OPTIMAL SPATIAL AND TEMPORAL UTILIZATION OF GRASSLAND RESOURCES FOR EXTENSIVE LIVESTOCK PRODUCTION

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ABSTRACT

South Africa naturally experiences variation in rainfall patterns with distinct seasonal distribution. The anticipated disruptive effects of climate change, in this region, on vegetation dynamics is likely to accentuate the impact of seasonal forage nutrient fluctuations on livestock production. Although there are several grazing philosophies that have been adopted to mitigate these constraints (continuous and variations of rotational grazing systems), debates on superiority between these systems continue to be of interest to researchers and livestock producers. Nonetheless, continuous grazing systems have largely been condemned due to the detrimental effects of extensive selective grazing on vegetation composition and soil conservation. Poor implementation of these systems has resulted in extensive veld degradation, significantly reducing sustainability of livestock production. This is more pronounced in communal rangelands where production capital is limited. Moreover, erratic rainfall and extreme temperatures have resulted in the abandonment of large areas of croplands, and thus further impacting negatively on livestock production dynamics.

Therefore, it is necessary to quantify utilization regimes of the abandoned crop lands, continuously and rotationally grazed veld and examine their effects on ecosystem health and livestock production. To examine these effects, a study was conducted in Mzongwana, Matatiele (old lands and continuously grazed veld) and in Wakefield Research Farm, Fort Nottingham (rotationally grazed veld). In each site, six 100m line-transects were laid and a 0.5 by 0.5m quadrat were placed in 2m intervals along each transect. In each quadrat, sampling for species composition, biomass accumulation, and bulk forage quality were sampled. Along each transect, soil samples were collected at 0-15cm depth at 25m intervals and analysed for soil fertility. To examine the influence of forage utilisation intensities, as affected by the previous management, seasonal nutrient dynamics, data were collected during summer (November, January, and April) and during winter (June and August).

The results revealed that species composition and biomass accumulation had a direct influence on forage quality, while grazing systems mostly affected soil fertility. Additionally, the results confirmed that previous cultivation has a negative effect on soil organic carbon (C) and nitrogen (N) concentrations, and revealed a significantly high mineral variation between seasons. These variations were also evident in the nutrient accumulation in the forage, with distinctively high crude protein (CP) and low acid detergent fibre (ADF) and neutral detergent fibre (NDF) in early summer. Therefore, to effectively utilize the old lands towards improved livestock production, grazing should be during early to mid-summer. On the other hand, despite soil nitrogen in the continuously grazed site being lower than the rotationally grazed site, CP was significantly higher and steadily declined over the season. Therefore, suggesting that biomass accumulation has a negative influence on forage quality. Moreover, lower forage quality in the rotationally grazed veld was largely attributed to extended rest periods which allowed grass to mature, thus reducing the overall quality.

Based on these findings, it can therefore, be recommended that the old lands be grazed during the early to mid-summer and rested during late-summer. This will improve nutrient availability for livestock and will allow for seeding rest to improve succession rate. Moreover, the continuously grazed veld is recommended to be grazed interchangeably with the old land, that is, in winter. As a result of slow crude protein decline in the continuously grazed veld, grazing in winter will improve livestock morbidity and mortality resulting from low forage availability. Finally, in the rotationally grazed veld high intensity grazing should be incorporated in the grazing systems employed to reduce biomass carryover and keep forage low and nutritious, as this veld in a high rainfall area.

Keywords: Old lands, continuous grazing, rotational grazing, species composition, soil fertility, forage quality, biomass

DECLARATION

I hereby declare that this dissertation, and the associated research, is my original work and has not been submitted by me to any other University. Research leading to the production of this work was conducted under the supervision of Kevin P. Kirkman, and all assistance and reviews used herein have been duly accredited.

X ______________________________

Ntomboxolo Mamayo

(Miss)

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Date

(DD/MM/YYY)

Approved as to style and content by:

X ______________________________

Kevin P. Kirkman

Supervisor

DEDICATION

This work is dedicated to young African women whose future is masked by troubles of the present and whose hope has been erased by the broken society we live in. I wish to extend this dedication to my Father (Fezekile Mamayo) and to my wonderful daughter (Alunamida Iyabuya Mamayo), I hope this leaves a traceable trail for you my darling.

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CHAPTER 1: INTRODUCTION

1.1 Background information

Grasslands occupy approximately 40% of the earth's surface and provide numerous ecosystem services essential for sustainable livelihoods (Egoh *et al*., 2011). With poor management, grasslands are vulnerable to recruiting bush/trees at the expense of the underlying herbaceous layer, and thus, changing to a savanna and/or forest. Of the Africa savanna, 43 million hectares occurs in South Africa and 84% of this is used for livestock farming (Hudak, 1999).

Veld dynamics are significantly influenced by the previous land use management (Grossman *et al*., 1999). In addition, Conant *et al*. (2001), suggested that improving land use management with the intention to increase forage production and soil carbon levels are likely to increase, increasing the soil organic matter levels. Furthermore, adequate levels of soil organic matter are very important in reducing erosion and improving soil aggregation, cation exchange and water holding capacity (Miller and Donahue, 1990) which are of great importance, especially, in the maintenance of semi-arid grasslands. Moreover, soil organic matter is significantly reduced by intensive cultivation (Kern, 1994), and

Continuous overgrazing year after year can make it almost impossible to sustain a productive livestock herd, by reducing vegetation productivity and quality, and limiting the forage availability during the dry season (Jacobo *et al*., 2006). To address such problems, nutritional stress during the dry season can be compensated by conserving excess feed during growing seasons (e.g. foggage, hay, and silage) and mineral supplementation. These feed conservation strategies have proven to be the best ways to provide yearlong forage and sustain productivity in commercial production systems when good grazing is limited. However, those with few to no resources, such as communal and emerging farmers, continue to struggle. The extent of continuous overgrazing, particularly in communal regions, has led to many studies comparing continuous to rotational grazing system to bridge forage availability and quality gaps throughout the grazing season (Mcllvain and Savage, 1951; Heady, 1961; Walton *et al*., 1981; Heitschmidt *et al*., 1987;). Heady (1961) argued that rotational grazing increases vegetation diversity, but Heitschmidt *et al*. (1987) pointed out that differences in available forage quality and quantity are mainly a result of stocking rates and not necessarily the grazing systems employed. In contrast, continuous grazing systems at appropriate stocking rates have been shown to be superior to the rotational grazing systems in animal gains per year (Mcllvain and

Savage, 1951), as they allow animals to graze and select species that are more nutritious as opposed to being forced to graze on undesirable species (as in rotational grazing system).

Van der Wal *et al.* (2000) and Van Beest *et al*. (2010) noted that forage quality declines over the growing season while quantity increases as the growing season progresses. The quality-quantity shift, therefore, forces the livestock to compensate for reduced forage quality by increasing their intake by increasing time spent grazing.

1.2 Problem statement

Over the years livestock production potential in savannas and grasslands has declined with increases in livestock production intensity across the world (Walker, 1981; Hutley and Setterfield, 2018). Rapid population increase in recent years accelerated deterioration of the grazing lands by increased demand for agricultural produce (Fynn, 1998). Due to population increases, livestock numbers have surpassed the carrying capacity of the grazing land leading to veld degradation.

Generally, South Africa's climate is characterised by clearly defined warm-wet summers and cool-dry winter, leading to variability in forage quality and quantity over the year. During winter, herbivory nutrient requirements to sustain growth, lactation and for maintenance exceeds forage nutrients and availability. According to Tainton (1999), even veld in good condition does not provide enough quality forage for optimum livestock production, hence it is important to efficiently manage grazing.

Seasonally crude protein and fiber along with other minerals fluctuate, and the most significant variability is between the dormant and growing season. In general, South Africa's soils have a low nutrient status which may lead to low overall forage quality. In addition, Corre *et al.* (2002) argued that quality variations between seasons are most noticeable in areas where grasslands are unfertilized and the primary source of nitrogen (N) is the atmosphere. This is the situation in most communal farming systems of South Africa and is extremely aggravated by poor veld management.

Moreover, climate change has elevated the extent of seasonal forage dynamics through more erratic rainfall distribution. In addition, changes in rainfall distribution exacerbate the factors that have increased cropland abandonment globally (Ramankutty and Foley, 1999). This largely affects emerging and communal farmer in semi-arid regions of Africa, commonly leading to increasing livestock dependence, although, Ramankutty and Foley (1999) reported less cropland abandonment in Africa relative to other continents. However, their findings were based on data collected between 1700 and 1992 and abandonment has significantly increased in South Africa in the last few decades and in old lands generally revert to grasslands (Ramankutty *et al*., 2002). However, reduced soil organic matter (SOM), N and organic C have been reported as a result of cultivation (Powlson, 1980; Saviozzi *et al*., 2001; Evrendilek *et al*., 2004), leading to low forage quality on conversion from cropland to grassland.

1.3 Justification

Due to the above challenges, it is necessary to provide quantitative data on the seasonal dynamics of forage nutrients old lands, continuously overgrazed veld and rotational grazing communal rangelands. This information will allow for traditional grazing systems to evolve and improve grazing management of old lands and ultimately improving livestock production. Communal farmers have insufficient knowledge on the nutritive status of their rangelands and as a result, they continuously develop un-informed supplementation plans, leading to unnecessary costs and/or poor winter feed supplementation. Amongst other things, low herd productivity is one of the most persistent problems in communal farms, therefore lack of knowledge on seasonal forage dynamics in different sward communities only makes these problems worse.

With increasing abandonment of cultivated lands in communal areas, it is then of great importance to quantify forage quality dynamics and trace soil fertility to enhance management practices for improved livestock production in these areas.

In general, the study provides quantitative information variations on nutrient availability between the seasons and assist in developing a grazing plan incorporating old lands and improve resting programs. Effective utilisation of old lands is important as they form a large proportion of the landscape in the region and are substantially unstable. This study largely contribute towards improving herd productivity in communal and emerging farmers, by providing knowledge on the relationship between available forage nutrition (diet) and soil health. In addition, the results of this study influence the developing of profound winter supplementation and reduce unnecessary expenses. Sufficient knowledge in the dynamics of veld nutrition and health is very important to improve the competitiveness of emerging and communal farmers in the beef industry.

1.4 Objectives

Short-term objectives:

- Investigate the relationships between previous land use history; and species composition, grazing management, forage quality and quantity.

Long-term objectives

- To examine the grazing management in the natural veld of South Africa
- To provide utilization regimes of the old lands for efficient livestock production in communal communities

1.5 Research questions

- Can utilization regimes of the continuously grazed veld sustain livestock production throughout the year?
- Can the forage utilization pattern of the rotationally grazed veld maintain low seasonal nutrient dynamics throughout the year?
- Can strategic utilisation of old lands efficiently contribute to increased livestock production?

1.6 Dissertation Outline

- Introduction
  - Background information
  - Problem statement
  - Justification
  - Objectives
  - Research questions
- Literature review
  - Introduction
  - Theory base and general literature review
- Three individual experimental chapters
  - Introduction
  - Methodology (The methods and analysis may be repeated in all chapters)

- Presentation of results
- Discussion
- Sub-conclusions

- Integration and synthesis of data from the three study sites
  - Graphs are presented to compare the results from the 3 chapter
  - Summarised discussion of findings
  - Conclusion
- General Conclusions

The study sites have been dealt with in separate chapters, as the objectives were not to directly compare sites and grazing systems, but to study each grazing system in detail and then consider how the available resources in the communal grazing areas can best be utilised for sustainable livestock production.

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CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The natural veld in South Africa is deteriorating in condition and increased population and inappropriate management are by far the main factors influencing this (Hudak, 1999). Tainton (1999) noted that 15% of South African land has the potential for arable farming, and the remaining 85%, 40% receives less than 375 mm precipitation/annum. Therefore, as a result of increased degradation extent, global warming, and urbanization cropping efficiencies have declined and economically sustainable farming practices are becoming increasingly marginal in many areas (Ramankutty *et al*., 2002). In addition, 45% of the land receiving enough rainfall is topographically unsuitable for cropping, and can only be utilized for grazing (Tainton, 1999). These grazing areas vary in botanical composition, and nature of forage available and are categorized into different biomes.

Over the years, veld degradation has become an important factor influencing increases in the vulnerability of livestock production and rural economy and is widely associated with poor veld management (Hudak, 1999). Neke and Du Plessis (2004) suggested that veld degradation generally follows a trend in which species composition shifts from perennial to annuals and basal cover declines. Furthermore, surface run-off rate increases leading to increased soil erosion and leaching rates, and thereafter, decreased overall veld productivity (Neke and Du Plessis, 2004). This process can be easily rectified at early stages of decreased basal cover, but as the process progresses it becomes almost impossible to reverse to the original state (Tainton and Hardy, 1999).

Generally, overstocking is the main limiting factor for achieving progressive rehabilitation, therefore, reducing the stocking rate to a more conservative stocking may be a starting point to reversing veld degradation (Forbes and Trollope, 1991). Consequently, where degradation is severe, annual grasses like *Microchloa caffra*, *Aristida congesta*, and *Setaria verticillata* become abundant reducing run-offs and erosion, therefore protecting the soil environment for more perennial species such as *Eragrostis*, *Hyparrhenia* (Tainton and Hardy, 1999). Progressively, some *Sporobolus* species which can stabilise the soil and thereafter, more desirable species such as *Themeda triandra* and *Brachiaria serrata* then begin to establish (Trollope, 1985; Forbe and Trollope, 1991; Tainton and Hardy, 1999).

The process by which vegetation changes, over time, with or without interference by man is known as plant succession. Tainton and Hardy (1999) highlighted that succession is brought about by plant reactions and interactions, however, grazing activities and fire regimes modify both the speed and direction of succession. The most important successional process, in this study, is secondary succession which occurs in areas where the existing plant communities have been disturbed (Tainton and Hardy, 1999), commonly by cultivation or inappropriate grazing intensity. In natural veld, poorly managed grazing reduces the plant's ability for vegetative production, resulting in decreases basal cover and sward diversity (Wolfson, 1999). Excessive defoliation reduces the capacity of the plant to photosynthesis and consequently plant vigour and growth of lateral daughter tillers (Wolfson, 1999). In contrast, appropriate levels of defoliation may stimulate daughter tillers' growth by removal of older leaves to allow light penetration, which favours tiller growth. The pattern of defoliation and effect on individual plant and sward productivity are greatly influenced by the method, timing, and intensity of grazing (Wolfson, 1999). Therefore it is important to employ revised grazing system which matches the livestock production system and veld resource.

In Southern Africa, two main grazing approaches are extensively adopted namely, continuous and rotational grazing. According to Booysen (1967), continuous grazing (CG) is when animals are allocated to a camp at the beginning of the grazing season and they or their replacements remain in the camp for the rest of the grazing period each year. Rotational grazing (RG) is defined as a system where these animals are divided into groups and the camps subdivided such that the number of camps is more than that of animal groups then the groups are moved amongst the camps (Booysen, 1967). According to Tainton *et al*. (1999), both systems have 'degrees of sophistication' but RG requires more capital and therefore might be unsuitable for communal areas. In Southern Africa, continuous grazing has long been condemned, mostly due to the risks and consequences of continuous overgrazing in semi-arid and arid savannas and grasslands of the region. These have frequently resulted in reduced forage quantity and quality and livestock productivity simultaneously in this region.

Forage quality and quality fluctuate within and between seasons, mainly due to plant growth stages and leaf: stem ratio. To compensate for forage quality and quantity constraints, herbivores can increase their bite rate, grazing time and select more of the nutritious species (Vivas and Saether, 1987). This increases pressure on desirable species like *T. triandra,* which results in a decline in vigour and productivity. Moreover, the main reasons for low cattle productivity in communal areas is generally low forage availability and quality, especially during the dry season, and due to inefficient health management strategies. Hence, grass nutritional status is very important to keep animals in good body condition (Ndlovu *et al*., 2009; Lake *et al*., 2009).

2.2 Ecology of South African grasslands

Grasslands are mainly dominated by an herbaceous layer with a very thin bush and/or shrub distribution. According to Belsky (1994), the woody component encourages species diversity and provides quality browse during the dormant season. Grasslands mainly establish in areas where rainfall is seasonal with dry and cold winters (Tainton, 1999).

Semi-arid grasslands occurring in the communal regions of South Africa are generally poorly managed, and as a result, they are frequently overgrazed and/or encroached by bushes. In these regions, vegetation growth is limited by water availability and the consequences of misuse are very prominent. When domestic animals were introduced in the semi-arid regions a series of changes occurred bringing about significant changes in vegetation which comprised of decline in perennial grass layer and increase in annual herbaceous plants and woody component have been documented (Walker *et al.*, 1981). In the present state shrubs and/or thickets are now invading the grasslands and practically supressing grasses (Richter *et al.*, 2001).

2.2.1 Sour veld and sweet veld

According to Tainton (1999), the quality and nature of grasses diverge from sweet in the more arid region to sour in moister regions. These veld types are distinguished according to the quality of the grass component throughout the dormant season (Stuart-Hill and Tainton, 1999). In general, sweet veld occurs in the more arid region and particularly fertile soils, whereas the sour grasslands occur in more humid regions mainly where the soil is infertile.

The sour veld is less palatable but provides good biomass between October/November and April/May, and is suitable to be used for spring and summer grazing (Hardy *et al*., 1999). On the other hand, the sweet veld provides good, year-round, palatability to herbivory, however, forage availability is a limiting factor as the veld type occurs in more arid regions (Hatch, 1999). Forage quality in the sour veld is limited by leaching of nutrients below the root zone, to the lower soil horizon due to high average precipitation (Mapiye *et al.*, 2009). This veld generally loses quality rapidly as soon as growth stops towards the end of the growing season, and thus has low quality in winter (Danckwerts, 1989). The supply of mineral licks and protein supplements may improve utilization of available forage and inevitably body condition during the dormant season. Whereas forage palatability and quality are higher during winter in the sweet veld, forage availability in this veld is limited by low average annual precipitation and distribution, therefore forage conservation by a form of hay and/or foggage are important in these regions.

2.3 Livestock production potential of the natural veld in SA

Livestock farming has been reported to generally deteriorate the veld condition (Neke and Du Plessis, 2004) and this gives alien and/or invasive species an opportunity to increase in abundance. Grasslands and savannas are extensively invaded by woody species, reducing the grass component and consequently the carrying capacity, stocking rate and productivity of the veld per animal unit (Forbes and Trollope, 1991; Tainton, 1999). Carrying capacity is reduced when productive species like *P. maximum* and *T. triandra* are replaced by some *Eragrostis, Sporobolus* and *Aristida* species and which are less desirable due to low forage production and digestibility. Although more than a quarter of SA's livestock population is in communal rangelands (Everson and Hatch, 1999), bush encroachment has been reported to prevail in these regions (Angassa and Oba, 2008). In addition, Trollope (1980) suggested that high levels encroachment in these regions is elevated by low grass fuel loads for burning to suppress woody encroachment.

Nevertheless, high-quality forage, throughout the year, in the sweet veld facilitates good animal condition, provided there is enough forage. However, low and erratic rainfall limits forage availability and thus carrying capacity. On the other hand, the sourveld provides high forage quantity but production is limited by low quality, most pronounced in winter. The importance of managing the veld in relation to its condition and the type of animal unit is well documented (Danckwerts, 1989; Forbes and Trollope, 1991). Stocking rate is evidently a significant factor in conserving forage and/or quality for a sustained production. In addition, Danckwerts (1989) suggested that stocking rate is a limiting factor for forage intake and average daily gains. He further highlights that the stocking rate has a positive correlation with animal gains/ha and an inverse relationship with gains/head. Therefore, to enhance productivity in a natural veld the stocking rate should be in relation to the veld needs and livestock production.

2.4 Grazing systems and implication on veld productivity

Grazing systems are manipulated to reach a unique goal of sufficient and efficient pasture production and thus optimum livestock production. According to Snyman (1998), living organisms and the environment interact and cannot exist independently of each other. Therefore any grazing system employed should be in line with the basic ecological principles.

Grazing systems are a manipulation of plant ecology so as to produce optimal forage quantity and quality aiming to improve livestock production (Briske *et al*., 2008) while maintaining and/or improving veld condition. There are two grazing philosophies commonly adopted in rangelands of South Africa namely, continuous and rotational grazing systems.

2.4.1 Continuous Grazing Systems (CGS)

By definition, a continuous grazing system is a system where livestock graze on a grazing land for extended periods of time with no resting (Booysen 1967; Trollope *et al.,* 1990; Tainton *et al*., 1999). Continuous grazing is a practice commonly used in most communal areas of South Africa. In contrast to the society belief, continuous grazing is not limited to one big camp, but multiple camps may be available and grazed simultaneously (Booysen, 1967; Tainton *et al*., 1999). This system encourages continuous selective grazing of high-quality grass, reducing vigour and recovery chances (Barnes, 1989; Tainton *et al,* 1999). The desirable grasses are therefore suppressed while undesirable species thrive, resulting in a poor quality sward community.

2.4.2 Rotational Grazing Systems (RGS)

Rotational grazing is an alternative to the continuous system where a grazing land is divided into paddocks greater than livestock groups and livestock are rotated to manipulate frequency and intensity (Mcllvain and Savage, 1951; Walton *et al*., 1981; Koerth *et al*., 1983; ; Bertelsen, 1993; Briske *et al*., 2008;). In addition, Tainton *et al.* (1999) also highlighted that for successful implementation of the system, the number of paddocks should always exceed the number of the animal group to ensure flexible grazing frequencies and intensities.

In most communal areas, the rotational grazing systems were informally implemented but due to a number of sociological challenges, proper system implementation is difficult (Everson and Hatch, 1999). Hence the rates of degradation have increased in the communal veld of South Africa, which reduces animal performance and local economies. Tainton *et al*. (1999) pointed out that the primary objectives of RGS are: 1) To control grazing frequency and allow recovery; 2) Control grazing intensity by manipulating the number of animals and period of occupation, and; 3) Reduce the impact of selective grazing. These objectives gave rise to many debates on how they can be achieved, and important philosophies of applies RGS were born.

The commonly adopted rotational philosophies in South Africa are High Production Grazing (HPG) and the High Utilisation Grazing systems (HUG) (Tainton *et al.*, 1999). HPG suggests moderation forage grazing of desirable species, like *Themeda triandra*, and minimum or no grazing on undesirable grasses so they become moribund and smother themselves (Booysen, 1969; Barnes, 1989; Tainton *et al.*, 1999). According to Tainton *et al*. (1999), HPG is best for more arid regions where regrowth may be limited by drought and carryover forage is important for winter graze.

HUG, on the other hand, promotes high stocking densities, longer occupation, and rest, to force animals to graze even the least palatable grasses, on the expense of desirable species to minimise selective grazing (Booysen, 1969; Barnes, 1989; Tainton *et al*., 1999). However, this system is feasible in humid regions where rainfall encourages rapid regrowth (Tainton *et al*., 1999), which is generally in the sour veld.

2.4.3 Continuous vs Rotational Grazing System: Animal performance

An adopted grazing system has a significant influence on the efficiency of range management in meeting production requirements. In South Africa, these systems are mainly categorised as either continuous or rotational system. However, continuous grazing systems have been reported to promote low veld productivity (O'Reagain and Turner, 1992; Tainton *et al*., 1999) owing uncontrolled selective grazing leading to veld degradation. Nonetheless, increased initial animal performance has been reported under continuous systems (O'Reagain and Turner, 1992; Briske *et al*., 2008). This increase is justified by the freedom to select high nutrient species.

In contrast, Danckwerts (1989) and Barnes (1992) maintained that at low-intensity grazing, under continuous grazing, improved veld and animal production may be achieved. Numerous studies conducted on these grazing philosophies continue to overlook the advantages of continuous grazing systems, recommending the implementation of the rotational systems (Briske *et al*., 2008). Although the rotational grazing systems are supported as the only systems that promote high veld and animal production, there is compelling evidence that veld and animal production are largely influenced by the stocking rate, irrespective of employed grazing systems (Barnes, 1992; Danckwerts, 1989; Briske *et al*., 2008). In contrast, Tainton *et al.* (1999) maintained that rotational grazing systems increases carrying capacity with little declines in livestock gains/ha, however, the increase is subject to topography, soil type, climate, vegetation type and animal type. In addition, Bertelsen *et al*. (1993) observed a general increase in animal gains/ha under rotational as compared to continuous grazing at similar stocking rates however, found no differences in daily gains of animals. It is, therefore, necessary to adequately investigate and improve quantitative data on appropriate grazing system to adopt for specific veld types and animal types in relation to farming interests.

2.5 Cultivation impacts on soil fertility

Soil fertility is an important aspect of productivity in all agricultural systems and it is mainly defined in terms of the potential and ability of the soil to provide minerals in forms in which plants can utilize. Natural veld largely relies on soil organic matter to improve soil chemical, biological and physical properties (Carter, 2002; Nortcliff, 2002; Watson *et al.* 2002) and sustain forage production. Plant growth has a direct correlation with soil organic matter, soil carbon, and pH, which affects the availability of soil nutrients to plants (Carter, 2002).

It is well known that plants require macro and micronutrients to successfully grow, but land use practices like cultivation have been reported to have a noticeable effect on the proportion and availability of these essential nutrients (Campbell and Souster, 1982; McGrath *et al.*, 2001). With cultivation, reduced soil organic carbon, soil nitrogen, and soil organic matter have been reported (Srivastava and Singh, 1989; Silgram and Shepherd, 1999; Islam and Weil, 2000;). In addition, Dick (1983) reported accumulation of organic carbon and nitrogen where cultivation has not taken place despite soil type. Soil pH is reduced under cultivation limiting the availability of pH-sensitive soil nutrients. Along the pH gradient, minerals like phosphorus, manganese and iron decrease with increasing alkaline conditions and potassium and copper decline with increasing acidic conditions (Smith, 2006), which may affect the availability of nutrients in old lands.

2.6 Influence of previous cultivation on old lands

A progressive development of plant communities after disturbance is best described by Tainton and Hardy (1999) and is explicitly visible in abandoned cultivated lands. This phenomenon is well known as plant succession and has been well studied in the past, a process by which a vegetation of a given area changes over time, and these changes take place with or without human interference (Bazzaz, 1979; Tainton and Hardy, 1999). Plant succession can move toward either a regressive or progressive direction. Tainton and Hardy (1999) suggested that the direction of succession is greatly influenced by human, grazing, and fire interference.

Succession is categorized into primary and secondary succession. Primary succession is the establishment of a new plant community in an area where there was no plant growth (Tainton and Hardy, 1999), with generally no known seed banks. According to Tainton and Hardy (1999), this succession initiates in bare areas such as rocks or in a pond of water where no vegetation has grown before. These are harsh conditions with minimum nutrients available for plant utilization. The first established plants are those adapted to survive such conditions, such as lichens. Such organisms' modify the environment so other species such as mosses can grow, then gradually the existing diverse ecosystems develop.

Through human activities, natural vegetation is disturbed and the extent of disturbance determines how far back successional process is initiated. Cultivation is a good example of severe disturbance of the ecosystem. Cultivation is used as a tool to control weeds, manage plant residues and prepare soils for the next crop stand (Silgram and Shepherd, 1999). In so doing removing the litter and roots leaving the soil bare and susceptible to erosion and alien plant invasion. Establishment of weeds and initiation of the vegetation shifts from annuals to perennials after abandonment is rapid (Figure 1), provided that there is no further disturbance (Whalley, 1994). However, the old croplands are frequently utilised for livestock production, therefore intensity of grazing may influence the rate of plant succession in such areas. Nonetheless, the rate of succession then slows down owing to a long-life span of perennial species (Whalley, 1994). Moreover, Silgram and Shepherd (1999) and Srivastava and Singh (1989) confirmed that cultivation encourages excessive porosity in soils, resulting in the reduced water holding capacity, soil organic matter (SOM) and organic carbon, which may influence the successional rate by more desirable perennial species.

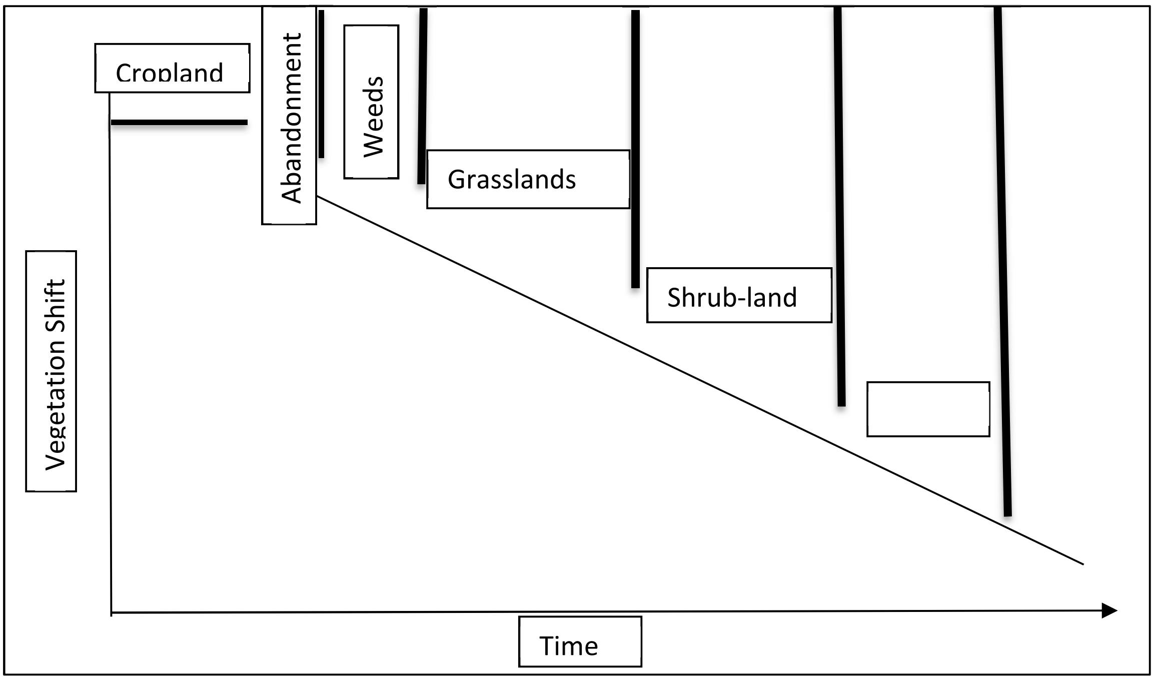

Figure 1.1: Illustration of successional process after cropland abandonment (derived from, Whalley, 1994)

Nonetheless, in a given plant community changes in individuals of different species is less noticeable than variations in vegetation structure (Whalley, 1994), which both significantly contribute to understanding the dynamics of vegetation shifts. Generally, in natural vegetation, changes are inevitable and total stability is seldom. The growing need to understand plant succession after different intensities of disturbance led to the development of two major hypotheses. One school of thought believes that after a disturbance at a given climatic region succession always progresses to the same climax state (Clements, 1916). The other school of thought maintained that different stable climax states can occur in a single climatic region as influenced by random environmental factors (Tansley, 1935). Disputes around these hypotheses lead to a well-accepted 'state and transition model' that was developed by Westoby *et al*. (1989), which acknowledges that heterogeneous vegetation exists in a single climatic region and following disturbance an alternative vegetation state may occur (Stringham *et al*., 2003). This model examines the dynamics of changes in a persistent plant community after disturbance, which are very important for strategic utilisation during and after the transition.

The significant degradation in soil fertility and physical structure (Srivastava and Singh, 1989; Silgram and Shepherd, 1999; Islam and Weil, 2000), implies that cultivation reduces the ability of soil to successfully support crop production unless crop production is supported by continual nutrient addition. Therefore sustained production will need fertiliser application which is very expensive and this may lead to cropland abandonment. After abandonment, the landscape, soil, and vegetation are transformed and the new environmental conditions allow for the area to gradually evolve back towards the original ecosystem state. This evolution is through secondary succession, generally, the succession begins with broad-leaved weeds and annuals (Tainton and Hardy, 1999), which improves soil conditions for better grasses, and later the weed and annual community is replaced by perennial grasses. This succession is the most important in agriculture and improves understanding of plant community dynamics.

2.7 Forage quality

Forage is the main and sometimes, in case of communal regions, the only source of feed supply for livestock and provides a variety of nutrients to meet the nutrient requirements of animals. To quantify forage quality, a plant is divided into its basic constituent, the cell wall, and cell contents. These constituents are further categorized into digestible, indigestible and poorly digestible constituents (Meissner *et al*., 1999), which then gives an idea of how much nutrients can animals absorb from the forage. The cell wall consists of cellulose and hemi-cellulose, and the amount of these in the feed determines the proportion of the feed that animals cannot utilize. Cell contents, on the other hand, consists of essential nutrients such as carbohydrate, vitamins, minerals, and protein. For optimum animal performance and production, adequate nutrient balance in diets is essential. Moreover, cell wall: cell content ratio of a feed is an important tool to quantify forage quality and supplement interventions for different physiological stages of animals (Danckwerts, 1989; Meissner *et al*., 1999). Natural vegetation, generally, is unable to provide good forage year round mainly as a result of plant growth physiology within and between seasons (Wolfson and Tainton, 1999). Therefore, there is need to supplement pasture-based livestock to improve animal performance.

In grassland communities, quality is a determinant of palatability and acceptability of available forage grasses. According to Meissner *et al*. (1999), palatability is a measure of the attractiveness of a grass species to be grazed by an animal and the ability to retained attractiveness throughout the grazing period. Meissner *et al*. (1999) then describes acceptability as a measure of the attractiveness of a species when alteration, such as supplementation, are made and/or attractive only for a short period of time. For example, species like *Hyparrhenia spp*. are acceptable during the early growing season when still young (Van Oudtshoorn, 2012). Hence it is important to understand forage dynamic of grazing areas dominated by different grasses to produce efficient supplement programs.

2.8 Feeding and diet selection of cattle

Animals require nutrients to maintain basic body functions such as supporting growth, lactation, and pregnancy. Prache *et al*. (1998) suggested that feeding behaviour is mainly influenced by animal factors such as animal type, physiological phase, experience with the available vegetation and habitat exploration. Additionally, plant factors such as availability, physical and qualitative features of the plants (Prache *et al*., 1998). A cow undergoes three different physiological states in their life cycle, namely gestation, lactation and the dry state, and different stages require a distinct nutrition management strategy (van Ryssen, 1992).

According to Gertenbach *et al.* (1998) on average, pregnant heifers require 798g/day of crude protein and lactating cow require 85.3g more per day. In addition, variations in nutrient requirements of an animal are greatly influenced by the current animal physiological stage. The seasonal dynamics of forage quality and quantity, apart from water limitations, are mostly influenced by growth and the maturity processes of the grass plant (Sollenberger and Burns, 2001). These dynamics force animals to find ways to satisfy their nutrient requirement at different stages. Lactating animals achieve a greater intake than dry animals mainly through an increase in grazing time. A high-producing animal may take bigger bites and spend less time per bite by choosing to reduce mastication rate in favour of increased biting rate.

2.9 Conclusion

The landscape of the communal grazing lands is generally diverse, mostly characterised by large patches of currently and/or previously cultivated lands (old lands). Old lands are mostly dynamic and unstable, making them more vulnerable to poorly managed grazing. Moreover, poor grazing management is widely documented in most communal regions of South Africa, and this phenomenon reduces the resilience of the natural vegetation and, thus of the ecosystem. Consequently, successful livestock production may be difficult to achieve. The conditions in the communal regions are elevated by the high abandonment of croplands, mostly due to effects of global warming, leading to high dependence on livestock. As a result, livestock population has significantly increased whereas the veld is rapidly degrading.

Traditionally, communal rangelands are under continuous grazing systems. However, these systems have gained a negative reference in Southern Africa, favouring the rotational grazing systems. Nonetheless, an effective and sustainable grazing system is that which balances the sociological, ecological, and economic interests of the specific communities. Therefore, it is very important to investigate the relationships between the land use history, veld productivity and livestock production to find suitable strategies towards achieving sustainable management in communal systems. With the aim to reduce unnecessary expenditure on supplements and align high-quality forage season to breeding programs and, thus improving herd productivity.

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CHAPTER 3: FORAGE PRODUCTION AND SOIL FERTILITY IN OLD LANDS.

ABSTRACT

Inconsistent rainfall and high frequency of drought have resulted in many farmers abandoning crop farming, resulting in high dependence on livestock. This has created vast areas of old lands, which are now used for livestock grazing, however, these lands are largely unstable and proper grazing strategies should be implemented. Quantitative information on the effects of cultivation on soil fertility, forage production and species composition in abandoned croplands is necessary to improve utilization and productivity of these lands. A study to examine these effects was conducted in Mzongwana near Matatiele. Data on forage quality, biomass accumulation, and soil fertility were collected, seasonally, by sampling along six 100m transects so that a good representation of the site is depicted. The results showed that old lands had a progressive plant succession, however, as a result of further disturbance by poor grazing management, the succession rate was slowed down. Although the soil organic carbon (C) and nitrogen (N) concentrations were low in these lands, forage quality remained relatively high. However, due to poor species composition and grazing managements forage quality rapidly decline over the seasons.

3.1 Introduction

Conversion of abandoned croplands to grazing lands has become an important transition to alleviate veld degradation, especially in the communal region of South Africa. Cramer *et al.* (2008) suggested that successful restoration of croplands towards historic vegetation states is greatly influenced by intensive cultivation techniques and rapid environmental changes, such as conventional tillage and climate change. Communal farmers mostly cannot afford heavy ploughing machinery and inorganic fertilization, with no further disturbance, restoration in these regions may be more rapid. In addition, cultivation and fertilization can significantly change soil nutrient pools and cycles, mainly by altering soil biology (Compton and Boone, 2000). In temperate regions, it has been reported that cultivation reduces soil carbon and nitrogen mainly due to reduced soil microbes and thus slow decomposition, and reduced plant input and erosion of surface soils (Compton and Boone, 2000).Yet sufficient information on soil fertility and forage quality of old land in communal regions of South Africa is not available.

Nonetheless, Campbell and Souster (1982) and McGrath *et al.* (2001) suggested that the ability of the soil to naturally mineralise nitrogen (N) is significantly reduced by cultivation. In addition, cultivation reduces the amount of soil organic matter (SOM) which contains active N fractions which can be immediately available for plant utilisation (Campbell and Souster, 1982). Therefore, N fractions in the SOM are greatly reduced by conversion from natural veld to croplands and the decline is aggravated by persistent cultivation (Compton and Boone, 2000). The soil properties in old lands may be unstable and, therefore, promote the establishment of pioneer and/or annual grasses. A plant community dominated by pioneer and invasive species can be very unstable and vulnerable to excessive defoliation (Teague 1989; Tainton and Hardy, 1999).

The instability of such a plant community reduces forage quality and quantity throughout the year, thus reducing the potential of the old land for sustainable livestock production (Teague 1989). In addition, increasing trends of abandonment necessitate an extensive understanding of plant community developments, soil fertility and forage quality dynamics of old lands to enable conservation and restoration of these areas for livestock utilisation.

3.2 Methods

3.2.1 Site description

The study was conducted in Mzongwana near Matatiele (Figure 2), situated at 30° 20’32” S (longitude) and 28° 48’22” E (latitude) and is estimated to be 1779 m above sea level. In this region precipitation ranges between 620-816 mm per annum and occurs mostly during mid-summer with moderate to severe frost in winter (Munica and Rutherford, 2006). The grassland is classified by Munica and Rutherford (2006) as the East Griqualand Grassland characterised by an undulating landscape with light bush densities which include *Leucosidea sericea* (only found on moist regions) or *Diospyros lycioides*, *Acacia karroo*, and *Ziziphus mucronata* in low-lying and very dry sites. The dominant herbaceous layer includes, *Themeda triandra*, *Hypperhenia hirta*, *Digitaria tricholaenoides*. Soils originating from mudstone and sandstone of the Beaufort Group of the Karoo sequence predominate in this grassland, and sedimentary rocks of the Molteno, Elliot and Clarens formation are present (Munica and Rutherford, 2006). The soils in these lands are categorised by Black (1957) as loamy sandy soils (15.9% clay).

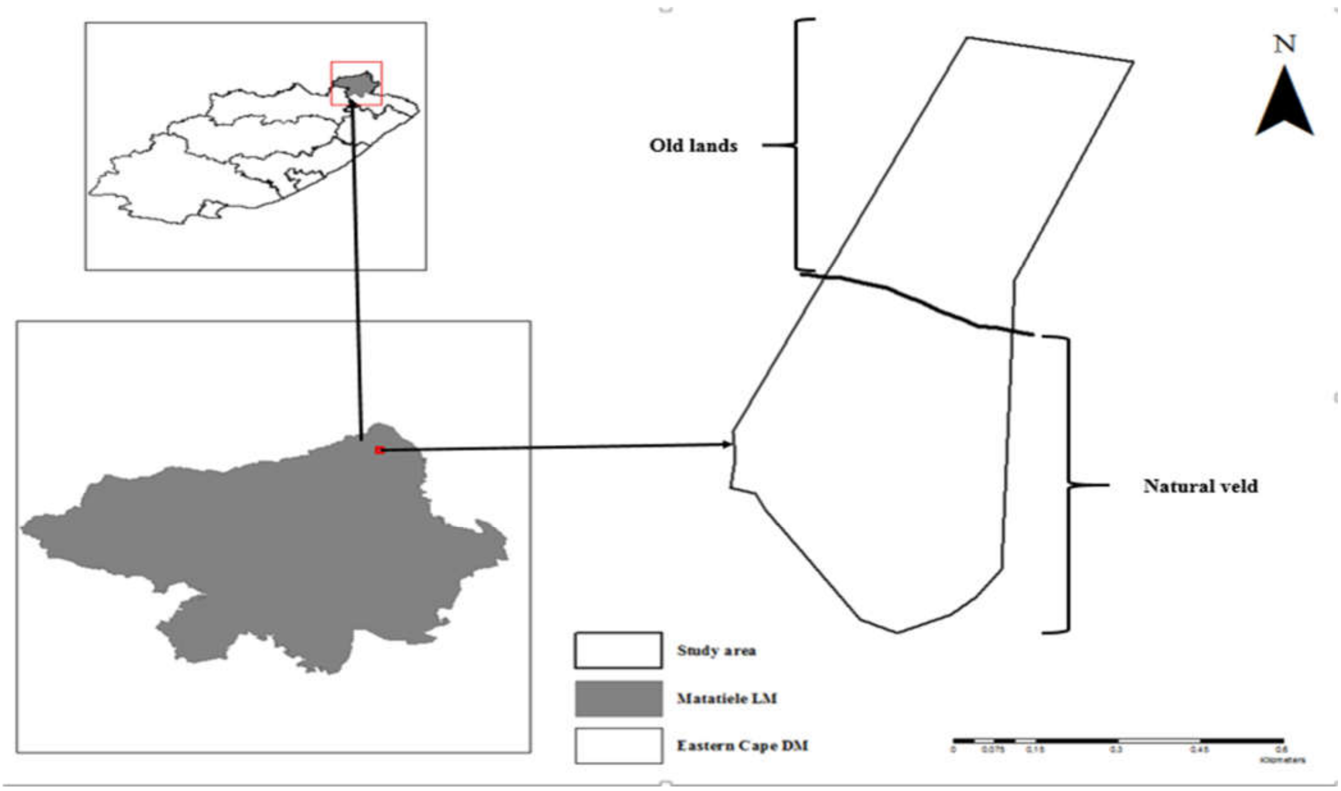

Figure 3.1: Location of the old lands in Mzongwana near Matatiele

3.2.2 Experimental design

The old lands are a large proportion of the landscape and were abandoned for, approximately, 10 years. They typically on low lying areas close to homesteads and settlements and also close to other croplands. Because of this, they are often used during winter. In summer grazing takes places on the natural veld which is on the other side of the road (Figure 3.1) and livestock is excluded in the old lands for the whole growing season by herders. Although the current stocking rate in these lands unknown, it is estimated to be high. In addition, the old lands have patches of seasonal wetlands which were sampled as part of the old lands. However, there is no current information on when it is best to utilise these for both forage production as well as restoration.

3.2.3 Data collection

Species composition:

A 100m line-transect was laid, six times, 25m apart in each site. Along each transect a 0.5 by 0.5m quadrat was laid every 2m and grass species within the quadrats were identified, then species frequencies were derived.

Soil fertility:

Along each 100m line-transect, four soil samples were collected at 25, 50, 75, and 100m in all sites. The samples were collected at 0-15cm depth and stored into paper bags then air dried for 7 days. The samples were then stored in plastic bags for soil fertility analysis in Cedara laboratory (Research and Technology Development, Analytical Services). The laboratory analysed for soil pH and acid saturation, macro-minerals (N, K, P, Mg, Ca), micro-minerals (Zn, Mn, Cu), and organic carbon.

Forage quantity:

The biomass of the sites was estimated using the comparative yield method which is widely used for estimating dry matter yields (Friedel *et al.*, 1988; Dekker *et al.*, 2001). The method is rapid and has been reported to be adequate for large areas such as rangelands. The technique required a set-up of rank-reference quadrats, the quadrat with the least biomass was ranked 1 and the one with the highest biomass ranked 10. Along each of the six 100 m line-transects a

0,5 m by 0,5 m quadrat was laid 2 m apart, to represent the area surveyed six transects, 25 m apart were laid. All sampled quadrats were ranked accordingly and the biomass within every fourth quadrat was clipped to the height of 5 cm and oven dried at 60 ºC for 48 hours. The dried grass was thereafter weighed to estimate the dry matter content. Then the data was calibrated using the linear regression technique to estimate the above ground biomass, in kg/ha, available for utilisation by livestock.

Forage quality:

After drying, the bulk grass samples collected for biomass were then milled using a 2mm sieve, and stored in plastic jars for a full feed analysis in the Cedara laboratory. Forage was analysed for the levels of the acid detergent fibre (ADF), neutral detergent fibre (NDF), crude protein (CP), macro-nutrients (calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), sodium (Na)), micro-nutrients (zinc (Zn), copper (Cu), manganese (Mn), iron (Fe)), and the mineral matter (ash).

3.2.4 Analysis

The data were analysed using the IBM SPSS version 24. The Multivariate (MANOVA) of the General Linear Models (GLM) were used to determine the effect of season in old lands on soil fertility and forage quality. The Tukey's post-hoc test was used to compare the means.

3.3 Results

3.3.1 Species composition in the old lands

The old lands were dominated (>20 %) by *Eragrostis plana, Hyparrhenia hirta,* and *Sporobolus africanus* (Figure 3), which have low palatability but with strong root systems for holding soil particles and thus reducing erosion. Species such as *Paspalum dilatatum, Microchloa caffra* and other *Eragrostis* species were common (5-20 %) in the area and the only decreaser species found on the site, *Digitaria tricholaenoides,* was very rare (< 5%).

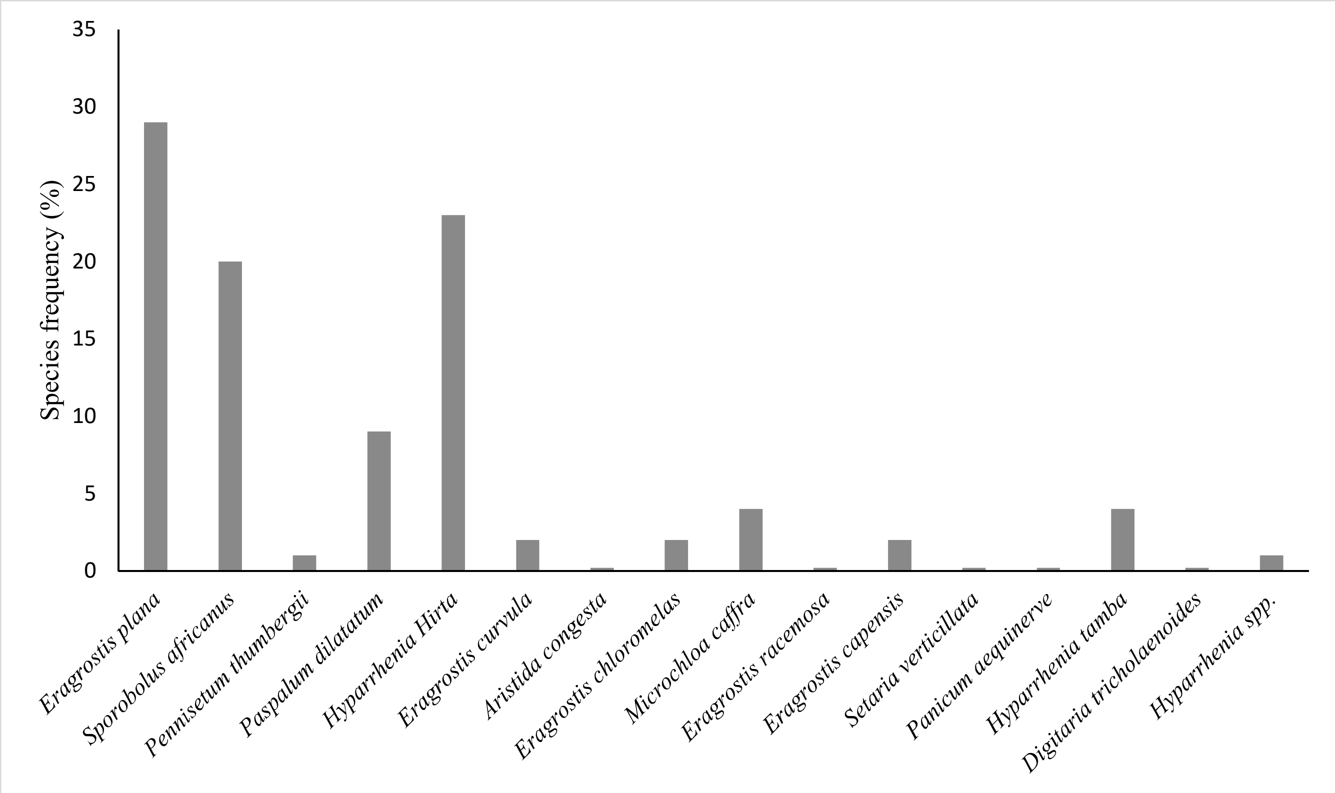

Figure 1.2: Species composition frequencies (%) on old lands of Mzongwana near Matatiele

3.3.2 Soil fertility of the old lands

The soils in the old land had generally low N and organic C, although the concentrations were significantly higher in early summer (P<0.05) than other seasons (Table 1). Soil P is lowest in early summer (P<0.05) then progressively increases from late summer to be highest in late winter (P<0.05). The results also revealed that soil concentration in K, Zn, and Mn were generally high, these minerals were, however, lower in late summer, with the exception of K.

Table 3.1: Seasonal soil fertility dynamics on Mzongwana old lands near Matatiele. **Refer to Appendix D**

Season	P (ppm	K (ppm)	Zn (ppm)	Mn (ppm)	Acid Sat. (%)	Org.C (%)	pH (KCL)	N (%)
Early summer	3.33^{a}	93.17^{ab}	2.05^{ab}	21.83^{b}	2.17^{a}	1.23^{b}	4.81^{a}	0.15^{b}
Mid-summer	4.33^{ab}	79.33^{ab}	1.68^{ab}	16.47^{b}	3.30^{a}	1.05^{ab}	4.75^{a}	0.14^{ab}
Late summer	5.17^{bc}	122.83^{b}	1.22^{a}	5.17^{a}	2.50^{a}	0.40^{a}	4.64^{a}	0.06^{a}
Early winter	5.83^{c}	88.17^{ab}	2.48^{b}	17.00^{b}	5.17^{a}	0.83^{ab}	4.61^{a}	0.11^{ab}
Late winter	6.00^{c}	55.17^{a}	2.57^{b}	7.00^{a}	9.00^{a}	0.73^{ab}	4.49^{a}	0.08^{ab}
Means	4.93	87.73	2.00	13.53	4.43	0.85	4.70	0.10
SE	0.16	5.91	0.13	0.92	0.96	0.08	0.07	0.01

In the above table, different superscripts in a column depict significant differences (P<0.05) of a nutrient component between seasons.

3.3.3 Biomass accumulation in the old lands

The biomass accumulation in the old lands (Figure 4) increased rapidly in summer, from 740 kg/ha in early summer to 8697 kg/ha in late summer. During early winter, the biomass decreased to 1945 kg/ha and thereafter the biomass had a steady decline to 1540 kg/ha in late winter.

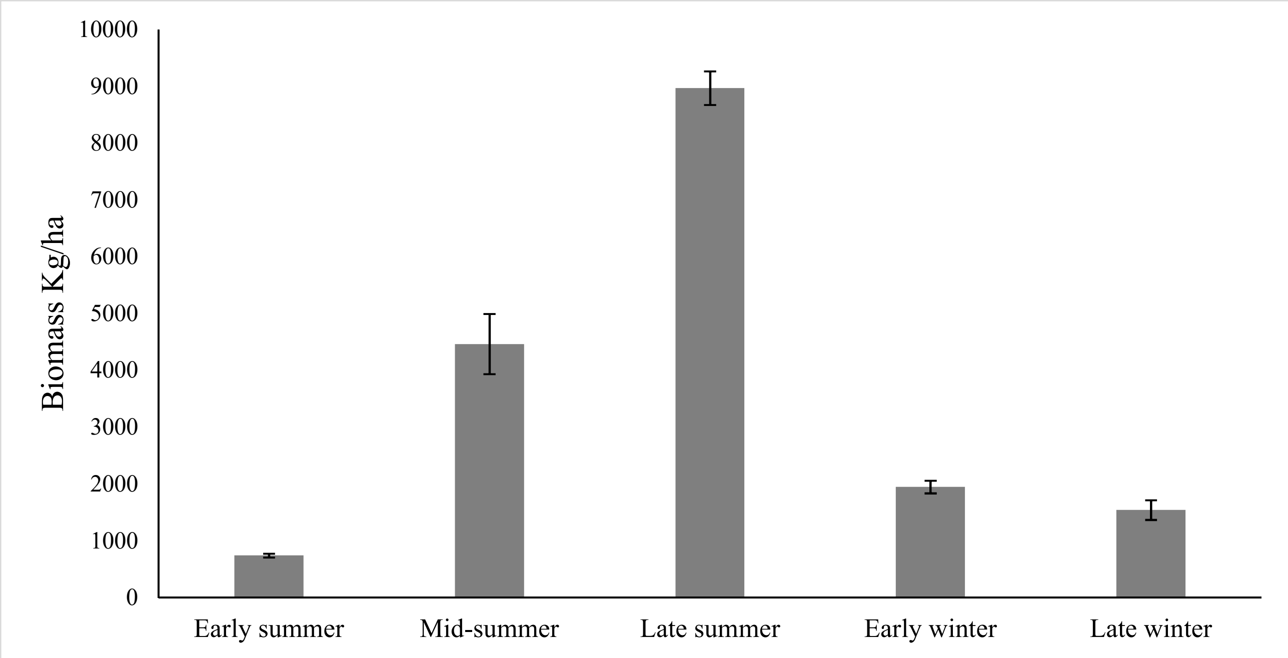

Figure3.2: Biomass accumulation on the old lands of Mzongwana (Matatiele)

3.3.4 Forage quality of the old lands

The results (Table 3.2) reveal that forage quality in the old lands was significantly high in the beginning of the early summer , but declines rapidly thereafter. The forage ADF and NDF content were high throughout the year, however, lower levels were recorded during the early summer season ($P<0.05$). During the early summer season, the old lands had higher CP levels ($P<0.05$) but rapidly declined as the season progressed to lowest levels ($P<0.05$) during winter. The macronutrients (Ca, Mg, K, P) and micronutrients (Zn, Cu) levels were generally higher ($P<0.05$) in summer, but the Fe levels were lowest ($P<0.05$) in late summer.

Table 3.2: Forage quality of the old lands in Mzongwana over the year (analyses on 100% dry matter basis). **Refer Appendix A**

Season	ADF (%)	NDF (%)	CP (%)	Ca (%)	Mg (%)	K (%)	P (%)	Zn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)
Early summer	41.73^{a}	78.32^{a}	12.05^{a}	0.32^{a}	0.11^{ab}	1.46^{a}	0.21^{a}	21.36^{a}	5.09^{a}	232.06^{ab}
Mid-summer	52.04^{b}	82.68^{b}	6.36^{b}	0.28^{ab}	0.11^{b}	1.48^{a}	0.14^{b}	18.03^{ab}	3.43^{b}	309.28^{b}
Late summer	63.70^{c}	87.02^{c}	3.32^{c}	0.23^{b}	0.08^{cd}	1.15^{b}	0.07^{c}	12.04^{b}	1.88^{c}	64.06^{c}
Early winter	57.24^{b}	82.46^{b}	2.42^{cd}	0.31^{a}	0.89^{ac}	0.56^{c}	0.06^{c}	13.87^{ab}	1.46^{c}	208.68^{a}
Late winter	55.82^{b}	85.98^{bc}	2.05^{d}	0.25^{b}	0.64^{d}	0.25^{d}	0.03^{c}	18.92^{ab}	1.35^{c}	303.24^{b}
SE	0.80	0.40	0.13	0.01	0.00	0.20	0.01	0.90	0.70	9.90

In the above table, different superscripts in a column depict significant differences ($P<0.05$) of a nutrient/mineral between seasons.

3.4 Discussion

3.4.1 Species composition in the old lands

The old lands (Figure 3.1) are predominated by *E. plana*, *H. hirta* and *S. africanus*. These grasses are known to grow in disturbed soils such as abandoned cultivated lands (van Oudtshoorn, 2012) commonly as successors of annual grasses like *S. verticillata* which is rare in this area (Tainton and Hardy, 1999). The dominance of these grasses indicate that the area is recovering well from cultivation and plant succession is moving in a positive direction. The dominant species are perennial grasses but have low grazing values (van Oudtshoorn, 2012). Their low grazing value is due to low leaf production, strong and tough leaves, especially with regards to *E. plana* and *S. africanus*. These grass species might be relatively acceptable to livestock only when young, during the early growing season.

The old lands are generally dominated by sub-climax grasses which suggest that the area is in a progressive secondary succession phase (Tainton and Hardy, 1999). These include grasses such as the *Eragrostis spp*. which are also mostly accepted by livestock during the early growing season. However, acceptability declines as the season progress which makes them poor grazing grasses due low leaf: stem ratio production. *M. caffra* and *A. congesta* are few pioneer grass found in this area which suggests that the plant community is relatively shifting towards positive plant succession.

Palatable grasses with good grazing values such as *D. tricholaenoides* are rare. The presence of *Paspalum dilatatum* confirms that the area has wetlands. The species is a problematic weed in cultivated areas, due to the difficulty to eradicate when it is mature (van Oudtshoorn, 2012), but a good grazing grass and it produces good leaf yields and in some regions is used as a cultivated pasture.

3.4.2 Soil fertility of the old lands

The old lands were generally low in fertility (Table 3.1), with low soil organic carbon (organic C) and N and were both significantly lowest in late summer, 0.4 and 0.06% respectively. The concentrations of both these elements were significantly higher in early summer. Reduced levels of organic C and N in old lands is largely attributed to the period cultivation, as the crop-lands were recently abandoned in less than 10 years ago. Campbell and Souster (1982) suggested that cultivation reduces the amount of soil organic matter (SOM), and therefore reduces N mineralization. Moreover, low levels of organic matter (OM) as the dominating grass species producing limited leaf material and contributions to low basal cover, may have an influence.

Soil P, Zn, and Mn concentrations in the old lands were generally low. Zn levels were lowest in late summer late (1.22ppm) and thereafter increased with relatively constant amounts in winter. According to Foth and Ellis (1988), Zn decreases with reduces SOM, and in these land, the topsoil has been exposed to erosion by cultivation, which has been reported to reduce SOM (Campbell and Souster, 1982). The concentration of Mn is lowest in late summer and late winter (5.17 and 7 ppm), and remain significantly high in other seasons. In contrast to these findings, Foth and Ellis (1988) suggested that Mn should be high in acidic soils. They then argue that low Mn might be as a result of high CO_2 which results for low drainage, which might be true for these lands as they have seasonal wetlands in the area. However, pasture deficiencies in these minerals are very rare (Miles and Manson, 2000).

P is inherently low in South Africa and P availability to plants is further inhibited by the soil acidity levels (Foth and Ellis, 1988; Meissner, 1999). The pH level in the old lands is low (4.7 KCl), and according to Foth and Ellis (1988), soil pH and P concentration have a negative correlation. In contrast, Miles and Manson (2000) suggested that acidity and its correction (liming) has limited effects on soil P sorption and immobilisation, respectively, further suggesting that soil P availability is largely influenced by type and amount of clay, levels of SOM, and soil temperature. Moreover, the results also show that P levels are lower in early to mid-summer and significantly increase in from late summer. This may be due to differences in sampling points between samples, nevertheless, the results are similar to those reported by Chen *et al* (2003) on a study in New Zealand, investigating the seasonal P variations between grasslands and forest. Additionally, increases in soil P in winter may be attributed to low P mineralisation in summer, due to low SOM, and increased immobilisation in winter. Mostly, P uptake is greater over the growing season when grasses are establishing (Chen *et al*., 2003; Miles and Manson, 2000) and this might deplete soil P reserves especially where soil P is initially low. Hence the P levels are low in summer and increase throughout winter, as absorption by plants declines.

Higher levels of K in the lands were generally available throughout the year, and were significantly higher in mid-summer than late winter. The variation can be attributed to leaching, which may be highly profound in sandy soil, such as the soils in these lands. Nevertheless, grasses are reported to effectively adapt in areas of low nutrient content, and limited water availability (Bradshaw *et al*., 1958; Wang *et al*., 2010), therefore low fertility in the old lands but might not be a limiting factor in grass growth but in forage quality. Snyman (2002) argued that after fertilization grasses use up the nutrients but reach a point of no significant differences in biomass production but the CP content of the forage may continue to increase. Therefore, in these lands, it is convincingly clear that low soil minerals may negatively influence the concentration of essential nutrients in the forage and consequently affect livestock production, especially where supplementation is limited.

3.4.3 Biomass accumulation in the old lands

The biomass increased significantly throughout the growing season (Figure 3.2). During the early growing season (November) biomass was very low (740 kg/ha) but as the season progressed biomass increased and was close to 8697kg/ha during the late growing season, which is very high. The biomass accumulation may be as a result of animal exclusion for the entire growing season. Furthermore, the presence of temporal wetlands may have influenced the high levels of biomass accumulation in summer. In addition, biomass included stems and flowers and *H. hirta* which contributed significantly to the biomass, but do not necessarily contribute to utilisable forage. The high biomass accumulation may also be due to rainfall distribution through the growing season (November- April), this region received more rainfall in mid-late growing season, therefore grass growth was rapid and undisturbed, and hence the huge increase in biomass production. Furthermore, these lands have patches of seasonal wetlands which may have accelerated the biomass production. In addition, in a study in the Moist Tall Grassveld, assessing veld condition under different grazing systems, found that the control paddock, where grazing was excluded, had the highest biomass production throughout the growing season (Tainton *et al.*, 1978).

In the beginning of the winter season (June) the old lands were grazed and there was a rapid decline in biomass then biomass slowly declined in the late winter (August). This might be as a result of rapid increase in crude fibre and declined quality during this season, and livestock reducing intake due to reduced forage acceptability. Moreover, the old lands were dominated by grasses with low grazing value like *H. hirta, E. plana* and *S. africanus* which do not retain their palatability throughout the growing season. Therefore, animals are most likely to avoid these species especially during the late dormant season when they are mature and have high cell wall content. In addition, these forage grasses are not likely to be consumed by cattle and sheep even if they are utilized it is often at a later stage when better forage is not available (O'Reagain and Mentis, 1989; O'Reagain and Grau, 1995; O'Reagain and Goetsch, 1996).

3.4.4 Forage quality of the old lands

Forage quality in the old lands (Table 3.2) was relatively high during early summer and thereafter, rapidly declined. ADF (mostly cellulose and lignin) and NDF (hemicellulose and partly cellulose and lignin) were generally high and dynamic throughout the season, increasing as the season progresses. According to Cullison (1982), NDF is more digestible as compared to ADF and its digestion occurs mainly in the rumen. The results showed that ADF and NDF were lower in early summer but drastically increased as the season progressed and were highest in late summer and thereafter gradually declined throughout the dormant season. High ADF and NDF contents during the late growing season were attributed to rapid growth and stem elongation (due to flowering) as a result of high rainfall during this season. The seasonal increase in ADF and NDF was mostly as a result of plant growth and maturity (Wolfson and Tainton, 1999), as the forage grasses grow leaves and stem toughen.

High ADF and NDF contents in the old lands suggest that forage is highly indigestible and essential nutrients available in the forage are inadequately digested and absorbed by the animals (Cullison, 1982; Beauchemin, 1996; Meissner *et al.*, 1999). In contrast, van Soest *et al.* (1991) argues that rumination time, maintenance of milk fat, rumen pH, and cellulolytic microorganisms are directly related to the intake of high NDF levels. In addition, increased

NDF intake maintains an extended gastrointestinal fill as it is fibrous and therefore is slowly digested. However, high ADF and NDF content in the feed decreases the feed value, and Short and Adams (1988) pointed out that low-quality feed delays puberty, reduces the secretion of progesterone, and increases the postpartum interval, which inevitably reduces the cow efficiency and therefore herd productivity declines.

On the other hand, forage CP showed an inverse relationship with ADF and NDF, which is as the ADF and NDF levels increase the CP declines (Allred *et al*., 2011). CP is the most important constituent in animals' nutrition (Meissner *et al*., 1999) and satisfies two significant roles which are, to provide nitrogen (N) for ruminal microorganisms and amino-acids for cell development and growth (Coleman and Moore, 2003). As anticipated, CP was dynamic throughout the seasons and was significantly higher (12.05%) during the early growing season, and thereafter showed a rapid decline and reached a very low levels during the late winter. The rapid decline in quality may be attributed to dominance by undesirable species (*E. plana* and *H. hirta*) which mature and lignify very fast. Generally in winter, grasses require less N because growth is no longer a primary factor and this consequently results in lower CP levels at maturity. Where forage availability is limited, CP, Ca and P required by beef cattle at minimum for growth (5.5, 0.2 and 0.1%), for pregnancy (5.6, 0.2 and 0.2%) and for lactation (8.4, 0.3 and 0.3%) respectively (Meissner *et al*., 1999). Maintenance requirements may be lower than these and are influenced by body weight, body condition and intensity of production. Although the old lands can provide adequate amounts of Ca throughout the year, CP and P can only support production during the early growing season and thereafter cannot support neither maintenance nor growth of beef cattle.

Protein and energy are the main limiting nutrient components in livestock production, especially in pasture-based animals. In addition, low CP reduces fibre digestion and Coleman and Moore (2003), suggested that at CP< 8% forage intake is reduced as a result of fibre accumulation in the rumen. However, McDowell *et al*. (1984) and Judson and McFarlane (1998) suggested that mineral requirements for livestock vary between breeds and state of production and further suggest that ruminants on tropics require at most 1.8-6, 0.4-1.8, 1.8-4.3, and 6-8% of Ca, Mg, P, and K respectively, the lower interval for growth and the upper interval for lactation. The old lands' macro-minerals, Ca, P, K, and Mg were lower than this throughout the year and this reduces the optimum livestock production of the old lands.

Nonetheless, P followed a similar trend with CP and was highest during the early summer and declined significantly from the late growing season onwards. These trends were also evident in soil mineral content of P and N, although these minerals were generally low (0.2% N and 3.3 mg/L P) in early summer, low soil acidity (4.3%) did not inhibit absorption by roots.

3.5 Conclusions

The findings of the study suggest that forage quality is directly influenced by species composition and biomass accumulation. Although soil organic carbon and nitrogen concentrations were low in the old lands during early summer, forage quality remained high during this time. Leading to a conclusion that soil fertility has a nominal influence on forage quality. On the other hand, the species frequency trends suggest a progressive succession, however, poor grazing managements may be slowing the successional rate down as desirable species are slowly re-establishing (e.g. *D. tricholaenoides*).

Based on the findings of this study it is advisable to graze the old lands strategically with effective resting to promote positive plants succession. This can be achieved by grazing the lands during early-mid summer when dominating grasses are still young and quality is high. This may improve calving and calf survival as the early growing season is the recommended calving period. Thereafter, the lands should be rested during late summer to autumn so as to promote seeding, increase basal cover to prevent wind erosion during winter, and ultimately improve veld condition.

Moreover, efficient defoliation during the early-mid growing season may be necessary to reduce vigour of less desirable species such as the *Eragrostis* species and *Hyparrhenia* species. This is likely to be achieved in these old lands through high intensity grazing, as the stocking rate is estimated to be high. This will facilitate in promoting the establishment of desirable grasses which can efficiently tolerate grazing, such as *Digitaria.*

Although these study was based on a small scale and lacks replication, the findings clearly suggest that the current grazing management hinders livestock productivity in this area, this is elevated by the extent and ongoing degradation of the natural veld. In addition, information of the current forage production of veld is important to improve livestock production in this area. Furthermore, quantification of economic returns following improved grazing managements is necessary to convince land user to farm sustainably.

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CHAPTER 4: VELD PRODUCTIVITY UNDER CONTINUOUS GRAZING

ABSTRACT

Communal rangelands of South Africa are largely degraded and this is mainly attributed to poor veld management. The continuous grazing systems are thought to have a major influence in degradation of these areas. Nevertheless, there is strong evidence that supports the implementation of continuous grazing under appropriate stocking rates. Although the successes of the systems are limited by negative effects of selective grazing, greater short-term livestock production may be achieved. Hence, there is a need to investigate the effects of utilisation regimes on soil fertility and forage quality. To address this aim, a study was conducted in a communal rangeland in Mzongwana near Matatiele. In the camp, six 100 m line-transects were laid and along each transect data on species composition, forage quality, biomass, and soil fertility were collected. The results showed that the soils were low in nitrogen (N), organic carbon (C) and phosphorus (P). There were no significant variations in N levels amongst the seasons. This attributed to a balance in the levels of N availability and the amount of organic N from animal excretion since occupation of livestock is continuous. Forage crude protein (CP) was relatively high and maintained as such in summer by continuously grazing the grass which keeps it in a vegetative stage throughout the growing season. Additionally, the constant supply of N may play a role in the ability of the forage to retain CP at significantly stable levels. The fibre content of the forage was high but maintained a steady increase throughout the year.

4.1 Introduction

Although a number of studies have shown that vegetation composition and animal performance can be influenced by the grazing systems employed (Heady, 1961), there is strong evidence that any grazing systems implemented at appropriate stocking rates, under good management may yield relatively the same outcome with regards to vegetation and animal response (Walton *et al*., 1981; Hart *et al*., 1988; Gillen *et al*., 1998; Hart *et al*., 1993). Heady (1961) pointed out that experimental studies looking at the effect of grazing systems on animal response vary, however strong evidence in the US favours continuous grazing. Nevertheless, Hart *et al*. (1993) found that as a result of long-distance walking in continuous systems, daily gains of cattle were higher in the rotational system. According to Heady (1961), differences found in these studies are not necessarily due to the adopted systems but factors like stocking rates, plant resistance to grazing, seasonal dynamics, uniformity of the pasture, grazing frequency, topography and number of water points.

Continuous grazing (CG) is historic grazing system in southern Africa and has received ample attention due to its susceptibility to selective grazing and veld deterioration. By definition, CG is a system where the number of camps is equivalent to the number of animal groups and each camp is grazed without effective rest for the entire grazing period of each year (Booysen, 1967; Trollope *et al*., 1990; Tainton *et al*., 1999). According to Booysen *et al*. (1975), CG has a lower "optimum stocking rate" as compared to rotational grazing, resulting in declines in production and profit over time. However, Walton *et al*. (1981) argued that heavy continuous grazing might reduce productivity but moderate continuous grazing might have an advantage with regards to gain per head compared to rotational grazing. The authors found that beef production increases in continuous grazing system over time than in rotational grazing system (Walton *et al*., 1981). Therefore, veld degradation in communal regions might not be as a result of continuous grazing system its-self but the structure and implementation of the system.

In China, Yon-Zhong *et al*. (2005) found that continuous grazing reduces vegetation cover, organic carbon and nitrogen concentrations, and microbial activity. Similar trends have been reported in South Africa (Trollope *et al*., 1990; Hudak, 1999; Tainton *et al*., 1999). In addition, Bertelsen *et al*. (1993) reported lower forage quantity, higher neutral detergent fibre (NDF) and acid detergent fibre (ADF), and lower crude protein (CP) in continuously grazed camps than in the rotationally grazed camps. With that said, Danckwerts (1989) pointed out that impacts of continuous grazing differ between veld types and emphasise the variances between veld types, forage quality in the sweetveld remain high throughout the year, as compared to sourveld, but forage availability fluctuates mainly as a result of stocking rate. Therefore, it is of significance to provide quantitative data on the dynamics of veld production in a specific condition, such as degraded conditions, to enable further research on rehabilitation and sustainable livestock production.

4.2 Methods

4.2.1 Site description

The study was conducted at Mzongwana near Matatiele (Figure 2) situated at 30° 20’32” S (longitude) and 28° 48’22” E (latitude) and is estimated to be 1779m above sea level. In this region precipitation ranges between 620-816 mm per annum and occurs mostly during mid-summer with moderate to severe frost in winter (Munica and Rutherford, 2006). The region is classified by Munica and Rutherford (2006) as the East Griqualand Grassland characterised by an undulating landscape covered by grassland with light bush densities which include *Leucosidea sericea* (only found on moist regions) or *Diospyros lycioides*, *Acacia karroo*, and *Ziziphus mucronata* in low-lying and very dry sites. The veld is a *Hyparrhenia*/*Themeda* mixed sour veld but currently dominated by *Heteropogon contortus*, *Sporobolus africanus* and *Microchloa caffra* and the soil is sandy clay loam. These soils originating from mudstone and sandstone of the Beaufort Group of the Karoo sequence predominate in this grassland, and sedimentary rocks of the Molteno, Elliot and Clarens formation are present (Munica and Rutherford, 2006).

4.2.2 Experimental design

The natural veld is under a continuous grazing system and is separated by a road with the old lands (Figure 3.1). Although the old lands are rested in summer, the natural veld is grazed year round mostly due to lack of urgency to conserve the natural resources. The precise stocking rate of the veld is unknown but for the purpose of this study, it is estimated to be high.

4.2.3 Data collection

Species composition:

A 100 m line-transect was laid, six times, 25 m apart from each site. Along each transect a 0.5 by 0.5 m quadrat was laid every 2 m and grass species within the quadrats were identified, then species frequencies were derived.

Soil fertility:

Along each 100 m line-transect, four soil samples were collected at 25, 50, 75, and 100 m in all sites. The samples were collected at 0-15 cm depth and stored into paper bags then air dried for 7 days. The samples were then stored in plastic bags for soil fertility analysis in Cedara laboratory (Research and Technology Development, Analytical Services). The laboratory analysed for soil pH and acid saturation, macro-minerals (N, K, P, Mg, Ca), micro-minerals (Zn, Mn, Cu), and organic carbon.

Forage quantity:

The biomass of the sites was estimated using the comparative yield method which is widely used for estimating dry matter yields (Friedel *et al.*, 1988; Dekker *et al.*, 2001). The method is rapid and has been reported to adequate for large areas such as rangelands. The technique required a set-up of rank-reference quadrats, the quadrat with the least biomass was ranked 1 and the one with the highest biomass ranked 10. Along each of the six 100 m line-transects a 0,5 m by 0,5 m quadrat was laid 2 m apart, to represent the area surveyed six transects, 25 m apart were laid. All sampled quadrats were ranked accordingly and the biomass within every fourth quadrat was clipped to the height of 5 cm and oven dried at 60 ºC for 48 hours. The dried grass was thereafter weighed to estimate the dry matter content. Then the data was calibrated using the linear regression technique to estimate the aboveground biomass, in kg/ha, available for utilisation by livestock.

Forage quality:

After drying, the bulk grass samples collected for biomass were then milled using a 2mm sieve, and stored in plastic jars for a full feed analysis in the Cedara laboratory. Forage was analysed for the levels of the acid detergent fibre (ADF), neutral detergent fibre (NDF), crude protein (CP), macro-nutrients (calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), sodium (Na)), micro-nutrients (zinc (Zn), copper (Cu), manganese (Mn), iron (Fe)), and the mineral matter (ash).

4.2.2 Analysis

The data were analysed using the IBM SPSS version 24. The Multivariate (MANOVA) of the General Linear Models (GLM) were used to determine the effect of the season on soil fertility and forage quality in continuously grazed veld. The Tukey's post-hoc test was used to compare the means.

4.3 Results

4.3.1 Species composition

The results (Figure 4.1) show that the veld is dominated (>15%) by species like *Heteropogon contortus*, *Sporobolus africanus*, and *Microchloa caffra*. Furthermore, species such as *Eragrostis plana*, *Eragrostis racemosa*, *Hyparrhenia hirta, Paspalum scrobiculatum, Eragrostis chloromelas, Digitaria tricholaenoides* and *Elionurus muticus* were common species (5-14%) in the veld. Additionally, grasses such as *Pennisetum thumbergii*, *Aristida congesta*, *Trachypogon spicatus*, *Brachiaria serrata*, *Monocymbium ceresiiforme*, *Paspalum dilatatum* and *Eragrostis capensis* were rare (<5%).

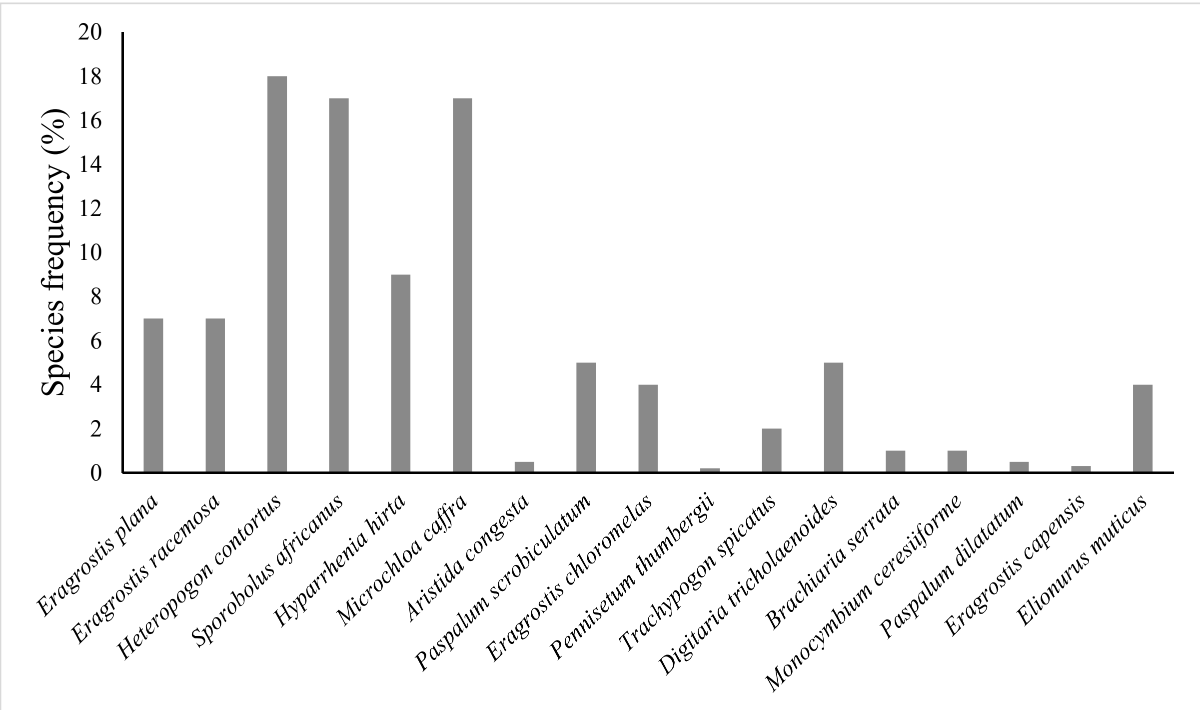

Figure4.1: Species composition frequencies (%) in the Mzongwana veld near Matatiele

4.3.2 Soil fertility

Soil phosphorus (P) and zinc (Zn) levels were low throughout the seasons (Table 4.1), P was significantly higher from late summer (P<0.05) and Zn was highest in late winter (P<0.05). Potassium (K) concentration in the soil was highest in late summer as compared to mid-summer (P<0.05). Concentration levels of nitrogen (N) were not significantly different amongst seasons. Acid saturation (P>0.05) and pH of the soil were low throughout the seasons, but the pH was significantly higher in mid-summer than in late summer (P<0.05) and there were no differences in other seasons.

Table 4.1: Soil fertility dynamics in the CG veld between seasons. **Refer to Appendix E**

Season	P (ppm)	K (ppm)	pH (KCL)	Acid Sat. (%)	Org.C (%)	N (%)	Zn (ppm)
Early summer	3.00^{a}	176.33^{a}	4.33^{ab}	5.33^{a}	1.48^{a}	0.12^{a}	1.75^{a}
Mid-summer	3.00^{a}	221.17^{ab}	4.89^{b}	2.00^{a}	1.92^{a}	0.16^{a}	1.05^{a}
Late summer	4.67^{b}	287.50^{b}	4.38^{ab}	5.17^{a}	1.65^{a}	0.12^{a}	2.75^{ab}
Early winter	5.33^{b}	218.67^{ab}	4.30^{ab}	4.33^{a}	2.10^{a}	0.19^{a}	1.83^{a}
Late winter	5.00^{b}	194.83^{ab}	4.17^{a}	7.50^{a}	2.03^{a}	0.16^{a}	4.40^{b}
Means	4.10	219.70	4.34	4.87	1.84	0.15	2.36
SE	0.11	11.55	0.03	0.68	0.14	0.01	0.21

In the table above, different superscripts in a column depict significant differences ($P<0.05$) of a nutrient component between seasons.

4.3.2 Standing Biomass

The biomass of the CG veld (Figure 4.2) was low throughout the year. In early summer the biomass was estimated to be 338 kg/ha and a decline in biomass was evident during mid-summer. In late summer, the biomass increased to 775 kg/ha thereafter, rapidly declined to 278 kg/ha during the early winter and further decreased to 46kg/ha during the late winter.

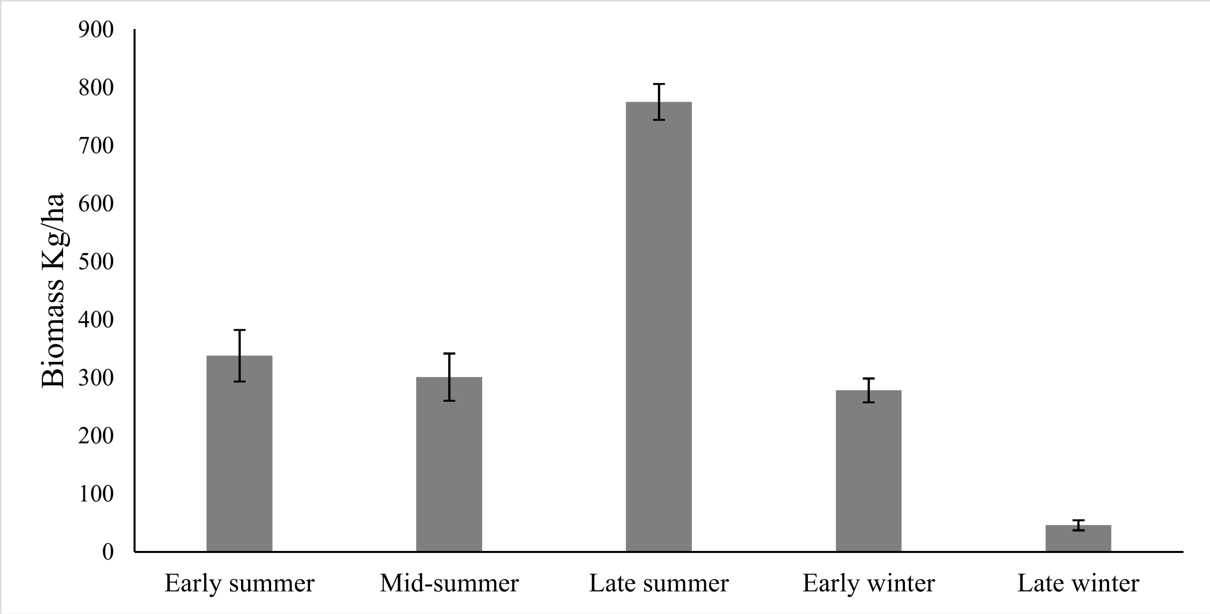

Figure 4.2: Biomass, minus cattle utilisation, in the CG veld of Mzongwana near Matatiele

4.3.3 Forage quality

The results (Table 4.2) shows that ADF was relatively lower throughout the sampling season but was lowest in early summer ($P<0.05$) and gradually increased as the season progressed to be highest ($P<0.05$) in late winter. The forage NDF followed a similar trend to ADF but was generally at high levels throughout the season with lowest levels in early summer ($P<0.05$) and highest levels ($P<0.05$) in late winter. Throughout summer, the forage had a relatively higher CP ($P<0.05$) and started to significantly decline in early winter, the CP levels were then constant throughout winter. Forage P levels were low throughout the season, with no significant differences in summer, but the lowest P levels were recorded in late winter ($P<0.05$). Macro and micro minerals (with the exception of Fe) were generally low and dynamic, with no clear trends between the seasons.

Table 3.2: Forage quality dynamics between and within seasons on the CG veld in Mzongwana, Matatiele, analysed on the 100% dry matter basis. **Refer to Appendix B**

Season	**ADF (%)**	**NDF (%)**	**ASH (%)**	**CP (%)**	**Mg (%)**	**K (%)**	**Na (%)**	**P (%)**	**Cu (mg/kg)**	**Fe (mg/kg)**
Early growing	43.41^{a}	80.42^{a}	6.30^{a}	7.28^{a}	0.08^{a}	0.93^{ab}	0.00^{a}	0.07^{a}	3.51^{a}	683.03^{a}
Mid-growing	49.43^{ab}	82.56^{ab}	7.10^{a}	6.57^{a}	0.08^{a}	1.20^{a}	0.01^{a}	0.06^{a}	3.29^{ab}	498.39^{ab}
Late growing	51.28^{bc}	85.15^{ab}	6.70^{a}	7.10^{a}	0.72^{a}	1.02^{a}	0.00^{ab}	0.07^{a}	2.63^{ab}	215.81^{c}
Early dormant	52.74^{bc}	84.41^{ab}	5.10^{b}	3.16^{b}	0.06^{ab}	0.64^{b}	0.36^{ab}	0.05^{a}	1.96^{b}	268.67^{bc}
Late dormant	56.56^{c}	86.26^{b}	4.70^{b}	2.38^{b}	0.04^{b}	0.28^{c}	0.05^{b}	0.01^{b}	2.06^{b}	337.88^{bc}
SE	0.70	0.60	0.10	0.20	0.00	0.40	0.00	0.00	0.15	28.33

In the above table, different superscripts in a column depict significant differences ($P<0.05$) of a nutrient component between seasons.

4.4 Discussion

4.4.1 Species composition

The CG veld (Figure 4.1) is dominated by *Heteropogon contortus*, *Microchloa caffra* and *Sporobolus africanus*. *H. contortus* is a sub-climax grass that mostly occurs in a disturbed veld, for example, overgrazed veld, and the grass is well grazed and palatable but has a low grazing value as a result of low leaf production (van Oudtshoorn, 2012), such grasses are not desirable for livestock production as they contribute very little to forage quantity. *S. africanus* also a sub-climax grass and has a low grazing value due to its tough leaves, its abundance in a veld is an indication of previous overgrazing, which is the case in this veld. *M. caffra*, on the other hand, is a less acceptable pioneer grass with a low grazing value due to low leaf yield, but its abundance suggests that the veld is overgrazed and is undergoing a reverse successional process. These results are in-line with Tainton *et al.* (1999) suggestion that in a continuous grazing system selection will inevitably occur and suppress desirable species in favour of undesirable species.

4.4.2 Soil fertility

The continuously grazed veld had a generally low soil fertility. Soil N concentration was low (0.15%) throughout the seasons and showed no variability throughout the year (Table 4.1). Low N concentration in this veld may be as a result of low biomass accumulation and topsoil erosion which resulted from continuous overgrazing. This ultimately resulted in low SOM, which has a direct correlation with N mineralization and concentration in the soil (Campbell and Souster, 1982; Foth and Ellis, 1988). The aforementioned reason may be a relative cause for less dynamic soil N, as the veld maintains very low OM. Moreover, insignificant seasonal variation may be due to an equilibrium balance between N losses and OM supplied through animals excretion, as the veld is continuously stocked. In contrast, N is reported to be very mobile in soils and seasonal variations have been exceptionally studied (Hardy *et al*., 1999; Hatch, 1999; Mile and Manson, 2000).

The soils were generally acidic, with pH levels higher in mid-summer (4.89 KCI) as compared to late winter (4.17 KCI) and the other sampling seasons showed no differences. In acidic soil, the P concentration is reduced due to the likelihood of bonding with Al and mineralization rate is reduced (Sumner *et al*., 1991). In contrast, Miles and Manson (2000) suggested that in oxide soils, such as these soils, P sorption is increased and acidity has limited influence on the process. Nonetheless, P concentration in the soils is largely influenced by the levels of SOM in which organic P is mineralized (Miles and Manson, 2000).

The results also show that Zn is generally low and is significantly higher in late winter (4.4 mg/L). In contrast, Zn concentration in the soil did not show a clear response to low pH levels, as suggested by Foth and Ellis (1988), however, Miles and Manson (2000) argued that liming reduces the availability of Zn and Cu. In addition, OM provides the largest quantity of usable minerals in the soil and therefore points out that Zn is reduced with decreased SOM (Foth and Ellis, 1988; Miles and Manson, 2000). Macrominerals, K, Mg, and Ca, have high concentrations in the soil, however, only K showed a significant difference in early summer (lower) as compared to late summer (higher). These variations may be attributed to the year-round supply of K through manure, as a result of the continuous occupation of the camp. Due to increased soil temperature and moisture, from early summer to late summer, the manure is rapidly decomposed thus increasing available soil K. In addition, K is relatively mobile in soils, however, it mobility may be limited to the sandy soils (<15% clay) (Miles and Manson, 2000). The soils in this veld consist of more than 31% clay, hence there is less variability between summer and winter. Nonetheless, availability and uptake of soil minerals are largely influenced by acidity (Foth and Ellis, 1988; Epstein and Bloom, 2005).

4.4.3 Standing biomass

The CG veld had a relatively low biomass (Figure 4.2), as a result of heavy grazing intensity and multiple livestock types grazing the veld. The first data set was collected in November (early growing season), after the first rains and the biomass was at 338kg/ha then during the mid-growing season (January) the biomass decreased to 301kg/ha. This decline is most likely to be as a result of delayed rains during the mid-growing season. Furthermore, active cattle consumption may have a significant impact on the accumulation of biomass in the CG veld. The veld is continuously grazed therefore grass is kept short and actively growing, then when good rain was received, during the late growing season, biomass started to rapidly increase to 775 kg/ha. Biomass at the beginning of the dormant season (June), as expected, drastically declined to 278 kg/ha and further declined during the late dormant season to 46 kg/ha which cannot support grazing. The declines in biomass during the dormant season might be as a result of continuously overgrazing and also due to the physiological dormancy of grasses during this period, especially in these areas where winters are dry and cool. These results are similar to results reported by Pavlu *et al*. (2006) on a study conducted in the Czech Republic on the effects of continuous grazing on forage quality, quantity and animal performance. In addition, McNaughton (1979) found similar results in the US and concluded that under continuous grazing biomass production is at its peak when grazed at moderate intensity and as the grazing intensity becomes heavy biomass drastically production declines. Therefore, due to heavy grazing intensity in this veld biomass was very low during the growing season and continued to rapidly decline throughout the dormant season making the veld less productive and unable to sustain livestock production.

4.4.4 Forage quality

Forage quality of the continuously grazed veld was generally poor (Table 4.2). The increase in fibre (ADF and NDF) and a decline in CP content of the forage were gradual and steady most of the year. Retained quality was mainly as a result of continuous grazing and keeping the grass short, in a vegetative stage (Allred *et al*., 2011). Pavlu *et al*. (2006) also observed that sward height significantly influences fibre, CP and digestibility of forage. The veld had the lowest ADF and NDF in early summer and then gradually increased to be higher in winter. Increase in forage fibre may attribute to level of maturity, in addition, Jones *et al*. (1988) and Meissner *et al*. (1999) suggested that tropical forage species have more cellulose content and a greater hemicellulose: cellulose ratio than temperate species, which might be due to a rapid growth rate of tropical species. Forage with high ADF and NDF content has low digestibility and the voluntary intake is significantly reduced (Jung and Allen, 1995; Meissner *et al*., 1999). In contrary, Russell *et al.* (1992) suggested that feed high in NDF increase rumination and saliva secretion which maintains favourable rumen pH (>6) and increases microbial survival and activity (Jones *et al*., 1988).

The CP level of the veld was highest in early summer and maintained the levels throughout the season and only started to significantly decline in winter to levels <5%. According to the minimum CP levels of beef cattle on limited forage availability described by Meissner *et al*. (1999), the veld can sustain growth and pregnancy during summer. The minimum CP requirements for lactation (8.4%) can only be achieved in this veld with adjusted resting programs and/or stocking rates. In addition, adjusting the grazing intensity and stocking rates in continuous grazing systems influences forage quality and animal performance (Jung *et al*., 1985; Heitschmidt *et al*., 1987).

The mineral matter (ash) content in the forage was significantly higher in summer than in winter. As defined by Cullison (1982), ash content represents the total amount of inorganic/mineral constituents present in the feed, include essential mineral and those that might not be absorbed by the animals. The average ash content (5.98%) of the forage was generally low, in relation to soil fertility. Soil minerals in this veld were high, with the exception of P and N, nonetheless, this is not reflected in the forage mineral matter. This may be attributed to low levels of N: P which reduces the ability of the roots to absorb P and other minerals (Miles and Manson, 2000). In addition, the low P levels generally inhibit root growth and performance.

Findings from this study suggest that the forage is low in mineral content as a result of low available soil minerals. In addition, Mg, K, Na, and P contents were low in the forage and significantly declined further in winter. According to Judson and McFarlane (1998), the mineral requirements of Mg, K, Na, and P for growing and lactating beef cattle are 1.9, 5, 0.8 and 1.2, and 1.8 and 3.3 % respectively. Although CP can support maintenance, growth and lactation in early to mid-summer, insufficient mineral content in this veld compromises the sustainability of livestock production.

4.5 Conclusions

The continuously grazed veld had low soil fertility, however, soil N and organic C remained steady throughout the year. Steady levels of N and organic C increased the period of nutrient supply, resulting in the ability of the forage to retain CP levels at livestock growth requirement levels throughout summer. Although the veld maintains good CP requirements, continuous overgrazing is reversing plant succession and less productive species such as *H. contortus*, *S. africanus* are replacing palatable species such as *B. serrata* and *D. tricholaenoides*. The palatable species present in this veld mentioned above, are leafy and mature slowly and may account for a relatively slow increase in forage fibre (ADF and NDF). In addition, active vegetation growth under the continuous grazing system may, however, be the principal factor contributing to good quality forage over the seasons.

Based on the stated finding, it is important to review the employed grazing system so as to restore vigour and competitiveness of desired grass species. This will be achieved by rotating livestock between the natural veld and the old lands. Thus, grazing the natural veld during late-summer to winter, as the CP and fibre levels are sustained at relatively good levels during winter. This grazing regime will encourage restoration of plant vigour and competitiveness during the following growing season. Therefore, it is necessary to consider resting of the veld during summer to promote rehabilitation of the natural veld and improve availability of good forage in winter through improved species composition.

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CHAPTER 5: FORAGE QUALITY UNDER ROTATIONAL GRAZING

ABSTRACT

Rotational grazing systems are frequently advocated to increase the overall productivity of veld, and consequently livestock production. However, adopting these systems requires a level of ecological knowledge and capital, making it challenging to optimally implement them, especially in the natural veld. With the aim to investigate the influence of grazing strategies on utilisation regimes and forage quality, a farm under an intensive strip-rotation system was selected (Wakefield). Data was collected seasonally for biomass, forage quality, and soil fertility, species composition assessment was done once. Biomass accumulation was determined before and after grazing to examine forage utilisation throughout the year. The study found that forage utilisation is directly influenced by active growth of forage, however, the biomass accumulation negatively affected the utilisation of forage over the year. Although the soil was fertile, biomass accumulation was the primary factor which reduced the quality of forage in this site. Moreover, a strong inverse relationship between biomass accumulation and forage crude protein (CP) was evident, throughout the year. Nonetheless, dominance by leafy and highly productive species such as *T. triandra* reduced forage fibre content throughout the year. It was, therefore, advisable to reduce the periods of livestock absence and increase grazing intensity so that forage may be kept in a vegetative state without reducing plant vigour.

5.1 Introduction

Rotational grazing, as defined by Booysen (1967), has gained a rapidly increasing interest in Southern Africa, especially in arid and semi-arid areas of the region (Wessels *et al*., 2007). The interest has mostly resulted from increasing degradation consequences that include decreased livestock production, decreased forage quantity and quality, and increased soil loss (Stringer and Reed, 2007). Because a livestock enterprise cannot successfully function without sustainable forage supply, it was then necessary to adopt a grazing plan that relatively secures production success and a number of rotational grazing system were adopted.

Although the rotational systems are widely recommended, there are a number of studies that suggest otherwise. Heitschmidt *et al*. (1987) concluded that the differences in forage (quality and quantity) were not necessarily affected by the type of grazing system but largely by the stocking rate. However, Heitschmidt *et al*. (1990) pointed out that forage production might not be influenced by the grazing system adopted but there is compelling evidence on influences on veld condition. According to Bailey and Brown (2011), even in rotational systems increasing stocking rates have some negative consequences and advises that increasing stocking densities at constant stocking rates can reduce the effects. Increased stocking rates encourage heavy defoliation, overgrazing of palatable grasses and reduced animal performance (Palvu *et al*., 2006).

Rotational grazing systems have been shown to improve in vegetation characteristics and are thought to the best options to sustain an excellent livestock production (Tainton *et al*., 1999). Nonetheless, many studies have been conducted to quantify the influence of one or more rotational systems on forage quality and quantity, species composition shift and animal gains in different vegetation types (Heitschmidt *et al*., 1987; Jacobo *et al*., 2006). According to Barnes (1989), these systems are all based on either the lenient utilisation philosophy which aims to increase forage production or the heavy utilisation philosophy aiming to increase the stocking rate. Hence, it is very important to investigate productivity and animal performance under rotational systems in a given environmental condition and not to generalise as the utilisations aims might also not be the same.

5.2 Methods

5.2.1 Site description

A study to evaluate the influence rotational grazing on forage quality was conducted in Wakefield Research Farm at Fort Nottingham, KwaZulu-Natal (KZN). Wakefield Research

Farm is situated at 29°9’0” S longitude and 28°47’60” E latitude and the terrain elevation above sea-level is estimated to be 1343m.

Figure5.1: Wakefield Research Farm location in KZN, South Africa

Rainfall is estimated to be about 890 mm per annum and its distribution is such that it peaks in mid-summer and significantly declines throughout winter (Munica and Rutherford, 2006). Frost seldom occurs (Munica and Rutherford, 2006). The vegetation of the farm is classified by Munica and Rutherford (2006) as the Drakensberg Foothill Moist Grassland which is characterised by mountains and river valleys of drier vegetation types and forests. The grassland is rich in forbs and is dominated by *Themeda triandra* and *Tristachya leucothrix*. Soils originate from mudstones and sandstones of the Tarkastad Super group, the Molteno Formation and dolerite (Munica and Rutherford, 2006). Dominant soils on the sedimentary parent material are well drained with the depth of more than 800mm (Munica and Rutherford, 2006). This sour veld is on sandy clay soils (42.3% clay) as categorised by Black (1957).

5.2.2 Experimental design

The rotationally grazed veld is situated on a 527 ha farm and is divided into 9 paddocks of different sizes. The veld is grazed by 156 Nguni cattle and the cattle are supplemented in winter.

The current stocking rate in this veld is unknown but estimated to be low. Biomass data were collected before and after grazing in all sampling periods to determine utilisation intensity.

5.2.3 Data collection

Species composition:

A 100 m line-transect was laid, six times, 25 m apart in each site. Along each transect a 0.5 by 0.5 m quadrat was laid every 2 m and grass species within the quadrats were identified, then species frequencies were derived.

Soil fertility:

Along each 100 m line-transect, four soil samples were collected at 25, 50, 75, and 100 m in all sites. The samples were collected at 0-15 cm depth and stored in paper bags then air dried for 7 days. The samples were then stored in plastic bags for soil fertility analysis in Cedara laboratory (Research and Technology Development, Analytical Services). The laboratory analysed for soil pH and acid saturation, macro-minerals (N, K, P, Mg, Ca), micro-minerals (Zn, Mn, Cu), and organic carbon.

Forage quantity:

The biomass of the sites was estimated using the comparative yield method which is widely used for estimating dry matter yields (Friedel *et al.*, 1988; Dekker *et al.*, 2001). The method is rapid and has been reported to adequate for large areas such as rangelands. The technique required a set-up of rank-reference quadrats, the quadrat with the least biomass was ranked 1 and the one with the highest biomass ranked 10. Along each of the six 100 m line-transects a 0,5 m by 0,5 m quadrat was laid 2 m apart, to represent the area surveyed six transects, 25 m apart were laid. All sampled quadrats were ranked accordingly and the biomass within every fourth quadrat was clipped to the height of 5 cm and oven dried at 60 ºC for 48 hours. The dried grass was thereafter weighed to estimate the dry matter content. Then the data was calibrated using the linear regression technique to estimate the aboveground biomass, in kg/ha, available for utilisation by livestock.

Forage quality:

After drying, the bulk grass samples collected for biomass were then milled using a 2mm sieve, and stored in plastic jars for a full feed analysis in the Cedara laboratory. Forage was analysed for the levels of the acid detergent fibre (ADF), neutral detergent fibre (NDF), crude protein

(CP), macro-nutrients (calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), sodium (Na)), micro-nutrients (zinc (Zn), copper (Cu), manganese (Mn), iron (Fe)), and the mineral matter (ash).

5.2.4 Analysis

The data were analysed using the IBM SPSS version 24. The Multivariate (MANOVA) of the General Linear Models (GLM) were used to determine the effect of the season on soil fertility and forage quality under a rotationally grazed veld. The Tukey's post-hoc test was used to compare the means.

5.3 Results

5.3.1 Species composition

The veld was dominated (>15 %) by *Themeda triandra* and *Tristachya leucothrix* (Figure 5.2). Species like *Sporobolus africanus*, *Eragrostis plana*, *Paspalum scrobiculatum*, *Diheteropogon filifolius* and *Eragrostis curvula* are common (5-15%) in the veld. Rare species (<5%) found in the veld include *Sporobolus pyramidalis*, *Aristida juncciformis*, *Pennisetum thunbergii*, *Hyparrhenia hirta* and *Trachypogon spicatus*.

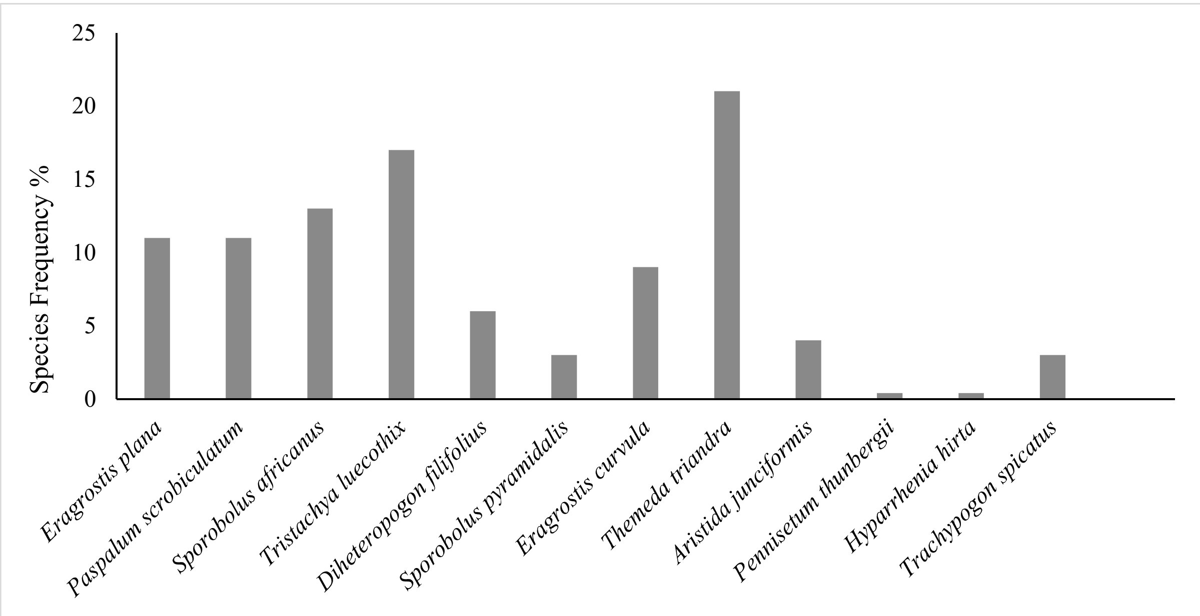

Figure5.2: Species composition (%) in the RG veld in Wakefield Research Farm (KZN)

5.3.2 Soil fertility

The soil fertility in the RG veld (Table 5.1) is relatively high. Mineral salts such as Ca, Mg and K have maintained high levels in the soil. Although Ca, Mg and K showed no significant difference (P<0.05) over the year, higher levels were evident during late summer. The soil is high in organic C and P, however, organic C showed no significant variations over the year and P was higher during early summer as compared to mid-summer ($P<0.05$). Concentration levels of N in the soil were, as anticipated, lower in winter and higher in summer ($P<0.05$). The veld had soils relatively low micro-minerals such as Zn and Mn, and variability of Mn levels was significantly evident. Although the soil of this veld was highly fertile, soil acidity remained high throughout the year and marked concentrations of acidity were during early-mid summer and late winter.

Table 4.1: Seasonal dynamics in soil fertility of the RG veld in Wakefield Research Farm (**Refer to Appendix F**)

Season	**P ppm**	**K ppm**	**Ca ppm**	**Mg ppm**	**Acid Sat. %**	**pH KCL**	**Org. C %**	**Zn ppm**	**Mn ppm**	**N %**
Early summer	14.67^{b}	232.17^{a}	247.17^{ab}	83.67^{ab}	46.83^{bc}	3.95^{a}	5.70^{a}	2.10^{a}	11.83^{c}	0.41^{b}
Mid-summer	7.00^{a}	197.33^{a}	366.33^{bc}	110.33^{b}	42.33^{bc}	3.99^{ab}	6.12^{a}	1.38^{a}	11.67^{c}	0.41^{b}
Late summer	8.17^{ab}	386.67^{b}	467.83^{c}	150.33^{c}	24.33^{a}	4.02^{ab}	5.00^{a}	1.45^{a}	10.00^{cb}	0.32^{ab}
Earl winter	9.33^{ab}	148.17^{a}	240.83^{ab}	82.50^{ab}	36.67^{ab}	4.09^{b}	5.08^{a}	1.87^{a}	7.50^{ab}	0.29^{a}
Late winter	11.00^{ab}	166.17^{a}	151.83^{a}	70.67^{a}	54.00^{c}	3.93^{a}	4.83^{a}	3.85^{b}	4.67^{a}	0.29^{a}
Means	10.03	226.10	294.80	99.50	40.83	3.99	5.35	2.13	9.13	0.34
SE	0.78	11.26	15.26	4.27	1.68	0.01	0.18	0.13	0.45	0.01

In the above table , different superscripts in a column depict significant differences ($P<0.05$) of a nutrient component between seasons.

5.3.2 Biomass production

Biomass production (Figure 5.3) was highest during the early growing season (2937 kg/ha) and lowest during the late dormant season (860 kg/ha). Biomass accumulation decreased (1744 kg/ha) during the mid-growing season and gradually increased (2287 kg/ha) in the late growing season the declined during the dormant season. The results also show an increase in the dry matter intake from the early-mid-late growing season (486, 843 and 1012 kg/ha, respectively), and a decrease throughout the dormant season.

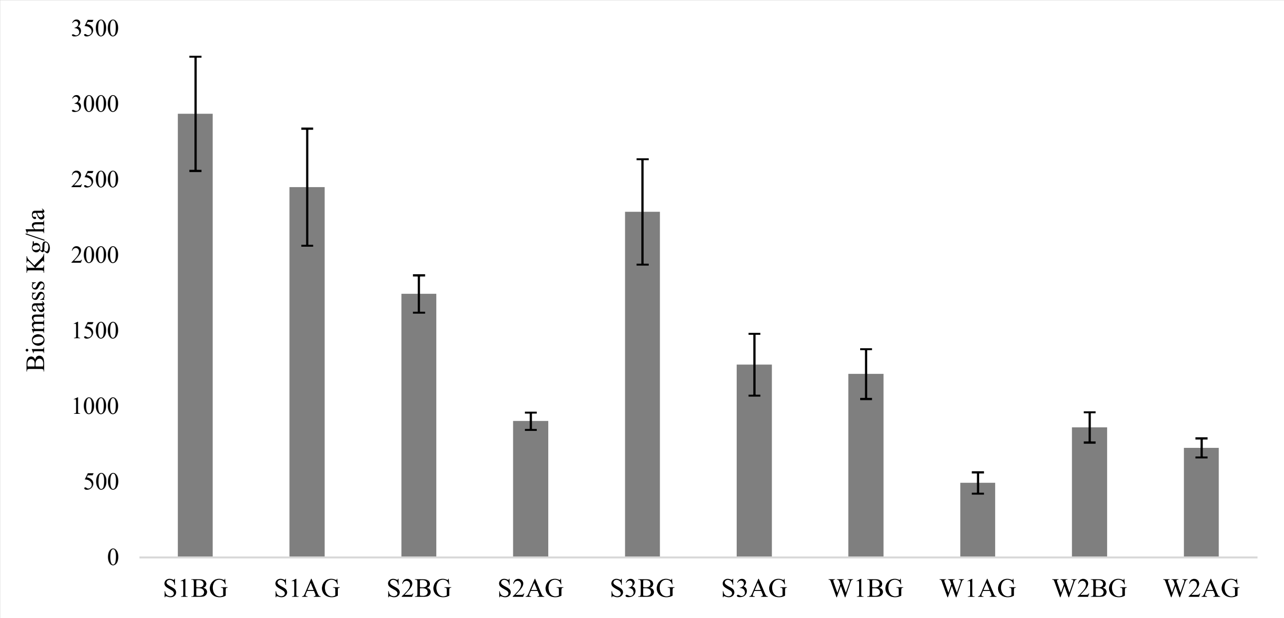

Figure 5.3: Biomass utilisation trends in the RG veld in Wakefield Research farm (S1-2-3: early-mid-late growing season; W1-2: early-late dormant season; (BG), (AG) before and after grazing respectively)

5.3.3 Forage quality

Forage quality in the rotationally grazed veld was low (Table 5.2). The NDF contents were lowest ($P<0.05$) in early summer and in early winter, and were highest ($P<0.05$) in late winter. The ADF levels of the forage were high throughout the sampling seasons, with the average of 51.27%. Forage from this veld had relatively low CP levels throughout the seasons and was highest ($P<0.05$) in early- and mid-summer then started to decline significantly in late summer and constantly low throughout winter ($P<0.05$). The mineral matter (ash) content was generally low in this veld but was highest in mid-summer ($P<0.05$) and lowest in early winter ($P<0.05$). The mineral content was generally low throughout the seasons, Ca, Mg, and Na levels were significantly high from mid-summer ($P<0.05$), and K and P contents were higher in summer ($P<0.05$) and began to decline from late summer ($P<0.05$) and were significantly reached a low hit in late winter. The micro-minerals, Zn and Mn, in the forage were significantly high in late summer and early winter, respectively.

Table 5.2: Seasonal forage quality in the RG veld in Wakefield Research Farm, analysed on 100% dry matter basis **Refer to Appendix C**

Season	NDF (%)	ASH (%)	CP (%)	Ca (%)	Mg (%)	K (%)	Na (%)	P (%)	Zn (mg/kg)	Mn (mg/kg)
Early summer	81.09^{a}	5.72^{ab}	6.14^{a}	0.12^{a}	0.05^{ab}	0.93^{a}	0.00^{a}	0.06^{a}	9.89^{a}	123.78^{a}
Mid-summer	82.52^{ab}	6.15^{b}	5.97^{a}	015^{ab}	0.07^{bc}	1.07^{a}	0.00^{ab}	0.05^{a}	11.68^{a}	117.95^{a}
Late summer	84.34^{ab}	5.57^{ab}	4.33^{b}	0.19^{b}	0.06^{bc}	0.81^{ab}	0.02^{ab}	0.09^{b}	15.54^{b}	117.56^{a}
Early winter	81.24^{a}	4.71^{a}	2.87^{c}	0.19^{b}	0.08^{c}	0.65^{b}	0.02^{b}	0.01^{c}	10.12^{a}	169.39^{b}
Late winter	86.33^{b}	5.10^{ab}	2.77^{c}	0.13^{a}	0.04^{a}	0.28^{c}	0.01^{ab}	0.01^{c}	10.13^{a}	114.15^{a}
SE	0.42	1.50	0.13	0.00	0.00	0.03	0.00	0.00	0.39	4.16

In the table above, different superscripts in a column depict significant differences (P<0.05) of a nutrient component between seasons.

5.4 Discussion

5.4.1 Species composition

The RG veld (Figure 5.2) is dominated largely by *T. triandra.* The species is mainly found in the undisturbed veld and is highly productive with an excellent grazing value throughout the year (van Oudtshoorn, 2012). Dominance by this species is an indicator of a good grazing management (Danckwerts, 1989; Teague and Danckwerts, 1989; van Oudtshoorn, 2012) and improves the organic matter content of the soil (Heady, 1966).

In this sourveld *T. triandra* commonly co-exists with *T. leucothrix* (Stoltsz and Danckwerts, 1990). In addition, Peddie *et al*. (1995) refered to these grasses as the most important in the sourveld. *Tristachya* is highly productive and is most palatable when young (during the early growing season) and the leaves become rough and tough on maturity (van Oudtshoorn, 2012). In contrast, a study done in the Dohne sourveld showed that *T. luecothrix* is the most preferred grass (over *T. triandra*) during the autumn and early winter (Stoltsz and Danckwerts, 1990). Nevertheless, the dominance of *Tristachya* in a veld is an indicator of underutilisation and irregular burns (van Oudtshoorn, 2012). The rotationally grazed veld is predominated by climax grasses which are resistant to controlled heavy defoliation (Peddie *et al*., 1995), which makes it more stable and thus, sustainable.

5.4.2 Soil fertility

The rotationally grazed veld soils are generally acidic (pH low and high acid saturation). According to Sumner *et al*. (1991), soil acidity is an important fertility determinant. Low pH levels and high acid saturation % in the veld soils indicates low soil fertility and a high Al^{3+} toxicity probability. The results (Table 5.1) revealed that a lowest pH levels in early summer and late winter acid saturation in highest (46.48% and 54%, respectively). Moreover, a direct correlation between acid saturation, Al^{3+} concentration and toxicity levels in the soil have been established (Foth and Ellis, 1988; Ritchie, 1989; Paterson *et al*., 1991). With that said, certain grasses may be well adapted to more acidic condition than others, such as *T. leucothrix* which tend to dominate in the sourveld, where soils are acidic (Hardy *et al*., 1999).

In addition, N concentration in the soil was very low throughout the sampling period although concentrations levels were higher in summer as compared to winter. In contrast, increased SOM has been reported to have a positive influence on usable N and amount of organic C (Campbell and Souster, 1982), which may be expected in veld where forage quality is not limited and moribund material may be high. Low N levels in the veld may be as a result of high acidity, which inhibits soil microbial growth and activities (Robson and Abbott, 1989). Nitrogen levels did not necessarily show an inverse correlation with increased acidity from summer to winter. This may be due to the general N leaching fluctuation between and within seasons.

The veld had high levels of minerals, the soil was mostly rich in K, Ca, and Mg. These minerals had the highest levels in late summer (386.67, 467.83, and 150.33 mg/L respectively) and the lowest levels were found in late winter (151.83, and 70.67 mg/L respectively) with the exception of K. High soil acidity has been, also, documented to encourage toxic levels of Al and Mn in the soil solution (Foth and Ellis, 1988; Paterson *et al*., 1991; Sumner *et al*., 1991), hence the high levels of Mn in summer when acidity was high. The authors also point out that in highly acidic soils Al is bound with P to reduce its availability for plant absorption. In contrast, P levels in this veld were highest in early summer when acidity was at its peak and did not show a clear response to pH and acidity levels. This might be as a result of excluding topography effect during sampling.

Nitrogen available has been suggested to influence species composition and basal cover, and competitive interactions between grass species in the Tall Grassland (Morris and Fynn, 2001). However, Hefer (1994) and Findlay (2010) concluded that even under N fertilization, forage quality (CP) is greatly influenced by plants' seasonal physiological stage and water availability. Therefore, growth and quality of natural forage grasses are, to some extent, not limited by soil fertility but by climatological factors such as rainfall.

5.4.2 Biomass

Biomass in the RG veld (Figure 5.3) was highest during the early growing season 2937 kg/ha (November) (Heitschmidt *et al*., 1987), this may be due to the high rainfall regimes during the early growing season but then the rains declined during the mid-growing season (January) which concurrently reduced the biomass (1744 kg/ha). As the growing season progressed, biomass gradually increased (2287 kg/ha) during the late growing season (April) when the rainfall was higher. Thereafter, the biomass decreased during the early (June) and late (August) dormant season due to reduced rainfall and inactive growth phase.

It is evident in the results that after the grazing period (14 days), utilised biomass increases as the growing season progresses, higher during the late growing season (1012 kg/ha) and lowest during the early growing season (486 kg/ha). The high biomass utilisation during late growing season may be due to a decline in forage quality and cattle are compensating for low quality by higher dry matter intake (Heitschmidt *et a*l., 1987; Bailey *et al*., 1996). As expected, during the early dormant season biomass utilisation decline (721 kg/ha), and is further reduced to 136 kg/ha during the late dormant season. This may be as a result of very low tiller production and/or inactive growth and most of the standing grass during this season is dead material (Heitschmidt *et a*l., 1987). Due to low quality during the dormant season, cattle tend to avoid grasses like *A. junciformis, S. africanus, S. pyramidalis, E. plana, D. filifolius*, as they have very high cell wall content especially during winter (van Oudtshoorn, 2012), hence lower forage utilisation during this season. As a result of cattle supplementation during the dormant season, selectively grazing and avoidance is likely, which may reduce overall forage utilisation.

5.4.3 Forage quality

The ADF levels of the forage are high throughout the season with an average of 51.27% and the NDF content is lower in early summer and early winter as compared to NDF levels in late winter (Table 5.3). The ADF and NDF levels in the forage from this veld were high, suggesting that a reduced amount of nutrients may be available for digestion and absorption by an animal.

Forage ADF and NDF are greatly influenced by forage maturity (Meissner *et al*., 1999), and in this veld forage high fibre levels may attribute to long resting period and allow biomass to accumulate (Figure 5.4), hence the quality of the veld is low (Palvu *et al*., 2006; Allred *et al*., 2011).

The forage CP content was relatively low throughout the seasons, although it was significantly higher in early- and mid-summer but, began to decline during late summer and further decreased to very low levels in winter. CP is the most significant nutrient components of the feed as it supports basic cell development and growth (Coleman and Moore, 2003), therefore adequate levels to sustain physiological changes of an animal are important for successful production. According to Jung and Allen (1995), high levels of CP in a feed enhances dry matter intake and the capacity of the rumen to digest fiber.

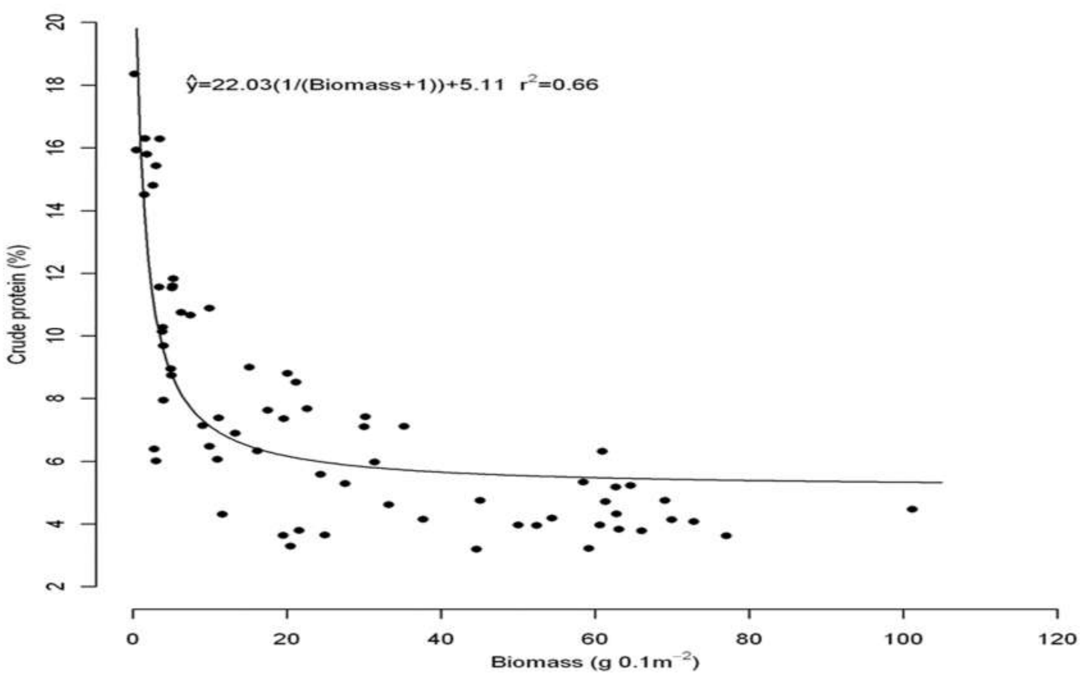

Figure5.4: The inverse relationship between biomass accumulation and forage quality, derived from Allred et al. (2011)

Forage available in this veld is high in fiber (ADF and NDF), hence the low CP levels, therefore animal cannot sufficiently digest nutrients available in the forage.

The rotationally grazed veld was generally low in mineral content, the total forage mineral matter (ash) was significantly higher in mid-summer as compared to early winter. This may be attributed to severe soil acidity and therefore low P availability. Due to the importance of P in root growth, reduced P availability inhibits the ability of roots to absorb available soil minerals

(Foth and Ellis, 1988; Ritchie, 1989; Paterson *et al*., 1991). Although essential mineral contents were less dynamic throughout the seasons, forage P levels followed the CP trend and were significantly high in early- and mid-summer and thereafter declined in late summer then further declined in winter. The average forage P (0.04%) in this veld is very low and may not support optimum livestock production throughout the year (Judson and McFarlane, 1998).

In addition, Meissner *et al*. (1999) pointed out that South African soils are generally low in soil P, therefore P should be supplemented in pasture-based livestock. Other macro-minerals were not as dynamic and did not show clear trends within and/or between seasons, but Ca was significantly higher in late summer and early winter, and Mg, K, and Na were significantly higher in winter. The levels of all the macro-nutrients available in the forage were low and may not sustain production (Judson and McFarlane, 1998). Zn content was higher in mid-summer and Mn was higher in early winter, with the average of 11.5mg/kg and 128.6mg/kg respectively, according to Judson and McFarlane (1998), these are adequate level for beef cattle.

5.5 Conclusions

The soil in the rotationally grazed veld was highly fertile. However, high levels of soil acidity may have reduced forage quality. On the other hand, high biomass accumulation in the veld, as a result of extended resting periods and residue carryover, reduced the overall CP content. The reduced forage quality of the veld was also reflected by the reduced forage utilisation which declined gradually throughout the year. Nevertheless, dominance by leafy and highly productive grass species such as *T. triandra* and *T. leucothrix* maintain a steady increase of the fibre content throughout the season. The results, therefore, clearly suggest that soil acidity and biomass accumulation are the major factors influencing the forage quality in this veld.

Based on these results, it is then essential to reduce the resting period of the camps and increasing the grazing intensity and/or stocking rate so that available biomass may not be carried over to the following grazing period and forage is not allowed to reach maturity during the growing period. It is also advised that the cattle should be supplemented with high P feed throughout the year, due to high P-deficiency risks resulting from high soil acidity.

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CHAPTER 6: INTEGRATION AND SYNTHESIS OF DATA FROM THE THREE STUDY SITES

6.1 Introduction

The study was conducted in a Research Farm (Wakefield) under a rotational system and communally grazed rangeland at Nzongwana near Matatiele. The Mzongwana rangeland comprises of old lands grazed mainly in winter and a continuously grazed veld. The stocking rates were estimated to be high in the old lands and the continuously grazed veld and low in the rotationally grazed veld. The aim of the study was to investigate the relationships between previous land use history, and grazing management, species composition, soil fertility, and forage quality and quantity over the year. The study was initiated to develop veld management recommendations for livestock production on veld and old lands in communal areas.

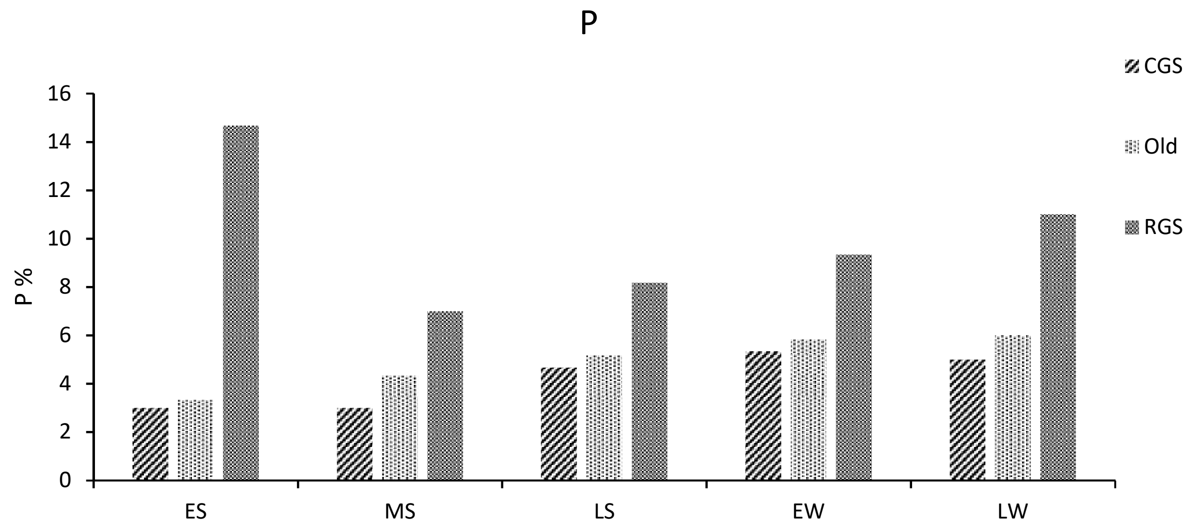
6.2 Species composition

Each site in the study showed unique grass species composition. As expected, the old lands were very low number of species and were dominated by less desirable grass with low grazing value (*Eragrostis plana, Hyparrhenia hirta,* and *Sporobolus africanus*). The continuously grazed veld, on the hand, had a greater number of species and dominated by species that are more accepted by livestock throughout the growing season (*Heteropogon contortus* and *Microchloa caffra*). However, these grass species produce low leaf material and, therefore, have a limited role in providing useful forage. Low leaf production in this veld promoted soil erosion risks as the forage is generally kept low by continuous utilization. Although the old lands had grasses like *H. hirta* which produces high leaf material, the grass is generally preferred by livestock when it is young and leafy. High producing grasses like these can be beneficial in the old lands to improve the conditions for more desirable grasses by protecting the soil and seed bank.

The rotationally grazed veld in Wakefield (KZN) was in a different grassland type (Drakensberg Foothill Moist Grassland), however, the concepts remain the same and for this study, the results will be comparatively discuss. The farm was dominated by *Themeda triandra* and *Tristachya leucothrix* which are valuable grasses for livestock production in this veld. These grass species are important grasses in this veld and are highly productive with high grazing preference. Nonetheless, *T. leucothrix* abundance is associated with low veld utilisation. Of all sites, the rotationally grazed veld appeared to be more stable as it was mainly dominated by climax grasses and therefore, can successfully tolerate high-intensity defoliation by grazing.

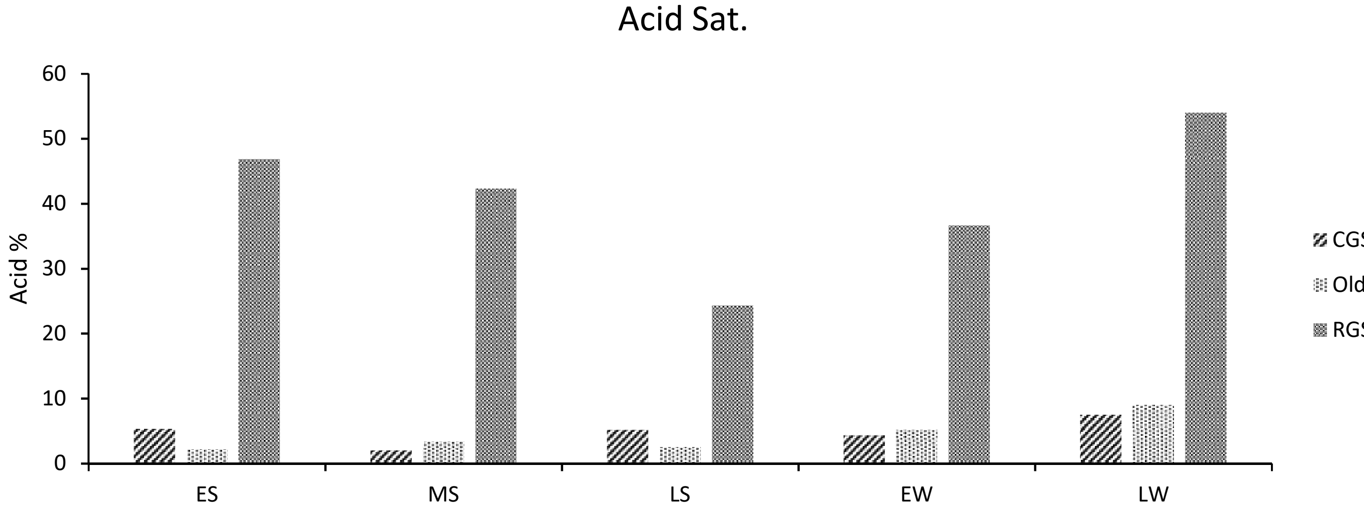
6.3 Soil fertility

Soil fertility is a measure of the capability of the soil to supply essential nutrients to plants in the required amounts for growth. By nature, animals are solely dependent on plants for growth, maintenance, and reproduction, therefore it is relevant to quantify the amount of nutrients that the plants can absorb to store for animal use. Although the soil has been reported to be inherently low in P, there is convincing evidence suggesting that P is one of the macro-nutrients essential for growth and photosynthesis. This study showed significant differences in the availability of P in the soil in all sites and these concentrations were less dynamic within and between seasons Table 3.1, 41, and 5.1. In the rotationally grazed veld, the P levels were higher throughout the year.

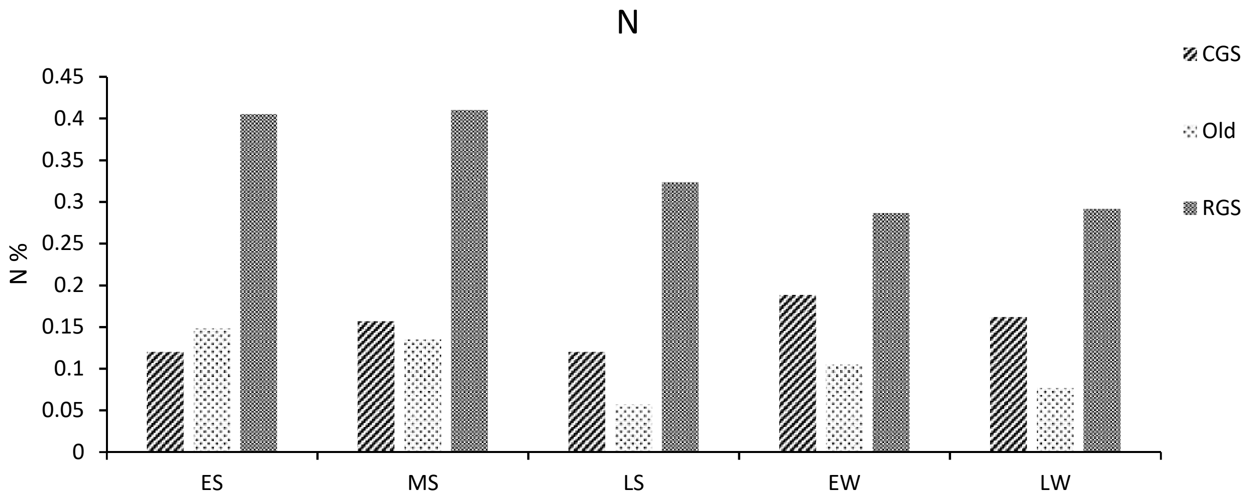


The old lands and the continuously grazed veld both had low P concentrations throughout the year. The similarities in P levels between these sites may be attributed to the fact that they are in the same area and the soils are derived from the same parent material which may be low in the P mineral. By contrast, the parent material in the rotational veld may possess greater P levels in the soils solution.

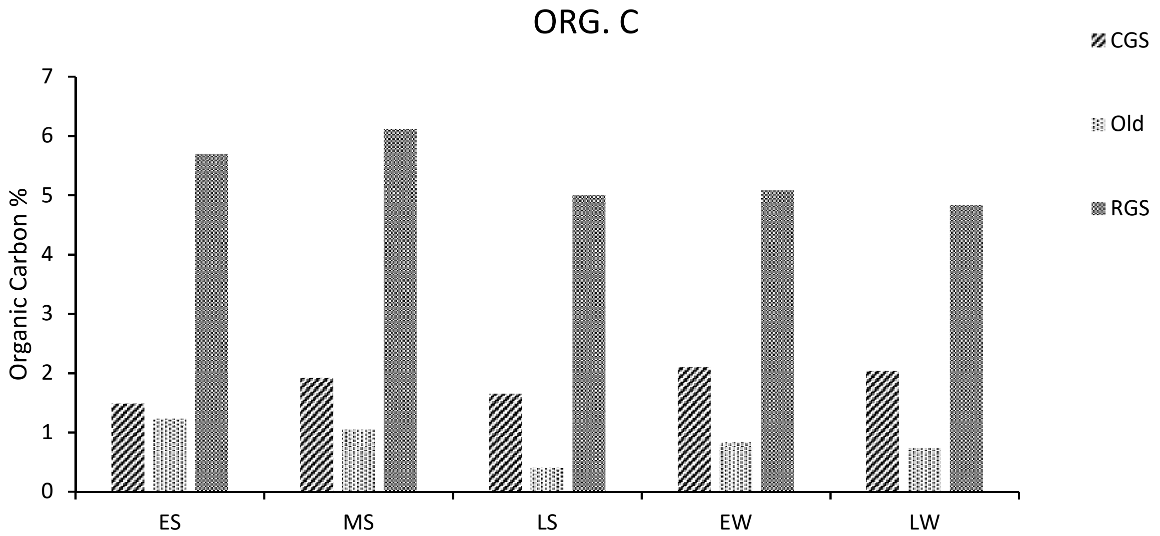
High soil acidity in the rotationally grazed veld may transforms P to a P species/compound that makes it unavailable to plant due to bounding with Al^{3+} which becomes highly active in acidic soils.



Soils in all site were high in K, Mg, and Ca, which are also essential macro-minerals, that is, utilized in large amounts by plants. The N concentration was relatively low and highly dynamic across sites, except for the continuously grazed veld. The rotationally grazed veld had generally higher N levels throughout the seasons.



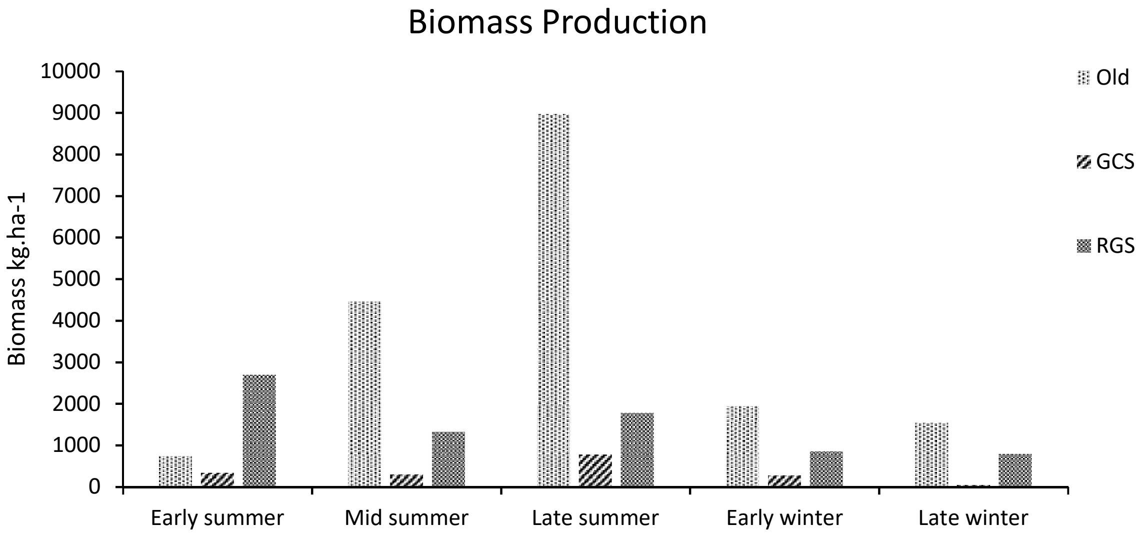
As opposed to the continuously grazed veld, the rotationally grazed veld has high biomass production and, therefore, reduced soil erosion which increases SOM. Hence this site had higher N levels as compared to other sites. However, the rate of N mineralization, amongst other things, assumed to have been slowed down by the declines in soil temperatures which results in decreased N levels in winter. On the other hand, the old land had the lowest N levels throughout the seasons and further declined during late summer. In addition, cultivation and tillage have been reported to reduce SOM and consequently N mineralization. Moreover, SOM is also associated with the levels of organic C which have been reported to be reduced by cultivation.



The findings of the study correspond with this and show that the old land has low organic C levels. The continuously grazed veld had a lower level of organic C , as compared to the rotationally grazed veld, but was relatively steady throughout the seasons.

6.4 Forage quantity

Biomass production is an important aspect in livestock production and high producing grasses are mostly preferred, especially in semi-arid areas. Availability of forage throughout the grazing seasons gives animals the opportunity to increase forage intensity, especially where quality is low, to meet nutrient requirements. The old lands had a full summer rest and therefore accumulated the highest biomass through summer.



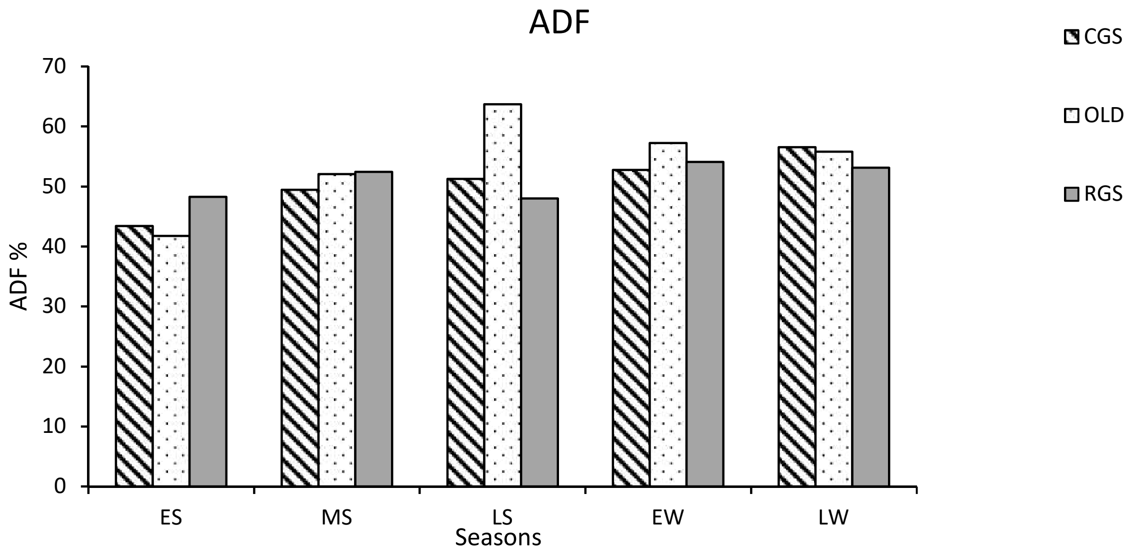
Biomass accumulation in the old lands rapidly increases as the season progressed, the increase may be as a result of increased rainfall from mid- to late summer. Thereafter, in early winter, after livestock introduction, accumulated biomass declined as a result of limited rainfall and utilization. However, the intensity of utilization declines as winter progressed mainly due to maturity and thus forage quality decline.

Irrespective of higher N levels and rainfall intensity, particularly during summer, in the continuous veld biomass accumulation remind low over the year. The low biomass accumulation in the continuously grazed veld may be attributed to continuous utilization and keeping the forage in a vegetative state which promotes high forage quality.

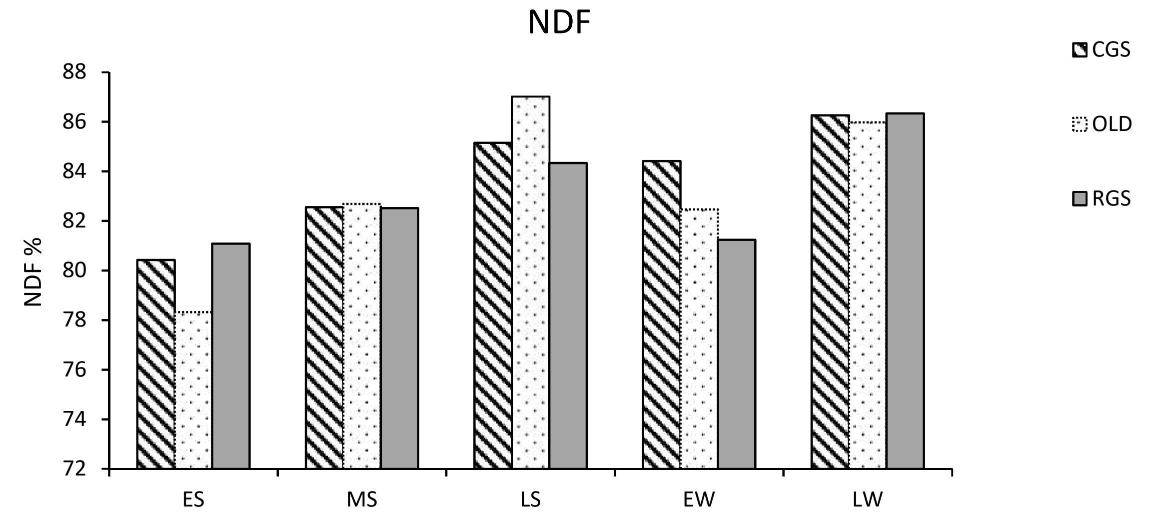
Although, biomass accumulation is high in the rotational veld, considering that there is frequent utilization, seasonal accumulation is highest in early summer. This suggests that utilization is lower in this veld, owing to domination by highly palatable grasses and supplementation. Reduced biomass accumulation, thereafter, suggests an increase in forage utilization and this may be due to decline in forage quality which necessitates increased foraging intensity.

6.5 Forage quality

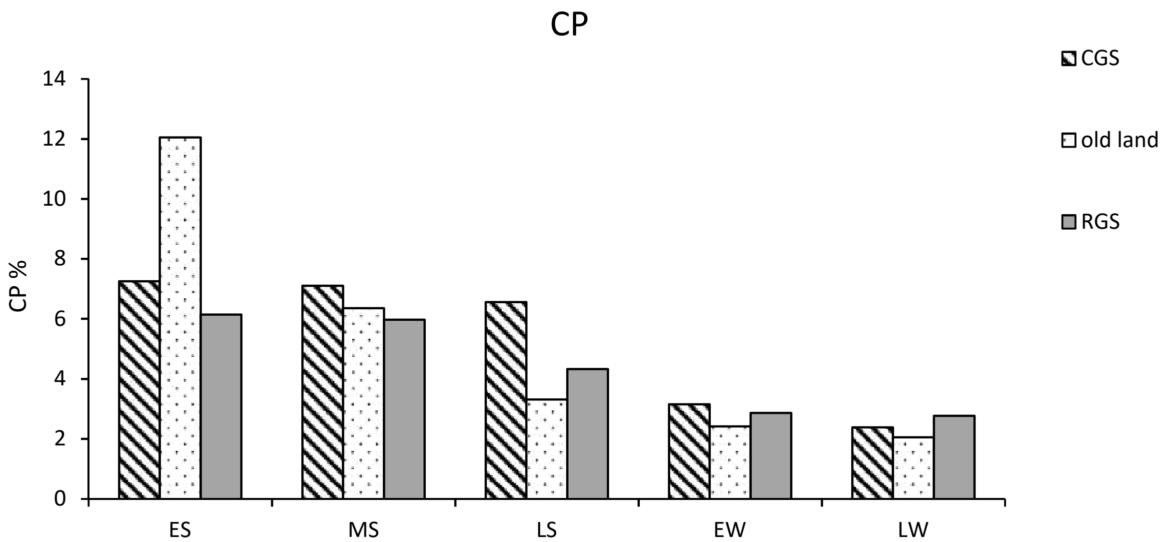
At a farm scale, forage quality maintenance plays a significant role in animal body condition which can inhibit growth, maintenance, and reproduction. There is compelling evidence on low livestock herd production, due to numerous reasons, in the communal areas of South Africa, therefore, it is very important to quantify quality in these regions. It is well established that with forage maturity, quality declines and this is as a result of accumulation of fiber (ADF and NDF) content in the cell wall. In the old lands, ADF and NDF content increase rapidly as the season progresses. The increase may be due to the quick maturing rate of dominant species and also because the area was rested in summer, promoting maturity.



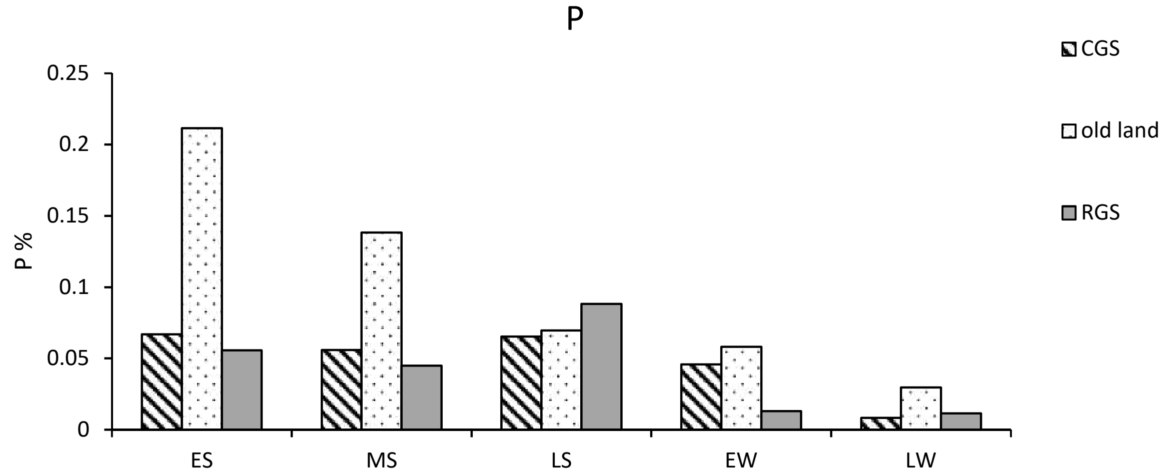
As opposed to the old lands, the rotational veld had high ADF and NDF contents in early summer but as the season progressed the levels gradually decline. The decreased levels of ADF and NDF may be as a result of reduced biomass accumulation and increased utilization which promoted new tiller growth with low fiber. On the other hand, the continuous veld had a steady and less profound increase in ADF content through the seasons, and the NDF content was highest in winter. The ADF and NDF trends in the continuous veld may be as a result of selective grazing, that is, less palatable grasses are avoided to grow and mature and therefore largely contribute to biomass accumulations and bulk forage quality.



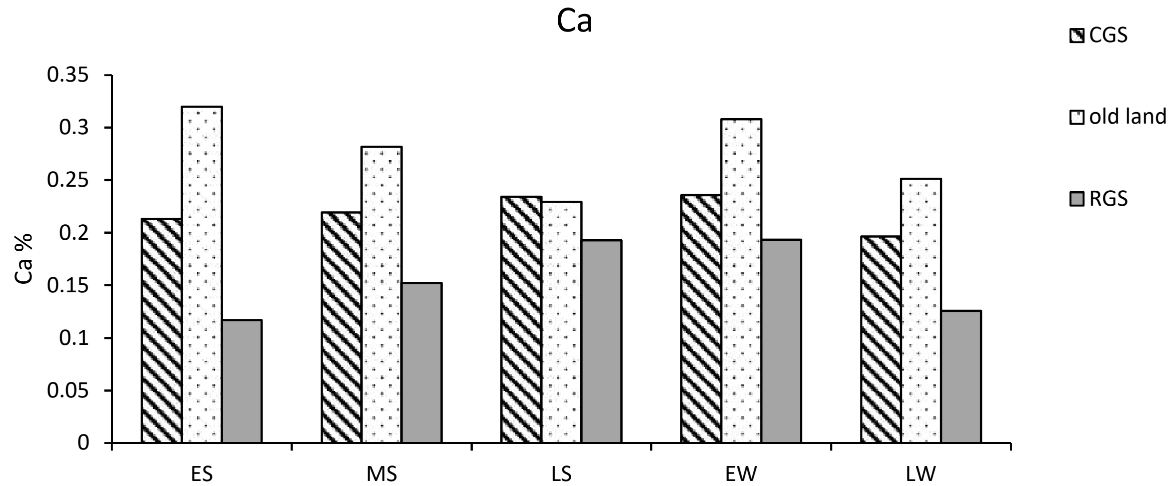
Moreover, old lands had steep fluctuations trends in CP content with the highest contents in early summer then declines to be lowest in winter. Although the lands have the highest CP content in the early growing season and can support lactations during that season, the CP content is highly dynamic partly as a result of the rapid maturity of dominant grass species.



In addition, full season rest may have a significant influence on the levels of CP as biomass accumulates. In the continuous veld where the grass is kept short at a vegetative stage, CP content is retained until late summer then rapidly declines but the decline slows down in the beginning of winter. CP content in this veld remains higher throughout the summer season as compared to the other two sites (old lands and rotational veld).



Nonetheless, CP content in the rotational veld is generally lower in summer, it declines gradually throughout mid-summer to early winter.



Although the rotational veld was highly fertile, CP, P, and Ca content in the forage was low. This may be due to resting the veld, in the rotation process, for extended periods which allows maturity of grass and thus reduced forage quality.

6.6 Implications on livestock production

Forage is a major source of minerals to livestock, especially in farming systems where production is solemnly dependent on natural pastures. Therefore, forage quality examination is more important when interpreted in terms of livestock requirements for optimum production, however, veld conditions are not always in a state to provide sufficient quality forage. For this study will focus on CP, Ca and P requirements owing to the influence these nutrients have on the absorption of most essential minerals.

Generally, nutrient provision in the natural veld is influenced by management history and is mostly insufficient for animal production. Hence, supplementation is widely recommended for livestock grazing the natural veld of South Africa. According to this study, old lands can provide the most quality forage during winter. However, the lands' forage quality declines very fast making it unsustainable for livestock production. On the other hand, the CG veld is more sustainable as a result of the ability of the veld to relatively retain quality forage over the year. Although the RG veld had a greater forage quality, over the year, forage quality was much lower but declined much slower than on the old lands and CG veld.

Therefore, production can be better sustained in the RG veld. However, the utilization of the veld should be revised so as to improve quality.

6.7 Conclusion

The old lands were dominated by grass species with low palatability which mature rapidly, and may only be acceptably grazed in early summer. Grazing exclusion over summer resulted to a rapid decline in forage quality from mid-summer and, thus reducing the potential of livestock productivity.

On the other hand, the continuously grazed veld was dominated by relatively acceptable grasses which produce very low leaf biomass. Nevertheless, this veld had high forage quality which slowly declines over summer due to continuous defoliation which keeps the grass young and actively growing. In addition, the ability of the forage to consequently retain its quality may be due to a less dynamic soil N concentration.

Although the rotationally grazed veld was dominated by highly productive grasses which mostly prefer fertile soils (*T. triandra*), the grazing strategies adopted in this veld allowed for underutilization which resulted in forage carryover and, thus reducing forage quality. Additionally, veld underutilization in this veld seems to have limited the response of forage quality to soil fertility.

CHAPTER 7: GENERAL CONCLUSION

This study investigated the influence of land use history and grazing management on species composition, soil fertility, and forage quality and quantity over the year. This study was conducted on old lands, the continuously grazed veld, and the rotationally grazed veld. The results revealed that species composition and biomass accumulation (at a given time) have an important contribution to forage quality. Although the old lands had the highest CP levels in early-summer, rapid decline in CP from mid-summer generally reduced the forage quality of the lands. Additionally, as a result of the physiology of the grasses dominant and extent of rest (biomass accumulation) the lands cannot retain quality even in summer (mid-late summer). Moreover, quality of these lands seemed to have a positive correlation with organic C and N concentration in the soil solution. Although the lands are dominated by poor grasses, quality forage can be provided in early summer when the grass is still young, however, quantity is limited by the low basal cover when accumulated biomass is low. Therefore, it can be concluded that the lands cannot supply enough quality forage to sustain livestock production even during summer. Nonetheless, grazing in early to mid-summer, with supplementation, can be recommended so as to achieve seed rest, to increase basal cover by inducing tilling, and standing biomass to improve SOM accumulation and reduce risk to soil erosion in winter.

The continuous veld had low biomass accumulation and was dominated by relatively leafy grasses which contributed to the ability of the veld to retain high-quality forage throughout summer. Although N was statistically insignificant, the trends reveal that N concentration was higher in winter which can be attributed to higher biomass accumulation, encouraging N mineralization. Therefore, to optimize livestock production it is recommended to allow for full summer rest to promote rehabilitation of grass cover and soil fertility. Although the forage quality of grasses is generally reduced with maturity, dominating grass species in this veld inherently have high leaf: stem ratio reducing the severity of high fiber content. In conclusion, on improved veld conditions continuous grazing can be sustainable with an appropriate stocking rate of all animal classes.

On the other hand, the rotational veld had a greater soil fertility but due to extended rest periods which allows biomass accumulation (degree of maturity) forage fiber (ADF and NDF) increases and the overall quality was lower in relation to the continuous veld. Although the veld was highly acidic, this seems to have a limited effect on forage quality as CP was highest at 46.83% acidic saturation showing that dominant grasses were well adapted to the high level of soil acidity. As a result of underutilization new tillers are suppressed in the overall bulk quality, hence the overall forage quality was lower. Therefore, low forage quality can be entirely attributed to the extended rest regimes employed in this veld. It is, therefore, necessary to increase the grazing intensity and frequency and/or by burning the biomass residues after grazing so as to keep the grass at vegetation and high-quality stage by the following graze.

Although the tools (mainly herding) adopted to exclude livestock, during winter, on the old lands were less effective, findings from this study may be useful in improving utilization strategies on these grazing areas, as influenced by the previous land use. Base on the findings from the continuously and rotationally grazed veld, livestock grazing management largely influences forage quality dynamics throughout the year. Additionally, appropriate grazing managements may have a significant influence on the overall veld and livestock productivity. In communal regions, the aim of livestock production is primarily to provide social security, and in that process veld health is ignored. This study provides quantitative information on the current soil fertility status, forage quality, and succession status as shaped by the historic land use management. This information will equip land users to make better decisions on breeding plans, supplementation plans, and grazing management appropriate for their farming practice. In addition, the findings from this study could provide land users with an understanding of the forage dynamics and influence of inappropriate grazing management on veld degradation.

APPENDICES

Appendix A: Forage quality in Old lands

ASH

SEASON	N	Subset
		1
Late winter	6	5.8150
Early summer	6	6.3315
Late summer	6	6.3590
Mid-summer	6	6.8868
Early winter	6	7.2319
Sig.		.328

Mean Square (Error) = 1.617.
Alpha = .05.

ADF

SEASON	N	Subset		
		1	2	3
Early summer	6	41.7332		
Mid-summer	6		52.0402	
Late summer	6			63.6970
Early winter	6		57.2414	57.2414
Late winter	6		55.8189	
Sig.		1.000	.287	.122

Mean Square (Error) = 19.937.
Alpha = .05.

NDF

SEASON	N	Subset 1	2	3
		1	2	3
Early summer	6	78.3198		
Early winter	6		82.4619	
Mid-summer	6		82.6835	
Late winter	6		85.9804	85.9804
Late summer	6			87.0158
Sig.		1.000	.065	.919

Mean Square (Error) = 4.688.
Alpha = .05.

CP

SEASON	N	Subset 1	2	3	4
		1	2	3	4
Late winter	6	2.0485			
Early winter	6	2.4169	2.4169		
Late summer	6		3.3164		
Mid-summer	6			6.3603	
Early summer	6				12.0506
Sig.		.886	.194	1.000	1.000

Means Square (Error) = .479.
Alpha = .05.

Ca

SEASON	N	Subset 1	2
		1	2
Late summer	6	.2294	
Late winter	6	.2512	
Mid-summer	6	.2817	.2817
Early winter	6		.3079
Early summer	6		.3200
Sig.		.065	.267

Means Square (Error) = .001.
b. Alpha = .05.

Mg

SEASON	N	Subset 1	2	3	4
Late winter	6	.0636			
Late summer	6	.0806	.0806		
Early winter	6		.0886	.0886	
Early summer	6			.1103	.1103
Mid-summer	6				.1132
Sig.		.218	.842	.069	.995

Means Square (Error) = .000.

Alpha = .05.

K

SEASON	N	Subset 1	2	3	4
Late winter	6	.2463			
Early winter	6		.5601		
Late summer	6			1.1502	
Early summer	6				1.4617
Mid-summer	6				1.4837
Sig.		1.000	1.000	1.000	.998

Means Square (Error) = .015.

Alpha = .05.

Na

SEASON	N	Subset 1
Late winter	6	.0108
Late summer	6	.0125
Mid-summer	6	.0220
Early winter	6	.0226
Early summer	6	.0244
Sig.		.092

Means Square (Error) = 7.92E-005.

Alpha = .05.

P

SEASON	N	Subset 1	Subset 2	Subset 3
Late winter	6	.0296		
Early winter	6	.0581		
Late summer	6	.0695		
Mid-summer	6		.1383	
Early summer	6			[illegible]
Sig.		.171	1.000	1.000

Mean Square (Error) = .001.

Alpha = .05.

Zn

SEASON	N	Subset 1	Subset 2
Late summer	6	12.0379	
Early winter	6	13.8703	13.8703
Mid-summer	6	18.0282	18.0282
Late winter	6	18.9175	18.9175
Early summer	6		21.3623
Sig.		.177	.120

Mean Square (Error) = 26.735.

Alpha = .05.

Cu

SEASON	N	Subset 1	Subset 2	Subset 3
Late winter	6	1.3501		
Early winter	6	1.4598		
Late summer	6	1.8824		
Mid-summer	6		3.4283	
Early summer	6			5.0934
Sig.		.843	1.000	1.000

Mean Square (Error) = .813.

Alpha = .05.

Mn

SEASON	N	Subset
		1
early summer	6	130.8338
Late summer	6	167.5547
Mid-summer	6	178.6777
Late winter	6	203.2016
Early winter	6	215.9119
Sig.		.239

Mean Square (Error) = 4786.314.
Alpha = .05.

Fe

SEASON	N	Subset		
		1	2	3
Late summer	6	64.0620		
Early winter	6		208.6794	
Early summer	6		232.0557	232.0557
Late winter	6			303.2396
Mid-summer	6			309.2811
Sig.		1.000	.943	.130

Mean Square (Error) = 2936.473.
Alpha = .05.

Appendix B: Forage quality of a continuously grazed veld

ASH

SEASON	N	Subset	
		1	2
Late winter	6	4.6861	
Early winter	6	5.0640	

Early summer	6		6.3374
Late summer	6		6.6853
Mid-summer	6		7.0995
Sig.		.864	.312

Mean Square (Error) = .452.

Alpha = .05.

ADF

SEASON	N	Subset		
		1	2	3
Early summer	6	43.4093		
Mid-summer	6	49.4343	49.4343	
Late summer	6		51.2769	51.2769
Early winter	6		52.7414	52.7414
Late winter	6			56.5136
Sig.		.080	.579	.154

Mean Square (Error) = 14.805.

Alpha = .05.

NDF

SEASON	N	Subset	
		1	2
Early summer	6	80.4180	
Mid-summer	6	82.5580	82.5580
Early winter	6	84.4135	84.4135
Late summer	6	85.1516	85.1516
Late winter	6		86.2619
Sig.		.132	.330

Mean Square (Error) = 11.083.

Alpha = .05.

CP

SEASON	N	Subset	
		1	2
Late winter	6	2.3832	
Early winter	6	3.1556	
Late summer	6		6.5650
Mid-summer	6		7.1044
Early summer	6		7.2583
Sig.		.822	.871

Mean Square (Error) = 1.573.

Alpha = .05.

Ca

SEASON	N	Subset
		1
Late winter	6	.1965
Early summer	6	.2133
Mid-summer	6	.2193
Late summer	6	.2341
Early winter	6	.2359
Sig.		.163

Mean Square (Error) = .001.

Alpha = .05.

Mg

SEASON	N	Subset	
		1	2
Late winter	6	.0431	
Early winter	6	.0581	.0581
Late summer	6		.0715
Early summer	6		.0783
Mid-summer	6		.0808
Sig.		.454	.106

Mean Square (Error) = .000.

Alpha = .05.

K

SEASON	N	Subset		
		1	2	3
Late winter	6	.2788		
Early winter	6		.6418	
Early summer	6		.9276	.9276
Late summer	6			1.0218
Mid-summer	6			1.2042
Sig.		1.000	.153	.175

Mean Square (Error) = .043.

Alpha = .05.

Na

SEASON	N	Subset	
		1	2
Early summer	6	.0076	
Late summer	6	.0079	
Mid-summer	6	.0149	.0149
Early winter	6	.0358	.0358
Late winter	6		.0453
Sig.		.084	.056

Mean Square (Error) = .000.

Alpha = .05.

P

SEASON	N	Subset	
		1	2
Late winter	6	.0084	
Early winter	6		.0459
Mid-summer	6		.0559
Late summer	6		.0654
Early summer	6		.0668
Sig.		1.000	.394

Mean Square (Error) = .000.

Alpha = .05.

Zn

SEASON	N	Subset
		1
Late winter	6	17.5949
Early summer	6	18.4251
Mid-summer	6	19.5612
Late summer	6	20.7583
Early winter	6	25.3522
Sig.		.073

Mean Square (Error) = 23.745.

Alpha = .05.

Cu

SEASON	N	Subset	
		1	2
Early winter	6	1.9587	
Late winter	6	2.0587	
Late summer	6	2.6339	2.6339
Mid-summer	6	3.2858	3.2858
Early summer	6		3.5138
Sig.		.062	.352

Mean Square (Error) = .656.

Alpha = .05.

Mn

SEASON	N	Subset
		1
Mid-summer	6	195.4720
Early summer	6	209.9994
Late summer	6	257.3435
Late winter	6	291.2794
Early winter	6	293.7113
Sig.		.171

Mean Square (Error) = 5359.011.

Alpha = .05.

Fe

SEASON	N	Subset		
		1	2	3
Late summer	6	215.8104		
Early winter	6	268.6684	268.6684	
Late winter	6	337.8754	337.8754	
Mid-summer	6		498.3873	498.3873
Early summer	6			683.0279
Sig.		.656	.108	.268

Mean Square (Error) = 24075.909.
Alpha = .05.

Appendix C: Forage quality of a rotationally grazed veld

ASH

SEASON	N	Subset	
		1	2
Early winter	6	4.7090	
Late winter	6	5.1011	5.1011
Late summer	6	5.5710	5.5710
Early summer	6	5.7191	5.7191
Mid-summer	6		6.1527
Sig.		.262	.227

Mean Square (Error) = .711.
Alpha = .05.

ADF

SEASON	N	Subset
		1
Late summer	6	48.0216
Early summer	6	48.2704
Mid-summer	6	52.4175
Late winter	6	53.1537
Early winter	6	54.0751
Sig.		.139

Mean Square (Error) = 18.573.
Alpha = .05.

K

SEASON	N	Subset			
		1	2	3	
Late winter	6	.2815			
Early winter	6		.6516		
Late summer	6		.8490	.8490	
Early summer	6			.9305	2.5182
Mid-summer	6			1.0676	4.3365
Sig.		1.000	.199	.127	6.3323
Mean Square (Error) = .023.					.056

Alpha = .05.

Alpha = .05.

CP

SEASON	N	Subset		
		1	2	3
Late winter	6	2.7685		
Early winter	6	2.8677		
Late summer	6		4.3260	
Mid-summer	6			5.9739
Early summer	6			6.1441
Sig.		.999	1.000	.993

Mean Square (Error) = .485.

Alpha = .05.

Ca

SEASON	N	Subset	
		1	2
Early summer	6	.1168	
Late winter	6	.1257	
Mid-summer	6	.1523	.1523
Late summer	6		.1928
Early winter	6		.1933
Sig.		.234	.130

Mean Square (Error) = .001.

Alpha = .05.

Na

SEASON	N	Subset	
		1	2
Early summer	6	.0029	
Mid-summer	6	.0039	.0039
Late winter	6	.0117	.0117
Late summer	6	.0194	.0194
Early winter	6		.0234
Sig.		.138	.055

Mean Square (Error) = .000.

Alpha = .05.

P

SEASON	N	Subset		
		1	2	3
Late winter	6	.0114		
Early winter	6	.0130		
Mid-summer	6		.0450	
Early summer	6		.0557	
Late summer	6			.0882
Sig.		.999	.419	1.000

Mean Square (Error) = .000.

Alpha = .05.

Zn

SEASON	N	Subset	
		1	2
Early summer	6	9.8878	
Early winter	6	10.1155	
Late winter	6	10.1336	
Mid-summer	6	11.6766	
Late summer	6		15.5421
Sig.		.590	1.000

Mean Square (Error) = 4.442.

Alpha = .05.

Cu

SEASON	N	Subset
		1
Late winter	6	1.6252
Early winter	6	2.6303
Mid-summer	6	2.8760
Early summer	6	3.1316
Late summer	6	3.4732
Sig.		.151

Mean Square (Error) = 1.794.

Alpha = .05.

Mn

SEASON	N	Subset	
		1	2
Late winter	6	114.1494	
Late summer	6	117.5608	
Mid-summer	6	117.9490	
Early summer	6	123.7806	
Early winter	6		169.3878
Sig.		.947	1.000

Mean Square (Error) = 519.395.

Alpha = .05.

Fe

SEASON	N	Subset
		1
Early winter	6	266.2555
Late winter	6	275.3650
Mid-summer	6	520.9112
Late summer	6	623.0770
Early summer	6	738.0169
Sig.		.059

Mean Square (Error) = 81812.722.

Alpha = .05.

Appendix D: Soil fertility on the old lands

P

SEASON	N	Subset		
		1	2	3
Early summer	6	3.3333		
Mid-summer	6	4.3333	4.3333	
Late summer	6		5.1667	5.1667
Early Winter	6			5.8333
Late winter	6			6.0000
Sig.		.285	.460	.460

Mean Square (Error) = .733.

Alpha = .05.

K

SEASON	N	Subset	
		1	2
Late winter	6	55.1667	
Mid-summer	6	79.3333	79.3333
Early Winter	6	88.1667	88.1667
Early summer	6	93.1667	93.1667
Late summer	6		122.8333
Sig.		.279	.169

Mean Square (Error) = 1046.027.

Alpha = .05.

Ca

SEASON	N	Subset
		1
Late winter	6	407.5000
Early Winter	6	585.5000
Late summer	6	635.1667
Mid-summer	6	788.3333
Early summer	6	886.8333
Sig.		.084

Mean Square (Error) = 95070.800.

Alpha = .05.

Mg

SEASON	N	Subset
		1
Late winter	6	119.6667
Early Winter	6	185.3333
Late summer	6	220.8333
Mid-summer	6	255.6667
Early summer	6	336.3333
Sig.		.090

Mean Square (Error) = 19953.207.

Alpha = .05.

2248

Acid Saturation

SEASON	N	Subset
		1
Early summer	6	2.1667
Late summer	6	2.5000
Mid-summer	6	3.3333
Early Winter	6	5.1667
Late winter	6	9.0000
Sig.		.193

Mean Square (Error) = 27.540.

Alpha = .05.

2249

pH

SEASON	N	Subset
		1
Late winter	6	4.4917
Early Winter	6	4.6133
Late summer	6	4.6383
Mid-summer	6	4.7450
Early summer	6	4.8450
Sig.		.454

Mean Square (Error) = .130.

Alpha = .05.

2260

Zn

SEASON	N	Subset	
		1	2
Late summer	6	1.2167	
Mid-summer	6	1.6833	1.6833
Early summer	6	2.0500	2.0500
Early Winter	6		2.4833
Late winter	6		2.5667
Sig.		.269	.219

Mean Square (Error) = .492.

Alpha = .05.

Mn

SEASON	N	Subset	
		1	2
Late summer	6	5.1667	
Late winter	6	7.0000	
Mid-summer	6		16.6667
Early Winter	6		17.0000
Early summer	6		21.8333
Sig.		.968	.406

Mean Square (Error) = 25.240.

Alpha = .05.

Cu

SEASON	N	Subset
		1
Late winter	6	2.3833
Early Winter	6	2.8167
Mid-summer	6	3.0167
Early summer	6	3.3667
Late summer	6	3.4833
Sig.		.468

Mean Square (Error) = 1.298.

Alpha = .05.

Org. C

SEASON	N	Subset	
		1	2
Late summer	6	.4000	
Late winter	6	.7333	.7333
Early Winter	6	.8333	.8333
Mid-summer	6	1.0500	1.0500
Early summer	6		1.2333
Sig.		.079	.254

Mean Square (Error) = .171.

Alpha = .05.

N

SEASON	N	Subset	
		1	2
Late summer	6	.0567	
Late winter	6	.0767	.0767
Early Winter	6	.1050	.1050
Mid-summer	6	.1350	.1350
Early summer	6		.1483
Sig.		.102	.156

Mean Square (Error) = .003.

Alpha = .05.

Appendix E: Soil fertility on the continuously grazed veld

P

SEASON	N	Subset	
		1	2
Early summer	6	3.0000	
Mid-summer	6	3.0000	
Late summer	6		4.6667
Late winter	6		5.0000
Early Winter	6		5.3333
Sig.		1.000	.313

Mean Square (Error) = .347.

Alpha = .05.

K

SEASON	N	Subset	
		1	2
Early summer	6	176.3333	
Late winter	6	194.8333	194.8333
Early Winter	6	218.6667	218.6667
Mid-summer	6	221.1667	221.1667
Late summer	6		287.5000
Sig.		.736	.114

Mean Square (Error) = 4001.193.

Alpha = .05.

Ca

SEASON	N	Subset
		1
Early summer	6	614.0000
Late winter	6	673.1667
Late summer	6	740.0000
Early Winter	6	755.6667
Mid-summer	6	788.8333
Sig.		.630

Mean Square (Error) = 46454.840.

Alpha = .05.

Mg

SEASON	N	Subset
		1
Early summer	6	240.0000
Late winter	6	263.5000
Early Winter	6	269.0000
Late summer	6	303.6667
Mid-summer	6	333.5000
Sig.		.428

Mean Square (Error) = 8648.173.

Alpha = .05.

Acid Saturation

SEASON	N	Subset
		1
Mid-summer	6	2.0000
Early Winter	6	4.3333
Late summer	6	5.1667
Early summer	6	5.3333
Late winter	6	7.5000
Sig.		.107

Mean Square (Error) = 13.720.

Alpha = .05.

pH

SEASON	N	Subset	
		1	2
Late winter	6	4.1717	
Early Winter	6	4.3033	4.3033
Early summer	6	4.3300	4.3300
Late summer	6	4.3833	4.3833
Mid-summer	6		4.4883
Sig.		.107	.196

Mean Square (Error) = .020.

Alpha = .05.

Zn

SEASON	N	Subset	
		1	2
Mid-summer	6	1.0500	
Early summer	6	1.7500	
Early Winter	6	1.8333	
Late summer	6	2.7500	2.7500
Late winter	6		4.4000
Sig.		.100	.116

Mean Square (Error) = 1.276.

Alpha = .05.

Mn

SEASON	N	Subset
		1
Late summer	6	21.3333
Late winter	6	21.6667
Mid-summer	6	29.6667
Early Winter	6	31.0000
Early summer	6	36.3333
Sig.		.343

Mean Square (Error) = 186.773.

Alpha = .05.

Cu

SEASON	N	Subset
		1
Early summer	6	3.3167
Late winter	6	3.8000
Early Winter	6	4.2833
Late summer	6	4.7833
Mid-summer	6	4.8167
Sig.		.483

Mean Square (Error) = 2.491.

Alpha = .05.

2298

Org. C

SEASON	N	Subset
		1
Early summer	6	1.4833
Late summer	6	1.6500
Mid-summer	6	1.9167
Late winter	6	2.0333
Early Winter	6	2.1000
Sig.		.614

Mean Square (Error) = .556.

Alpha = .05.

2309

N

SEASON	N	Subset
		1
Late summer	6	.1200
Early summer	6	.1200
Mid-summer	6	.1567
Late winter	6	.1617
Early Winter	6	.1883
Sig.		.314

Mean Square (Error) = .004.

Alpha = .05.

Appendix F: Soil fertility on the rotationally grazed veld

P

SEASON	N	Subset	
		1	2
Mid-summer	6	7.0000	
Late summer	6	8.1667	8.1667
Early Winter	6	9.3333	9.3333
Late winter	6	11.0000	11.0000
Early summer	6		14.6667
Sig.		.499	.095

Mean Square (Error) = 18.300.

Alpha = .05.

K

SEASON	N	Subset	
		1	2
Early Winter	6	148.1667	
Late winter	6	166.1667	
Mid-summer	6	197.3333	
Early summer	6	232.1667	
Late summer	6		386.6667
Sig.		.160	1.000

Mean Square (Error) = 3802.367.

Alpha = .05.

Ca

SEASON	N	Subset		
		1	2	3
Late winter	6	151.8333		
Early Winter	6	240.8333	240.8333	
Early summer	6	247.1667	247.1667	
Mid-summer	6		366.3333	366.3333
Late summer	6			467.8333
Sig.		.306	.101	.250

Mean Square (Error) = 6981.307.

Alpha = .05.

Mg

SEASON	N	Subset		
		1	2	3
Late winter	6	70.6667		
Early Winter	6	82.5000	82.5000	
Early summer	6	83.6667	83.6667	
Mid-summer	6		110.3333	
Late summer	6			150.3333
Sig.		.869	.268	1.000

Mean Square (Error) = 547.233.

Alpha = .05.

Acid Saturation

SEASON	N	Subset		
		1	2	3
Late summer	6	24.3333		
Early Winter	6	36.6667	36.6667	
Mid-summer	6		42.3333	42.3333
Early summer	6		46.8333	46.8333
Late winter	6			54.0000
Sig.		.172	.337	.214

Mean Square (Error) = 84.753.

Alpha = .05.

pH

SEASON	N	Subset	
		1	2
Late winter	6	3.9317	
Early summer	6	3.9533	
Mid-summer	6	3.9933	3.9933
Late summer	6	4.0217	4.0217
Early Winter	6		4.0867
Sig.		.297	.264

Mean Square (Error) = .006.

Alpha = .05.

Zn

SEASON	N	Subset	
		1	2
Mid-summer	6	1.3833	
Late summer	6	1.4500	
Early Winter	6	1.8667	
Early summer	6	2.1000	
Late winter	6		3.8500
Sig.		.424	1.000

Mean Square (Error) = .504.

Alpha = .05.

Mn

SEASON	N	Subset		
		1	2	3
Late winter	6	4.6667		
Early Winter	6	7.5000	7.5000	
Late summer	6		10.0000	10.0000
Mid-summer	6			11.6667
Early summer	6			11.8333
Sig.		.290	.410	.693

Mean Square (Error) = 5.960.

Alpha = .05.

Cu

SEASON	N	Subset
		1
Early summer	6	2.4000
Late winter	6	2.5333
Early Winter	6	2.6500
Late summer	6	2.7500
Mid-summer	6	3.8333
Sig.		.701

Mean Square (Error) = 3.720.

Alpha = .05.

Org. C

SEASON	N	Subset
		1
Late winter	6	4.8333
Late summer	6	5.0000
Early Winter	6	5.0833
Early summer	6	5.7000
Mid-summer	6	6.1167
Sig.		.195

Mean Square (Error) = .977.

Alpha = .05.

2334

N

SEASON	N	Subset	
		1	2
Early Winter	6	.2867	
Late winter	6	.2917	
Late summer	6	.3233	.3233
Early summer	6		.4050
Mid-summer	6		.4100
Sig.		.869	.186

Mean Square (Error) = .004.

Alpha = .05.

2335