sarmiento (1992) reported a reduction in the abundance of highly palatable grass sward under heavily grazed African savannas. Tesseman *et al.* (2011) observed that heavy grazing leads to excessive defoliation of annual and perennial grasses and has implications on species diversity and abundance in the semi-arid savanna of Ethiopia.

The above phenomenon has been observed between herbaceous and woody species. Grazing also reduces the competitive ability of grasses with tree saplings (Archer, 1994; Riginos, 2009), increasing woody species density. In semi-arid ecosystems, continual increase in woody species density beyond a critical density suppresses herbaceous growth and productivity (Richter *et al.*, 2001). Grasses out-compete trees in open savannas by growing fast and intercepting moisture from the upper soil layers, thus preventing trees from gaining access to moisture in the lower soil layers where their roots are mostly found (Ritcher *et al.*, 2001). In heavily grazed areas, grasses are removed and soil moisture becomes available to trees allowing them to grow, recruit and expand (Scholes and Archer, 1997; Richter *et al.*, 2001). However, Browning and Archer (2011) and Allred *et al.* (2012) have found contradicting results that showed no increase in shrub and tree cover under grazing and non-grazing areas suggesting that other factors or a combination of factors were responsible for woody plant species encroachment.

In general, changes in vegetation conditions along a distance gradient within a piosphere have been shown to exist in some rangeland management systems (Mphinyane, 2001; Makhabu *et al.*, 2002; Smet and Ward, 2005; Nsinamwa *et al.*, 2005). Nonetheless, the communal grazing management system has been blamed for rangeland degradation particularly in Botswana (Government Paper No. 1, 1991). Farmers in the communal grazing management system make more than 80% of livestock producers in Botswana (Statistics Botswana, 2014). The Government of Botswana in the 1970's introduced the Tribal Grazing Land Policy (TGLP) to curb rangeland degradation through fencing of grazing land with the aim that ranches would promote proper utilization of rangeland resources and limit degradation (Botswana Government, 1975). However, some studies in Botswana have revealed that rangeland degradation occurs in ranches than in communal grazing areas (Kgosikoma *et al.*, 2012a) while some report that it occurs similarly in both grazing management systems (Kgosikoma *et al.*, 2012b). There are studies in Botswana that have investigated vegetation conditions around water points (Mphinyane, 2001; Makhabu *et al.*, 2002; Nsinamwa et al., 2005) but did not cover the main grazing management systems in their respective ecological zones. Information is scanty regarding grass species abundance and woody plant density changes around water points in ranching and communal grazing management systems, respectively. Moreover, information is lacking in measuring these variables around water points in both grazing management systems in the hardveld and sandveld, respectively. Therefore this study was aimed at investigating grass species abundance, woody plant density and plant diversity around water points, in ranching and communal grazing management systems in the hardveld and sandveld ecological zones. Grazing intensity was measured by distance from water points, thus intensity increased as livestock moved closer for water.

3.2 Materials and Methods

3.2.1 Study areas

The study areas were located in ranches and adjacent communal grazing areas in the hardveld and sandveld ecological zones of Botswana. The hardveld stretches along the Limpopo far eastward of Botswana, covering areas of south of Kgatleng, east of Central and the North East districts (Figure 3.1). The sandveld covers almost three quarters of the country from the Kgalagadi, Ghanzi, north of the Kweneng and to the west of the Central districts (Figure 3.1). At each ecological zone, a total of two ranches and their adjacent communal grazing areas were used as study areas. Ranches refer to fenced grazing areas that are privately grazed and owned by individuals or groups of farmers, while communal grazing system is the shared use of rangeland in tribal lands by pastoral communities (Masike and Urich, 2008). Ranching is a commercial oriented production system and mostly focused on one or few livestock species (Kgosikoma *et al.*, 2012b). On the contrary, communal grazing system largely reflects traditional subsistence farming in which diverse livestock species are reared (Wigley *et al.*, 2010). The two grazing management systems are expected to have different impact on vegetation conditions due to differences on grazing pressure, the browser/grazer ratio and fire management practice (Wigley *et al.*, 2010).

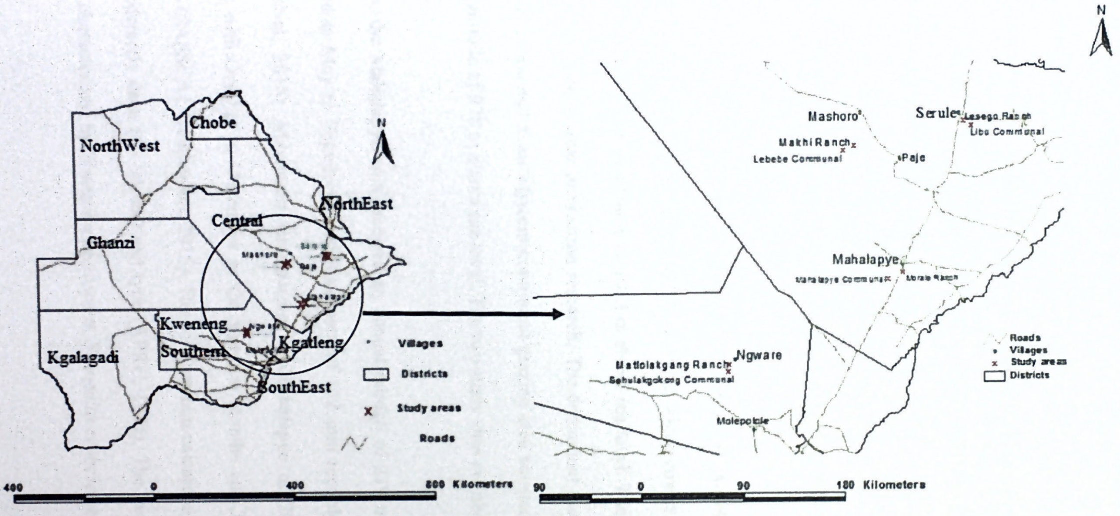

Figure 3.1: Location of study areas/sites.

3.2.1.1 Description of study areas

3.2.1.1.1 Hardveld

The hardveld receives 400-450 mm annual rainfall, with temperatures as high as 38^{0}C during the wet season (Parida *et al.*, 2006).Soils are mainly sandy loams to sandy clay loams, with shallow skeletal soils where heavy, sporadic rainfall washes newly formed soil materials into low lying areas and down drainage lines (Burgess, 2006). The soils are thus mainly alluvial. The area is characterized by surface water sources for example, rivers and dams.

In the hardveld, the study areas were on the peripheries of Mahalapye and Serule villages. In Mahalapye, the study was conducted at Morale ranch which covers 1622 ha and situated around 23°10'S and 26°49'E at an altitude of 1013 m above sea level. The ranch is used for beef cattle production and dairy goat production research. The communal management system part of the study was conducted at an adjacent communal grazing area situated around 23°13' S and 26°42' E at an altitude of 978 m above sea level. The two study sites are about 15 km apart.

In 2014, the Mahalapye area received an annual rainfall of 319 mm, with minimum of 0 mm recorded in May to September and maximum of 132 mm recorded in December (SASSCAL weatherNet, 2016). Maximum temperatures in Mahalapye of 2014 ranged from 13.8^{0}C to 24.4^{0}C, with October to December as the warmest months and June and July as the coldest months (SASSCAL weatherNet, 2016). The soils are non-calcareous, coarse loamy, well drained and moderately deep (60-90 cm) soil type (APRU, 1984). The vegetation type is tree savanna mainly characterized by *Senegalia nigrescens*, *Senegalia erubescens* and *Combretum apiculatum*

Table 4.2: Effects of ecological zones on mineral elements

	Elements	Hardveld	Sandveld	F-value	Pr>F
Macro	Mg	1.28±0.07	0.56±0.07	49.69	<.0001
(cmol/kg)	Ca	469.91±4.19	465.85±4.19	0.47	0.50
	K	0.0089±0.01	0.0063±0.01	15.90	0.0002
	Na	0.0053±0.001	0.0075±0.001	2.59	0.11
	P(mg/kg)	5.18±0.16	0.03±0.16	511.95	<.0001
	N (%)	0.10±0.02	0.17±0.02	4.21	0.04
Micro	Zn	2.80±0.38	1.95±0.38	2.42	0.1255
(ppm)	Fe	82.72±6.00	41.66±6.00	23.41	<.0001
	Mn	85.09±6.49	18.91±6.49	52.00	<.0001
	Cu	8.52±0.96	1.53±0.96	26.43	<.0001

Ca-calcium, Cu-copper, Fe-iron, K-potassium, Mg-magnesium, Mn-manganese, N-nitrogen, Na-sodium, P-phosphorus, Zn-zinc

4.3.4 Interactive effects of distance from water points, grazing management systems and ecological zones on soil pH and mineral elements

The 3-way interaction (distance*system*zone) and 2-way interactions (distance*system) and (distance*zone) did not significantly affect soil pH and mineral concentrations (P>0.05). However, the zone*system interaction affected (P<0.05) the concentration of soil potassium, phosphorus, iron and copper (Table 4.3). Mean separation was conducted using the Tukey's procedure to show specific significant interactions within the zone*system interaction.

Table 4.3: Effect of zone*system interactions on soil elements

		Hardveld		Sandveld			
	Elements	Communals	Ranches	Communals	Ranches	F-value	Pr>F
Macro	Mg	0.9957±0.010	1.5737±0.010	0.35±0.010	0.74±0.01	0.60	0.44
cmol/kg)	Ca	461.965±5.92	477.855±5.92	469.25±5.92	462.45±5.92	3.67	0.06
	K	0.0084±0.0006	0.0093±0.0006	0.0073±0.0006	0.0053±0.0006	5.45	**0.02**
	Na	0.0062±0.0012	0.0051±0.0012	0.0096±0.0012	0.0055±0.0012	1.71	0.18
	P(mg/kg)	4.1119±0.23	6.2394±0.21	0.02663±0.23	0.035±0.23	22.05	**<0.0001**
	N (%)	0.1133±0.03	0.09056±0.03	0.2502±0.03	0.094±0.03	3.77	0.06
Micro	Zn	1.85±0.54	3.74±0.54	1.17±0.54	2.74±0.54	0.09	0.76
ppm)	Fe	74.078±8.48	91.36±8.48	50.61±8.48	32.72±8.49	4.30	**0.04**
Micro	Mn	80.94±9.18	89.22±9.18	33.27±9.18	4.54±9.18	4.07	0.05
ppm)	Cu	5.04±1.36	11.99±1.3593	2.57±1.36	0.49±1.36	11.05	**0.0016**

Ca-calcium, Cu-copper, Fe-iron, K-potassium, Mg-magnesium, Mn-manganese, N-nitrogen, Na-sodium, P-phosphorus, Zn-zinc

4.4 Discussion

4.4.1 Comparison of soil pH and mineral elements between areas near (250 m) and those far (1000 m) from water points

Areas around water points are subjected to higher densities of livestock than areas further from them, hence the likelihood of increased macro and micro elements due to animal excreta around water points (Fernandez-Gimenez and Allen-Diaz, 2001; Nsinamwa *et al.*, 2005; Smet and Ward, 2006; Sasaki *et al.*, 2008; Shahriary *et al.*, 2012). Nsinamwa *et al.* (2005) reported that acidity (pH), macro (P, Mg, Ca, K) and micro (Zn, Fe, Cu) elements decreased with distance from water points. Sandhage-Hofmann *et al.* (2015) found that pH, Ca, Mg, K and Zn were elevated near water points. Moreover, along the grazing gradient the P contents decreased with increasing distance from water points (Sandhage-Hofmann *et al.*, 2015).In contrast, the current study found that macro (P, N, Mg, K, Na) and micro (Zn, Fe, Cu) did not differ near and further from water points. The interaction effects (distance*system, distance*zone and distance*system*zone) also did not affect soil pH and minerals. Consistent with the current study, Gebremeskel and Pieterse (2007) found no noticeable trend in the concentration of exchangeable Ca^{2+}, Mg^{2+} and K^{+} along the grazing gradient away from the watering point but noticed an increase for Na^{+} concentration along the grazing gradient toward the water source. Furthermore, Katjiua and Ward (2012) reported that distance from water points did not affect P and total N concentrations. In addition in the present study, soil acidity and calcium content were significantly increased at points 1000 m and at 250 m away from water sources, respectively. The higher Ca content could be due to dung deposition by cattle supplemented with Di-calcium phosphate mineral licks. In addition, more dung is deposited near water points than further from them as livestock congregate for water. Katjiua and Ward (2012) using the Scheffe *post hoc* test reported high P at 10-20 cm depth, 200 m away from a borehole probably due to dung deposition by cattle supplemented by phosphorus licks. Mineral supplementation is an integral component in livestock production in Botswana as calcium and phosphorus are generally low in the Kalahari environment (Mendelsohn *et al.*, 2002).

4.4.2 Effects of grazing management systems on soil pH and minerals

In Botswana, communal grazing systems generally have increased grazing pressure due to high cattle densities compared to ranches. Therefore major soil changes are expected to occur more in communal grazing areas than ranches. For example, Sasaki *et al.* (2008) and Zemmrich *et al.* (2010) observed that soil pH tends to respond positively to increased grazing pressure. In the current study, soils at communal grazing systems were significantly acidic than soils at ranching systems. In contrast, Moussa *et al.* (2008) found no differences in soil pH between grazed and ungrazed rangelands in Bophirima district, South Africa. Soil pH was not significantly different between heavily and moderately grazed North American rangelands (Liebig *et al.*, 2006). In addition, Kgosikoma *et al.* (2015) also reported that soil pH was not statistically different between communal and ranching grazing management systems in Botswana.

Ranching grazing management systems had significantly high Mg, P and Zn contents than communal grazing systems. Sandhage-Hofmann *et al.* (2015) observed significantly higher Zn contents in ranches than communal grazing management systems. High concentrations for soil P at the commercial farms near the water points were likely due to supplementary feeding given to the cattle (Smet and Ward, 2006; O'Halloran *et al.*, 2010; Kotze *et al.*, 2013).In the current study communal grazing systems were observed to have increased contents of K and N. Significant variations in Mg and total N were observed in heavily grazed rangelands of Missouri Plateau (Liebig *et al.*, 2006). In general, in the current study communal grazing areas had low soil mineral in half of the analyzed minerals (Mg, Ca, P, Zn and Cu). In support to these findings Sandhage-Hofmann *et al.* (2015)'s study reported that communal systems showed lower nutrient levels in Mg, Ca, P, Zn and Cu than commercial farms. In rangelands, it has been generally acknowledged that high grazing pressure reduces the growth rate and reproductive potential of individual grass plants, which has led to the nutrient status of soils being depleted, as seen under poor rangeland conditions of the communal grazing management systems (Abule *et al.*, 2005; Kotze *et al.*, 2013) as observed in the current study.

4.4.3 Effects of ecological zone on soil pH and minerals

No variations in soil pH were observed between the hardveld and sandveld ecological zones. The results contrasted with those by Nsinamwa *et al.* (2005) who found the hardveld to be significantly acidic than the sandveld. The difference in the two studies is that, soils in the sandveld were found to be more acidic than the period Nsinamwa *et al.* (2005) reported. In the current study variations in Mg, K, P, N, Fe, Mn and Cu between the hardveld and sandveld were observed. The hardveld had higher mineral contents than the sandveld except for N content. Generally, soils in the hardveld were higher in nutrient content that those of the sandveld as was found by Nsinamwa *et al.* (2005) probably due to poor soil fertility of the area. A study on soil fertility by Ramolemana and Machacha (2000) indicated that soils in the sandveld were deficient in phosphorus compared to those in the hardveld a result supported by the present study. The variation in soil elements between the ecological zones could likely be due to inherent diversity and parent materials in the hardveld (De Wit and Becker, 1990; Thomas and Shaw, 1991). The sandveld soils typically consist of over 95% fine sand-sized aelion-deposited sediment (Thomas and Shaw, 1991) and are predominantly deep, structure-less and lacking in N and P (Perkins and Thomas, 1993; Dougill *et al.*, 1998). The high proportion of sand encourages leaching of the nutrients that in turn contributes to low fertility (Sarah, 2006).

4.5 Conclusion

Soil acidity was high at distances further away from water points in communal grazing management systems and was similar in the hardveld and sandveld ecological zones. In general, most of the soil minerals (Cu, Fe, K, Mg, Mn, N, Na, P and Zn) studied were similar between distances from water points. Calcium content was found to be higher near water points than far from them. Ranching management systems had higher contents of Mg, Na and Zn than communal grazing management systems. Communal grazing systems were found to have higher contents of P and N. Mg, K, P, Fe, Mn and Cu were higher in the hardveld than sandveld. The sandveld ecological zone had higher N content than the hardveld. It is therefore vital for livestock producers in the communal grazing system in hardveld and in both ranches and communal grazing system in the sandveld ecological zone to give their livestock mineral supplements so as to increase mineral availability to livestock.

CHAPTER FIVE

5.1 General conclusion

Grass species abundance, woody plant density and grass and woody species diversity were similar around water points in both grazing management systems and ecological zones. Soil acidity was high at distances further away from water points and soil mineral status was similar between distances from water points. Strong perennial, decreaser, and highly palatable grass species were significantly higher in ranching than in communal grazing management system. Annuals, increasers and unpalatable grasses dominated communal grazing areas. Though insignificant, higher woody species density and diversity were observed in ranching management systems compared to communal grazing system. Ranching management system had higher contents of Mg, Na and Zn than communal management system. Communal management system were found to have higher contents of P and N. Increased grass abundance and woody plants density and diversity were found in the hardveld than in the sandveld. All grass categories were higher in the hardveld than sandveld. Mg, K, P, Fe, Mn and Cu contents were higher in the hardveld than sandveld. The sandveld ecological zone had higher N content than the hardveld. The higher number of palatable species found in the hardveld than the sandveld could be attributed to higher soil mineral status found in the hardveld than sandveld. Therefore, is necessary for livestock producers in the sandveld communal grazing system to give their livestock mineral supplements so as to increase mineral availability to livestock. Furthermore, the results suggest that ranching should be practiced in the sandveld and communal grazing areas in the hardveld provided there are stocked conservatively.

CHAPTER SIX

6.1 References

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6.2 Appendix

Table 1: Ecological zone and grazing management system interaction mean differences

Variable	Interaction	Mean difference (plants/100m²± SE)
Weak perennial grass abundance	HvC*HvR	10.6493±5.3984
	HvC*SvC	26.3021±5.6985*
	HvC*SvR	18.9896±5.3984*
	HvR*SvC	15.6528±5.1618*
	HvR*SvR	8.3403±4.8285
	SvC*SvR	-7.3125±5.1618
Strong perennial grass abundance	HvC*HvR	-15.0774±5.1911*
	HvC*SvC	4.3423±5.1911
	HvC*SvR	3.5069±4.9177
	HvR*SvC	19.4196±4.9874*
	HvR*SvR	18.5843±4.7022*
	SvC*SvR	-0.8353±4.7022
Decreaser grass abundance	HvC*HvR	-21.3065±5.8382*
	HvC*SvC	7.1417±6.3543
	HvC*SvR	2.4896±6.0585
	HvR*SvC	28.4482±6.1445
	HvR*SvR	23.7961±5.8382*
	SvC*SvR	-4.6521±6.3543
Increaser I grass abundance	HvC*HvR	-12.0938±2.6462*
	HvC*SvC	0.1771±2.4156
	HvC*SvR	0.1250±2.6462
	HvR*SvC	12.2708±2.4156*
	HvR*SvR	12.2187±2.6462*
	SvC*SvR	-0.05208±2.4156
Increaser II grass abundance	HvC*HvR	8.5795±3.1774
	HvC*SvC	13.7500±3.1222*
	HvC*SvR	10.9148±3.0730*
	HvR*SvC	5.1705±3.1774
	HvR*SvR	2.3354±3.1291
	SvC*SvR	-2.8352±3.0730
High palatable grass abundance	HvC*HvR	-21.3065±5.8382*
	HvC*SvC	7.1417±6.3543
	HvC*SvR	2.4896±6.0585
	HvR*SvC	28.4482±6.1445*
	HvR*SvR	23.7961±5.8382*
	SvC*SvR	-4.6521±6.3543
Low palatable grass abundance	HvC*HvR	10.9292±3.7086*

Variable	Interaction	Mean difference (plants/100m^2± SE)
	HvC*SvC	11.5303±3.1083*
	HvC*SvR	10.6383±3.1083*
	HvR*SvC	0.6011±3.3033
	HvR*SvR	-0.2909±3.3033
	SvC*SvR	-0.8920±2.6115

*Significant (Tukey, $P<0.05$), HvC-hardveld communal grazing systems, HvR-hardveld ranches, SvC-sandveld communal grazing systems, SvR-sandveld ranches

Table 2: Significant effects of zone*system interactions on soil elements

	Elements	Zone*System interactions	Mean difference ±SE
Macro	K(cmol/kg)	HvC*HvR	-0.0009±0.0009
		HvC*SvC	0.00105±0.0009
		HvC*SvR	0.0031±0.0009*
		HvR*SvC	0.00198±0.0009
		HvR*SvR	0.0040±0.0009*
		SvC*SvR	0.00204±0.0009
	P(mg/kg)	HvC*HvR	-2.1275±0.3216*
		HvC*SvC	4.0853±0.3216*
		HvC*SvR	4.0774±0.3216*
		HvR*SvC	6.2128±0.3216*
		HvR*SvR	6.2049±0.3216*
		SvC*SvR	-0.00794±0.3216
Micro (ppm)	Fe	HvC*HvR	-17.2800±11.9995
		HvC*SvC	23.4675±11.9995
		HvC*SvR	41.3600±11.9995*
		HvR*SvC	40.7475±11.9995*
		HvR*SvR	58.6400±11.9995*
		SvC*SvR	17.8925±11.9995
	Cu	HvC*HvR	-6.9555±1.9223*
		HvC*SvC	2.4693±1.9223
		HvC*SvR	4.5511±1.9223
		HvR*SvC	9.4248±1.9223*
		HvR*SvR	11.5066±1.9223*
		SvC*SvR	2.0819±1.9223

Significant ($P<0.05$), Cu-copper, Fe-iron, HvC- hardveld communal grazing systems, HvR-hardveld ranching systems, K-potassium, P-phosphorus, SvC- sandveld communal grazing systems, SvR- sandveld ranching systems