Cattle and veld interactions at the Armoedsvlakte Research Station

By

Gustav Nic le Roux
200274108

Submitted in fulfilment of the academic requirements for the degree Master of Science in the

Discipline of Grassland Science
School of Biological and Conservation Sciences
Faculty of Science and Agriculture
University of KwaZulu-Natal
Pietermaritzburg

Abstract

A long-term grazing trial was started in 1977 at Armoedsvlakte Research Station, about 10km west of Vryburg, in *Tarchonanthus* veld of the Ghaap's Plateau, which is a variation of the Kalahari Thornveld veld type. The main aim of this study was to use the extensive veld condition and animal production data set to investigate the effects and interactions of stocking rate, grazing system applied and seasonal rainfall on veld condition and cattle production. The grazing trial has changed three times since its inception resulting in three different phases.

The main changes in veld condition during phase one (1977-1991) was due to density independent effects (e.g. seasonal rainfall) and not density dependent effects (e.g. stocking rate). A major change occurred in 1985 following a multiple year drought. The drought resulted in adverse changes in species composition, basal cover and residual biomass of all treatments. The system did not recover from the drought during phase one, despite well above mean seasonal rainfall for a number of years after the drought.

During phase two (1992-1999) and phase three (2000 to present) completely different vegetation dynamics occurred than what was experienced during phase one. Density dependent effects (e.g. stocking rate) were more important in explaining variation in veld condition during these two phases. High stocking rates resulted in adverse changes in species composition, poor basal cover and a low residual biomass production. It is however important to note that seasonal rainfall did explain a significant additional amount of variation in veld condition. This suggests that a continuum of non-equilibrium and equilibrium vegetation dynamics occurred in these two phases.

The residual biomass and seasonal rainfall model for phase one indicate completely different results for the gain per animal data. In the seasonal rainfall model, stocking rate does not have a significant effect on gain per animal, but seasonal rainfall and the interaction of stocking rate with seasonal rainfall explains most of the variation in gain per animal. This suggest a continuum of non-equilibrium and equilibrium dynamics and that animal production is more sensitive to seasonal rainfall than to stocking rate, although the significant interaction of stocking rate with

seasonal rainfall suggest that the seasonal rainfall effect on animal production is dependant on stocking rate.

The residual biomass model however indicates that stocking rate is more important than rainfall in explaining variation in the mass gains per animal. The stocking rate effect on gain per animal was significant and indicated that as stocking rate increased, that gain per animal decreases. Seasonal rainfall and the interaction of stocking rate with seasonal rainfall had no significant effect on gain per animal.

The amount of variation explained by the seasonal rainfall model was larger than the residual biomass model and this indicates that rainfall explains more variation in gain per animal, than residual biomass does. This possibly indicates that non-equilibrium effects are stronger than the equilibrium effects, but it is important to notice that stocking rate had a significant effect in some cases.

The gain per hectare models (seasonal rainfall and residual biomass) for phase one indicates that stocking rate has a significant effect on gain per hectare. Increasing stocking rates resulted in higher gain per hectare, which suggests that the turning point of the typical "Jones and Sandland model" has not been reached and this might be due to light stocking rates applied during the duration of phase one. The seasonal rainfall model however has significant effects of seasonal rainfall and interactions of stocking rate with seasonal rainfall on gain per hectare. This suggests that the effect of stocking rate is dependent on seasonal rainfall and that seasonal rainfall explain an additional amount of variation in gain per hectare.

In general, it appreared that the optimal stocking rate for animal production was higher than those applied during the duration of the trial, but this is due to lower than planned actual stocking rates applied during all three phases of the trial. It is very difficult to determine a generic optimal stocking rate for different rainfall volumes and it is recommended that the actual stocking rate for different ecological zones be determined based on rainfall, biomass, species compostion, basal cover and available browse and not just on the provisional recommendations.

The type of grazing system applied did not show any statistically significant effects on both gain per animal and gain per hectare for the animal production data during phase one. This result is interesting and contradictive to most of the scientific literature where some authors concluded from their studies that rotational grazing systems produce higher animal production than continuous grazing systems, whereas others researchers state that continuous grazing systems produce higher animal production than rotational grazing systems.

In phase two both the residual biomass and seasonal rainfall models for phase two did not show any significant effects and interactions of stocking rate, seasonal rainfall level and/or residual biomass on both gain per animal and gain per hectare.

Both the residual biomass and seasonal rainfall models for phase three did not show any significant effects and interactions of stocking rate, seasonal rainfall level and/or residual biomass on animal gains per animal. The seasonal rainfall model did not show any any significant effects and interactions of stocking rate, seasonal rainfall level and/or residual biomass on animal gains per hectare. However, the residual biomass model indicated that stocking rate had a significant effect on gain per hectare and the production closely followed the Jones and Sandland (1974) model as at low stocking rates, gain per hectare increases at a rapid rate, but as stocking rates increases to high stocking rates, the rate of increase in gain per hectare declines, until it eventually reaches a turning point, where after gain per hectare declines with increasing stocking rates.

Stocking rate only had a significant effect on the condition score of cows during phase two and phase three, as high stocking rates resulted in poor animal condition in both phases. No significant effects and interactions of stocking rate and seasonal rainfall were indicated on calving percentage, weaning percentage, conception rates and percentage of desirable meat produced during phase two.

Declaration

The work described in this dissertation was carried out in the School of Biological and Conservation Sciences, University of KwaZulu-Natal, Pietermaritzburg, from January 2004 to July 2008, under the supervision of Mr. J.C.O du Toit.

The study represents original work by the author and has not otherwise been submitted in any form for any other degree or diploma to any University. Where use has been made of the work of others, it is duly acknowledged in the text.

Signed:
G.N. Le Roux

Signed:
J.C.O du Toit (Supervisor)

Acknowledgements

I would like to thank the following people whose contributions to this project has been invaluable and without these individuals, this project would not have been possible:

My Creator for giving me the finances to pay off all study depths and the endurance to complete the thesis. It reminds one of the scripture

“Delight yourself in the Lord, and He shall give you the desires of your heart” Psalm 37:4 (King James Version)

My wife for all the patience, love and support while completing this thesis and my son Xavier for really being an true blessing in my life.

My parents for providing me with financial support, their love and guidance throughout my university career. My brother and my two sisters are thanked for providing me with financial support.

Mr. J.C.O du Toit of the University of KwaZulu-Natal for his supervision and guidance throughout the duration of this project. Justin helped me extensively with creating pivot tables in Microsoft Excel, which saved a lot of time, when transforming data to get it into a specific format to analyse. His help with the analysis of the animal data is greatly appreciated.

Mr. C. D. Morris of the Agricultural Research Council for helping me with the statistical analysis of the data set and with the problems of analysing a repeated measures data set. Craig helped me calculate Euclidean distances with a program called Primer 4.5 and his help with this and in interpreting some statistical results is greatly appreciated.

Prof. K.P. Kirkman of the University of KwaZulu-Natal for helping me with statistical procedures. Prof Kirkman helped me adjust the Dry Weight Rank program so that it can process

biomass data for quadratic regressions. Prof Kirkman gave me advice right through the duration of this project and I am truly thankful for all his help.
Mrs. M. Coetzee of the National Department of Agriculture for explaining how the data was collected and for providing the large data set with regular updates.

Mr. I.J.M. van Zijl and Mr. R. Dames for showing and explaining the history of stocking rate and grazing system trial and for teaching me to identify most of the grass and shrubs species in the area.

Mr. W. Strydom and his wife Elsabe, for making me feel welcome at their house and for cooking awesome meals.

Mr. G. Koekemoer for showing me how the animal production data was collected and for explaining and answering any questions that I had.

All of technicians and their technical support staff for collecting the data over the years. I would especially like to thank Mr. W. Strydom, Mr. J. Phillander, Mr. J. Mochwaedi, Mr. V. Sioko, Mr. G. Ebusang, Mr. J. Basigi and Mr. D. Botlhoko for helping me identify grass and shrubs species, locating certain paddocks and showing me how the different veld condition methods and techniques are applied in the field.

Mr. H. Dicks who is retired, but still did not hesitate at all to help with some statistical problems and procedures on numerous occasions.

Mr J. Naiken for providing the necessary equipment for the bush density survey and Mr. B. Dalton for helping with the sampling that was done in 2004.

The Scientific Technical Support Services (STSS) of the North West Department of Agriculture, Conservation, Environment and Tourism (NW DACET) for providing the necessary funds to allow for this project to be completed.

Table of Contents

1. Introduction

There is currently a lack of knowledge on the effect of, and interactions between stocking rate, rainfall and grazing systems on animal production (e.g. average daily gains) and veld condition (e.g. basal cover, biomass production and species composition) in the Vryburg Shrubveld (Veld Type 16b1: Acocks 1988). An understanding of these factors will help to improve veld and animal management, as well as profit margins.

There has been much debate on whether non-equilibrium or equilibrium vegetation drives semi-arid rangeland systems. Some authors have suggested that there is continuum of non-equilibrium and equilibrium vegetation dynamics in these areas. The problem that needs to be solved in this project is to study the effects and interactions of stocking rate, grazing systems and seasonal rainfall on veld condition and animal production. The study of these variables will indicate the effect and importance of stocking rate, rainfall and type of grazing system applied in these areas and the results can be used to investigate what type of vegetation dynamics occur in the area. Long-term grazing trials were conducted at the Armoedsvlakte Research Station, near Vryburg. An extensive data set of veld condition and animal production collected since 1977, are used in this study.

1.1. Overview of the grazing trials at the Armoedsvlakte Research Station

The stocking rate and grazing system trials are conducted at the Armoedsvlakte Research Station, which is approximately ten kilometers west of Vryburg, situated at 24°28'E, 26°28'S and 1234m above sea level (Fourie 1974).

The Armoedsvlake stocking rate and grazing systems trials were initiated in 1977 and the main aim of the trial was to determine the effects of various grazing systems and stocking rates on veld condition and animal production (Coetzee 2002). Orignally (1977-1991), four different stocking rates were applied under both rotational and continuous grazing systems (Coetzee 2002) (

and **Error! Reference source not found.**). The rotational grazing treatments had six paddocks per treatment and herds were moved between paddocks on a weekly basis. This rotational grazing system allows for a period of absence of five weeks per paddock (Fourie 1983, Coetzee 2002). The rotational grazing herd comprised 22 animals, while the continuous grazing herd comprised 11 animals (Fourie 1983). Young Bonsmara steers and heifers (approximately 12 months old), were used as tester animals, while steers (approximately 36 months old), where used as fillers to obtain specific stocking rates (Coetzee 2002) (**Error! Reference source not found.**). A tester is an animal that is present in the treatment at all times and this animal did not experience any diseases or any other problems that might have affected the mass gain results and/or animal production variables. A filler is an animal that might not have been on the trial for the entire year or which experiences some problems and/or issues which will affect mass gains and other animal production variables. Coetzee (2002) reported that all the animals used in the trial were replaced annually during phase one. Animal production during phase one (1977-1991) was estimated by calculating the change in the body mass of the animals over time and veld condition was monitored by collecting species compositional data, biomass production data, basal cover data and bush density data (Coetzee 2002).

Analyses of the animal production data revealed that the highest animal production per hectare was obtained in the high stocking rate treatments and these results where not in line with the predictions of the Jones and Sandland (1974) model. Venter (1991c), cited by Coetzee (2002), indicated that possible reasons for deviations from the Jones and

Sandland (1974) model is the that the supposed negative effect of the high stocking rate on animal production was not realized, as the stocking rates applied were not high enough and the type of animal used was not suitable. A possible reason for the lack of response may be that the compensatory growth potential of young animals could “mask” some of the negative effects on animal production. It was therefore recommended that reproductive animals must be used in the trial during phase two (1992-1999) and phase three (2000 to present), which would highlight the negative effect of a high stocking rate more clearly (Coetzee 2002). The managers of the trial felt that the stocking rate effect would be mirrored in the reproductive potential of cows, as well as the production of calves. Therefore, since 1992 (start of phase two), the growing animals were replaced with a weaner production system (cow–calf system). Edwards (1969) reported on the advantage and disadvantage of using young animals for trials. Young animals results in a reduction in the experimental area used and these animals are also better converters of veld into meat, because they grow rapidly. The disadvantage of using young animals is that regular weight changes occur, when compared to older animals, which causes constantly changing stocking rates.

Twenty-one animals were used per stocking rate treatment during phase two. These consisted of seven groups of three animals, and each group represented an age group from one to seven years old. The continuous grazing system treatments were discontinued as they were found to be similar in terms of veld condition and animal production, when compared to the rotationally grazed treatments (Coetzee 2002). The number of stocking rate treatments was changed from four to three, and stocking rates were lowered as there was a decrease in veld condition in all treatments (**Error! Reference source not found.** and to

). The period of occupation within the six paddock rotational grazing system, was changed from one week to two weeks, to allow for a longer rest period (ten weeks, instead of five weeks).

During 2000 (the start of phase three), the stocking rates in all of the remaining treatments (e.g. rotationally grazed treatments at low, medium and high stocking rates) were increased, to obtain the turning point in the Jones and Sandland (1974) model, as animal production was still higher in the high stocking rate treatment (

) (Coetzee 2002).

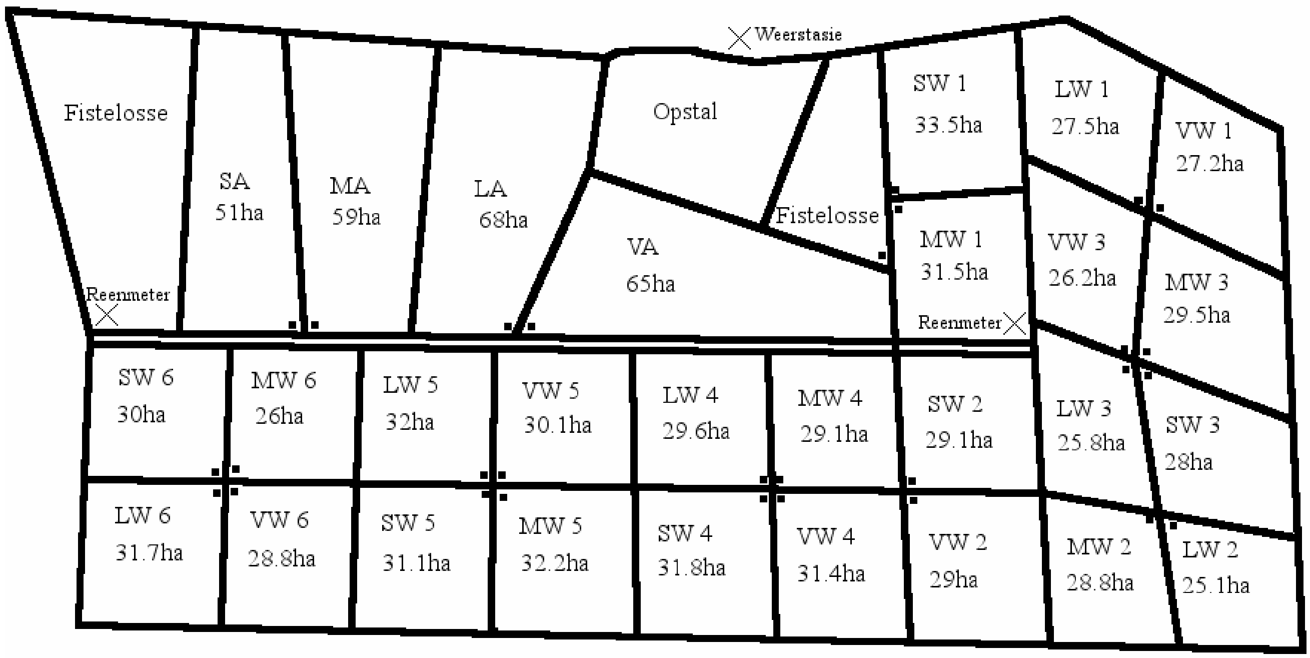


Figure 1-1: Original trial design during phase one (1977-1991) for the Armoedsvlakte grazing trial showing the sizes of paddocks and the treatment structure. **Error! Reference source not found.** has a list of abbreviations used to describe paddocks and treatments.

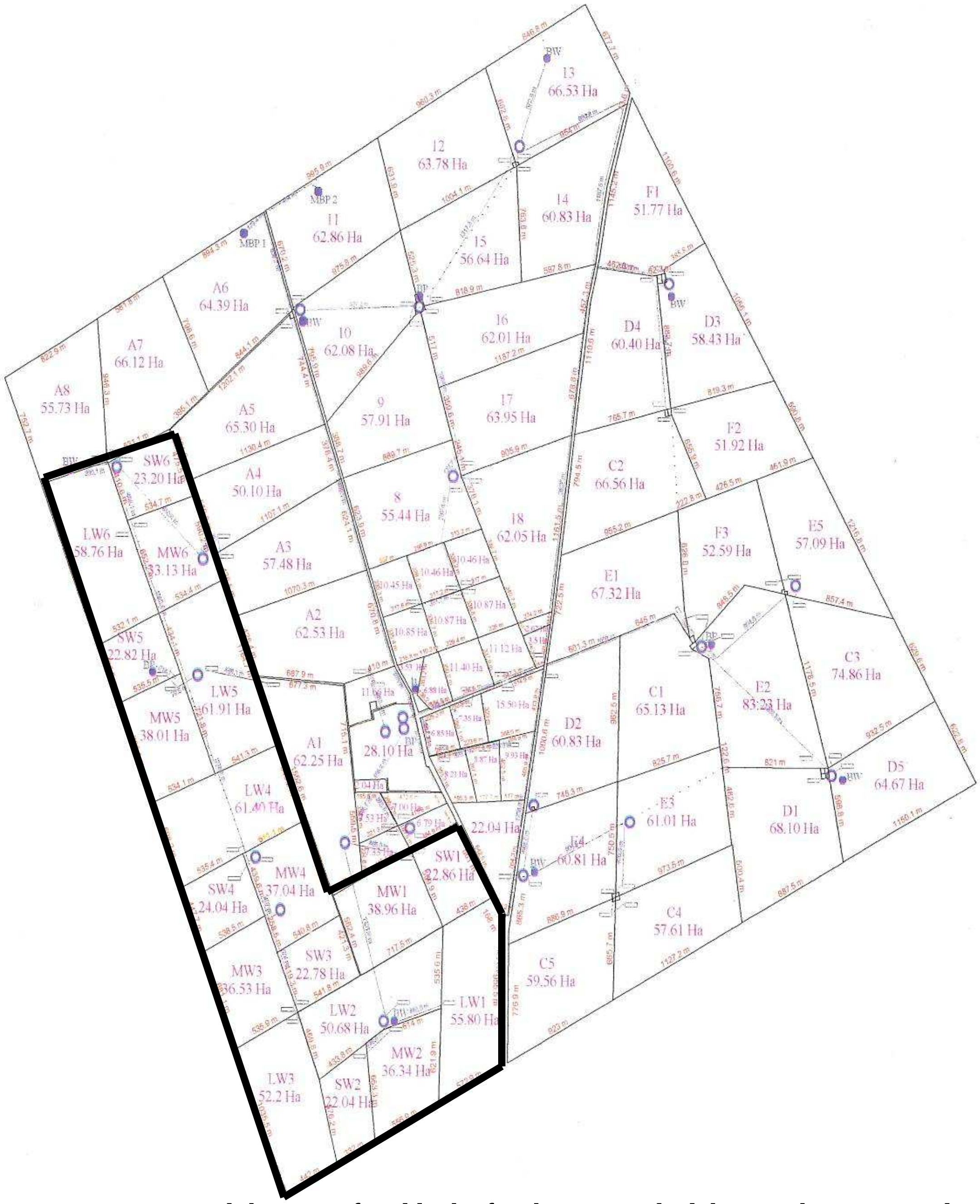


Figure 1-2: Layout and the size of paddocks for the Armoedsvlakte stocking rate and grazing systems trial for phase two (1992-1999) and phase three (2000 to present). The scale used was 1: 30 000. Paddocks within the black outline form part of the trial.

has a description of the abbreviations used to describe stocking rate treatments and paddocks.

Figure 1-3: A herd of cattle in one of the treatments at the Armoedsvlakte Research Station.

Table 1-1: Changes in suggested stocking rates during the duration of the stocking rate and grazing system trial at the Armoedsvlakte Research Station (Coetzee 2002). The four different stocking rates applied in phase one was for both the continuous and rotational grazing systems, while phase two and phase three only had rotational grazing system treatments. The actual stocking rates applied for all of the treatments for all three phases can be found in Appendix 4 to Appendix 17.

Phase One (1977-1991)	
Treatment	**LSU/ha**
Light	0.1000
Medium	0.1429
Medium-heavy	0.1818
Heavy	0.2500
Phase Two (1992-1999)	
Treatment	**LSU/ha**
Light stocking rate	0.0862
Medium stocking rate	0.1329
Heavy stocking rate	0.2148
Phase Three (2000 to present)	
Treatment	**LSU/ha**
Light	0.1149
Medium	0.1772
Heavy	0.2864

1.2. VEGETATION AT THE ARMOEDSVLAKTE RESEARCH STATION

Acocks (1988) described the vegetation of this area as the *Tarchonanthus* veld of the Ghaap's Plateau, which is a variation of the Kalahari Thornveld (Veld type 16b1, Acocks 1988). Mostert *et al.* (1971) cited by Fourie (1974) and Fourie (1983), sub-divides the vegetation into a further category, which is called Limeveld (**Error! Reference source not found.**). The dominant grass species that can be found in the Limeveld subdivision of *Tarchonanthus* veld are listed in **Error! Reference source not found.** (Fourie 1974, Fourie 1983).

Table 1-2: Grass species characteristic of the Limeveld, which is a sub-division of *Tarchonanthus* veld of the Ghaap's Plateau (Fourie 1974, Fourie 1983)

Climax species	**Sub-climax species**	**Pioneer species**
Anthephora pubescens	*Stipagrostis uniplumis*	*Aristida vestita*
Fingerhuthia africana	*Cymbopogon plurinodis*	*A. congesta*
Heteropogon contortus	*Eragrostis lehmanniana*	*A. meridionalis*
Digitaria eriantha	*E. superba*	*A. adscensionis*
Schmidtia pappophoroides	*E. trichophora*	*Enneapogon desvauxii*
Sporobolus fimbriatus	*E. nindensis*	*Tragus racemosus*
Chrysopogon serrulatus	*E. scoparius*	
Themeda triandra		

The most dominant shrub species is *Grewia flava*, while *Tarchonanthus camphoratus* is locally very common (**Error! Reference source not found.**). Other less common shrub species are *Protasparagus suaveolens, Gymnosporia heterophylla* (previously *Maytenus heterophylla*), *Rhus ciliata, Diospyros lycioides, Acacia hebeclada, Ziziphus mucronata*, *Z. zeyheriana*, *Rhus lancea*, *Elephantorrhiza elephantina* and *Lycium hirsutum*. The classification of species followed for grasses is as per Gibbs Russell *et al*. (1991) and trees and shrubs as per Germishuizen and Meyer (2003).

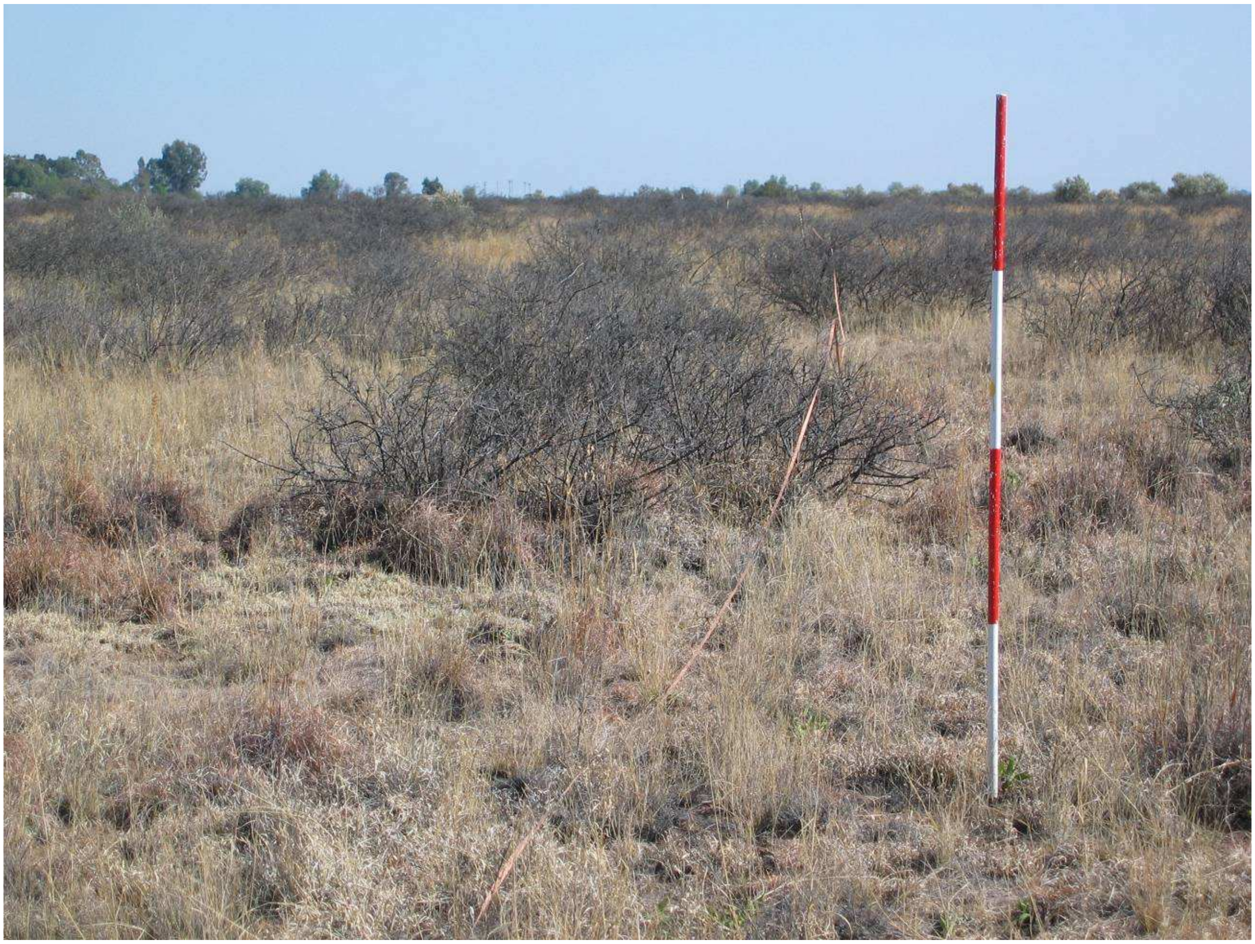


Figure 1-4: Typical example of *Tarchonanthus* veld of the Ghaapse Plato, with *Grewia flava* the dominant shrub species.

1.3. Climate at the Armoedsvlakte Research Station

The study area is in the summer rainfall area of South Africa and the rainfall is extremely variable and erratic (e.g. deviations from the mean often persist for a number of years) (Fourie 1983, Fourie *et al.* 1985a, Fourie *et al.* 1985b and Fourie *et al.* 1986a). The mean seasonal rainfall for the period 1 January 1976 to 30 May 2004 was 498 millimeters per annum (**Error! Reference source not found.** and to **Error! Reference source not found.**). The summers are extremely hot, while the winters are moderate (**Error! Reference source not found.**) (Anon 1972 cited by Fourie *et al.* 1985a and Fourie *et al.* 1986a). The highest temperature recorded at Armoedsvlakte is 41.8°C and the lowest temperature is –10.6°C (Koch 1979 cited by Fourie 1983).

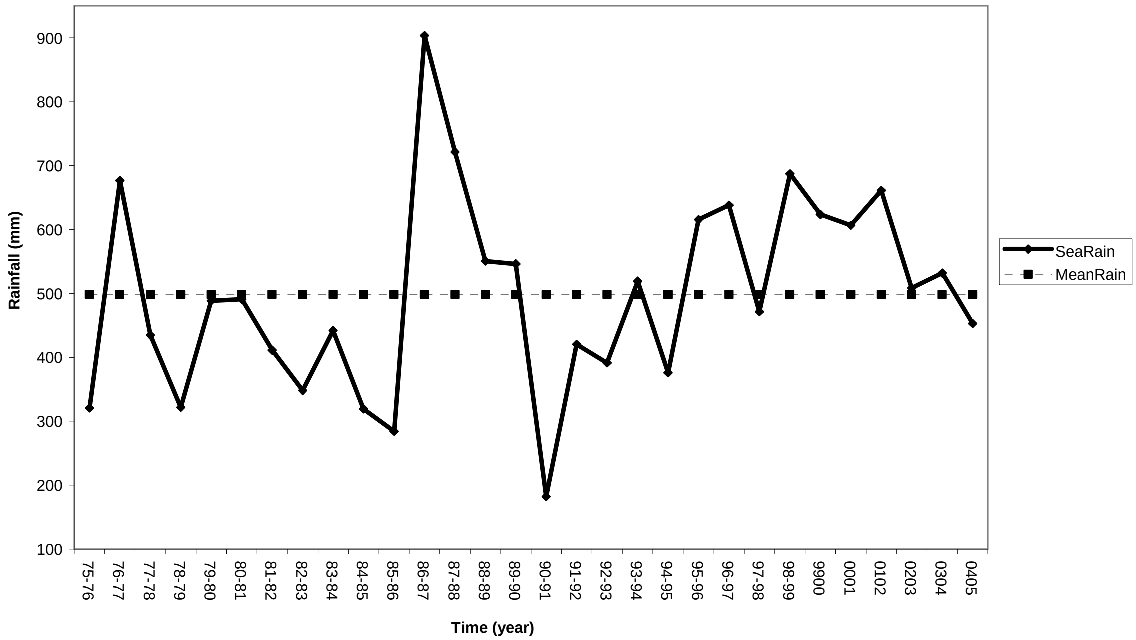


Figure 1-5: Seasonal rainfall and mean seasonal rainfall values for the period 1976 to 2004 at the Armoedsvlakte Research Station. The abbreviations used are SeaRain=Seasonal rainfall (mm) and MeanRain=Mean seasonal rainfall (mm) from 1976 to 2004.

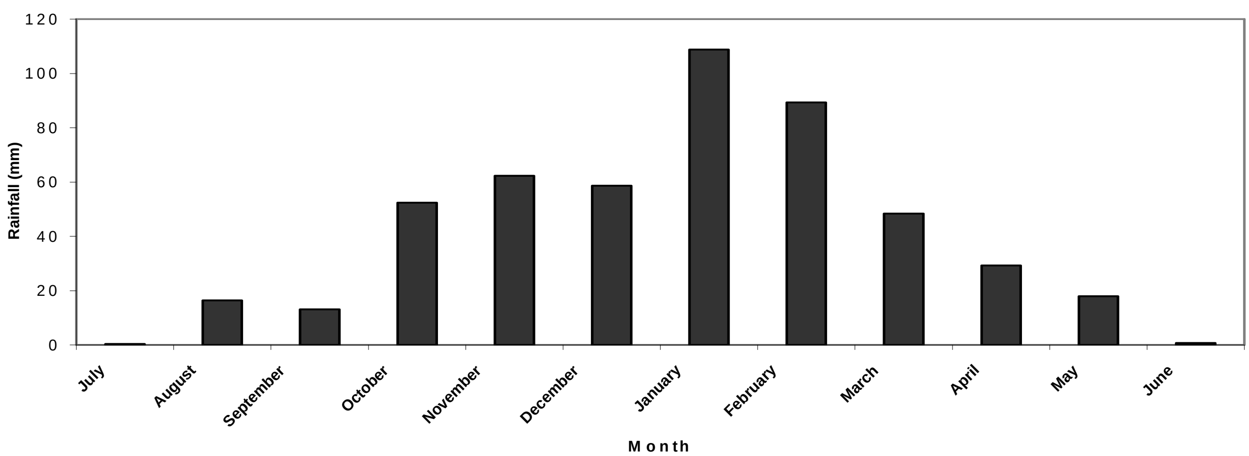


Figure 1-6: Mean monthly rainfall (mm) at the Armoedsvlakte Research Station from 1 January 1976 to 30 May 2004.

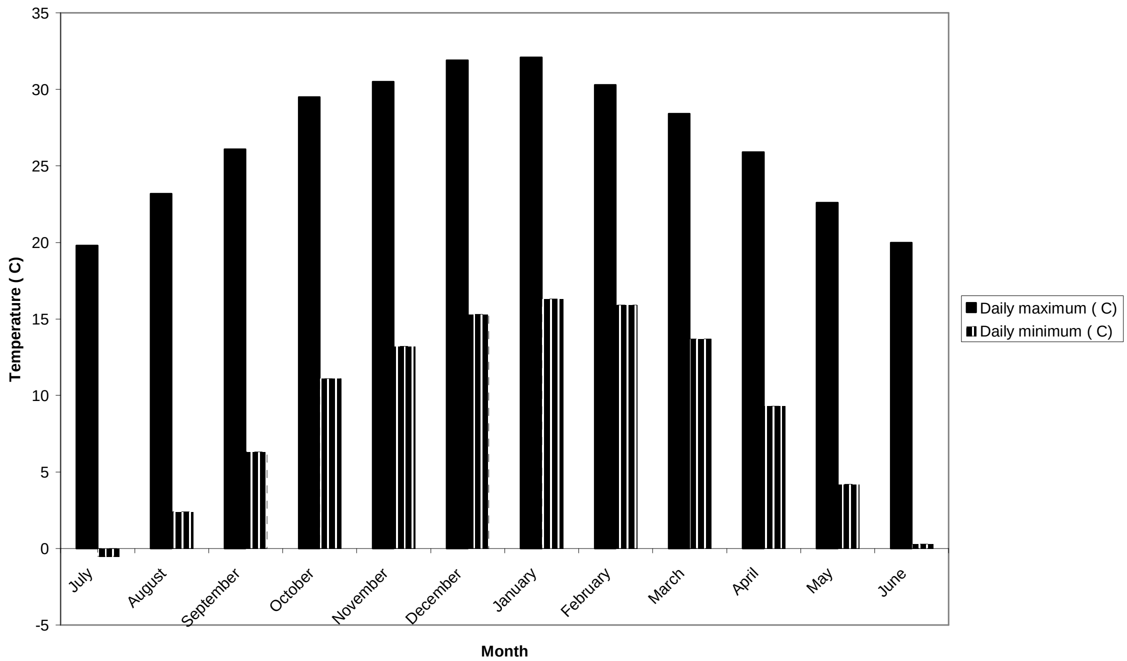


Figure 1-7: Mean monthly maximum and minimum temperatures (°C) at the Armoedsvlakte Research Station.

1.4. SOILS AT THE ARMOEDSVLAKTE RESEARCH STATION

Fourie (1974, 1983) reported that the soils at the Armoedsvlakte Research Station are lime soils, which are similar to Kalahari sand on lime rock as described by Van der Merwe (1941) cited by Fourie (1974). The A-horizon consists out of a brown sandy soil with a average depth of 28 centimeters that has the following texture: 9 % clay, 1 % silt, 69 % fine sand and 21 % sand, with a pH of 6.6 (Fourie 1974). The soil has an Orthic A-horizon and the B-horizon consists of hardpan carbonate (Fourie 1983). The soil form can be described as a typical Coega (Macvicar 1991).

1.5. OBJECTIVES OF THIS STUDY

1. To study the effects and interactions of stocking rate, type of grazing system applied and seasonal rainfall on veld condition (e.g. species composition, basal cover and residual biomass).

2. To study the effect and interactions of stocking rate, type of grazing system applied and seasonal rainfall on animal production (e.g. mass gains, calving percentages, conception rate, weaning rates and weaning masses).

1.6. RESEARCH QUESTIONS

1.1. What is the effect and interaction of stocking rate, type of grazing system applied and rainfall on species composition and veld condition?

1.2. What is the effect and interaction of stocking rate, type of grazing system applied and rainfall on the basal cover of species and ecological groups?

1.3. What is the effect and interaction of stocking rate, type of grazing system applied and rainfall on the residual biomass of species and ecological groups?

2.1. What is the effect and interactions of stocking rate, type of grazing system applied and seasonal rainfall on animal production variables (e.g. mass gain data, conception rates, weaning percentage and calving percentage)?

2.2. What is the relationship between stocking rate and Average Daily Gain (ADG) and gain per hectare?

2. Literature review on the effects and interactions of stocking rate, type of grazing system applied and rainfall on veld condition and animal production in semi-arid regions

2.1. INTRODUCTION

Managers of rangeland systems can manipulate the type and severity of defoliation in three ways. Firstly, they can manipulate the number or stocking rate of animals. Secondly, they can manipulate spatial patterns of utilization over time and this can be achieved by implementing a particular grazing system (e.g. continuous or rotational). Thirdly, they can manipulate the type of animal that the rangeland is stocked with (e.g. cattle, sheep, goats or combinations of these for commercial livestock production systems).

The relative importance of these three management variables (stocking rate, type of grazing system applied and animal type) have been debated widely in agricultural and ecological literature over the past few decades (Fourie 1983, Kreuter *et al.* 1984, and O'Reagain and Turner 1992). The effects of stocking rate and type of grazing system have however been regarded as the two most important variables in grazing management, with animal type receiving less attention and as a consequence it has generally been deemed to be of less importance (Fourie 1983, Kreuter *et al.* 1984, and O'Reagain and Turner 1992). The reason why animal type might be of less importance than the other two management variables are because certain species (or groups of species) have typically been associated with particular areas of the country. For example, cattle are seldom farmed in the Karoo, while sheep are usually unsuited for the Thornveld and other savanna areas.

Some authors suggest that stocking rate is the single most important management factor affecting animal production and the profitability of a livestock system (McMeekan and Walshe 1963 cited by Fourie 1983, Edwards 1980, Danckwerts and Drewes 1989, O'Reagain and Turner 1992, Bransby and Maclaurin 2000). One of the reasons why these authors support the above statement is because stocking rate influences the profitability of an enterprise in the short term and the natural resource base in the long term (Danckwerts and Drewes 1989, Foran and Stafford-Smith 1991 cited by Hatch *et al.* 1996). Stocking rate thus affects the financial and ecological risk to which an enterprise is subjected (Hatch *et al.* 1996). In this review stocking rate models that describe the effects, that stocking rate has on animal performance, will be discussed. In addition, the long term effects that stocking rate has on the vegetation and on soils, will be discussed.

Most authors agree that the type of grazing system applied is the second most important management variable, which influences the conversion of herbage to animal products (McMeekan and Walshe 1963 cited in Kreuter *et al.* 1984, Tainton 1985, O'Reagain and Turner 1992). There has been much debate whether rotational grazing or continuous grazing systems are superior (O'Reagain and Turner 1992). In this review, rotational grazing, rotational resting and continuous grazing systems are defined and the different approaches and forms of these grazing systems are discussed. The perceived disadvantages and advantages of both types of grazing systems are discussed and case studies (mostly from semi-arid areas) help to illustrate this point.

The rainfall in semi-arid areas is highly erratic and unpredictable (Barnes and McNeil 1978, Ellis and Swift 1988, Fynn 1998, Fynn and O'Connor 2002). It is for this reason that some authors state that rainfall is more important in affecting veld condition and animal production, than stocking rate and type of grazing system applied in these semi-arid regions. The effect that rainfall and drought has on animal production and veld condition in semi-arid environments is reviewed. The debate of whether equilibrium paradigm or non-equilibrium paradigms are more applicable to management in semi-arid areas is discussed.

2.2. STOCKING RATE

2.2.1. Importance of stocking rate

Stocking rate is a management tool that allows managers to largely determine the degree of interaction and utilization between the grazing animal and the vegetation, which in turn affects the production per animal and production per hectare (Morris *et al.* 1999). Stocking rate importance is recognized in South Africa, but not enough attention is given to the research of this subject (Fourie 1983). Carrying capacities of many veld types are recommended on extension officers' experiences and observations. This important management variable is in most cases not derived from experimental data and their associated analyses (Fourie 1983). The Kalahari Shrubveld (Acocks 1988) covers a large proportion of north-central South Africa, with much of the area being farmed extensively with cattle. Research has been conducted in the region over the past few decades (Fourie 1974, Fourie 1983, Venter 1991), but there does not appear to be consensus on how the veld should be managed regarding stocking rate and type of grazing system applied.

2.2.2. Stocking rate and animal performance models

Stocking rate can be expressed as animal numbers/hectare or land area (hectare) available for each animal (Morris *et al.* 1999). "Stocking rate on a particular portion of land, expressed in animals/hectare, increases linearly with an increase in the number of animals stocked" (Morris *et al.* 1999) (**Error! Reference source not found.**). However, stocking rate changes non-linearly with increase in livestock numbers, when expressed as hectare/animal (Morris *et al.* 1999).

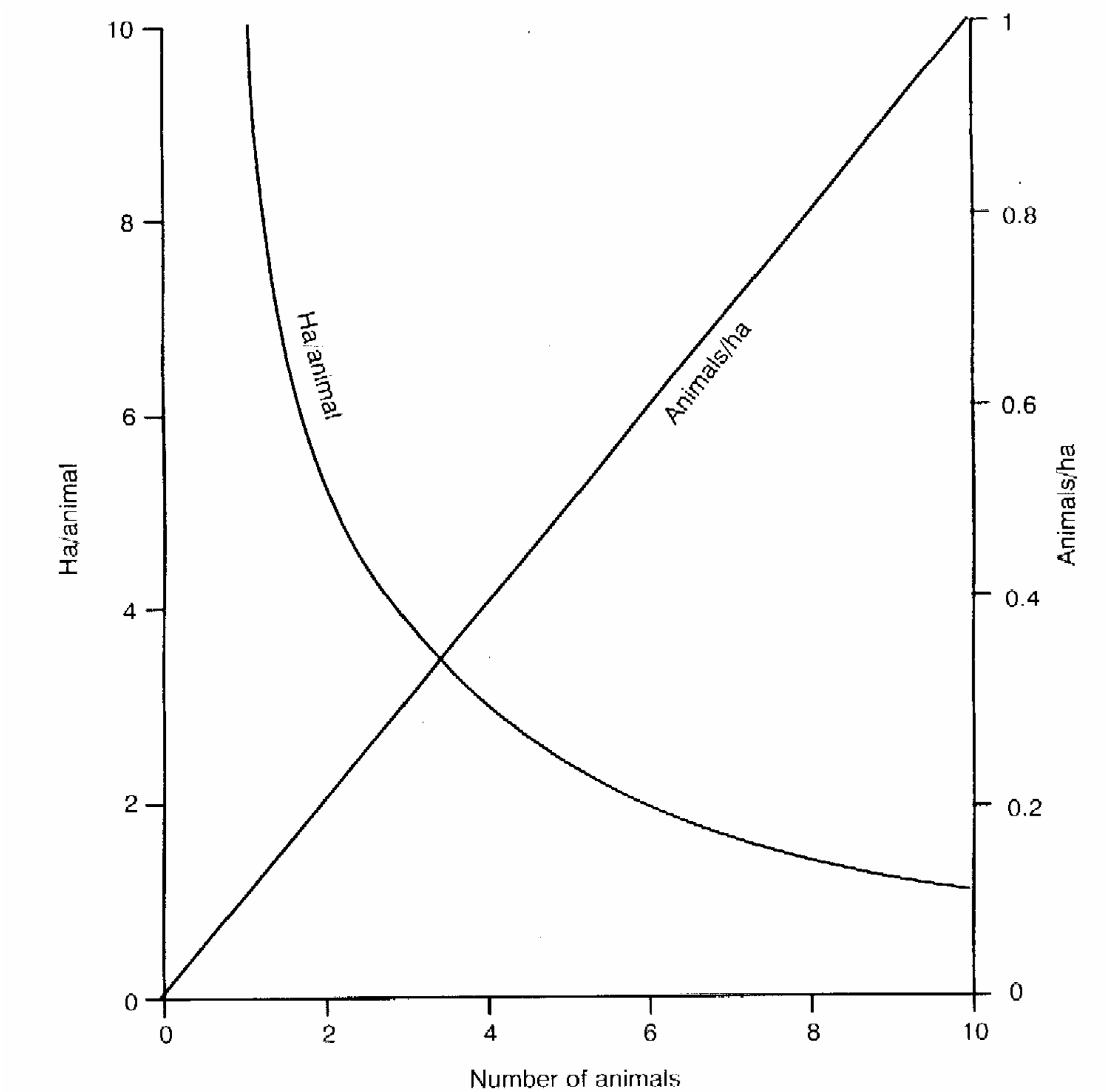


Figure 2-1: The relationship between hectares per animal and animals per hectare with increasing number of animals (Zero to ten) on a ten hectare area of land (from Danckwerts 1989b cited by Morris *et al.* 1999).

2.2.2.1. Average Daily Gain (ADG) model

The Jones and Sandland (1974) model is a useful and simple model that defines and explains the relationship between stocking rate and animal performance. The authors contended that many studies demonstrated a linear relationship between stocking rate and gain per animal and a curvilinear relationship between stocking rate and gain per hectare. They propose from the results of grazing trials that there is a linear relationship (e.g. y=a-bx, were a and b are constants and x is stocking rate) between Average Daily Gain (ADG) and stocking rate, over a range of stocking rates. The relationship between stocking rate and average daily gain is described by two lines and these are AB and BXn in **Error! Reference source not found.** (Morris *et al.* 1999). Line AB is parallel to the stocking rate axis and there is no improvement in animal performance when stocking rates are decreased from Xb to Xa (**Error! Reference source not found.**) (Morris *et al.* 1999). The main reason for this is that at very low stocking rates, intake is not restricted and the amount of forage available per animal does not limit animal performance (Morris *et al.* 1999). Animal production is limited by genetically defined growth potential and/or forage quality (Morris *et al.* 1999). Animal performance may in fact decline, as grass material accumulates and becomes less digestible, as the lignin and other cell wall contents increases and grasses can even become moribund (the drop in animal performance is shown by the dotted line A_1B in **Error! Reference source not found.**) (Stobbs 1970 cited by Morris *et al.* 1999). At low stocking rates, there is a drop in ADG and they attribute this to high levels of selection resulting in a large biomass of grazeable material of a poor digestible content (e.g. high lignin and cellulose levels and low protein levels) (Jones and Sandland 1974). At stocking rates greater than Xb, animal performance declines as stocking rate increases, as there is an increased demand for a limiting resource (Kennan 1969 and Gammon 1983a cited in O'Reagain and Turner 1992, Hart 1978 cited in Morris *et al.* 1999, Fourie 1983, Turner and Tainton 1990). Thus, quantity limitations and not quality limitations limit animal production and performance (Morris *et al.* 1999). Eventually a stocking rate Xw is reached, where the average daily gain is zero and animals just maintain their body condition (**Error! Reference source not found.**) (Morris *et al.* 1999). Zero animal gain is usually found at stocking rates double that maximum gain per hectare and maximum gain per animal and maximum gain per hectare never coincides with each other (Jones and Sandland 1974). Maximum individual animal performance on a particular veld type, for a given class of animal occurs at a stocking rate where quality and quantity limitations are balanced (Turner and Tainton 1990). Deviations from the ADG model (Jones and Sandland 1974) have been reported by Peterson *et al.* (1965) and Connolly (1976) cited by Morris *et al.* (1999) especially at high stocking rates, where animal performance may drop off more rapidly with increasing stocking rates, than at low stocking rates. The reason for this may result due to the increased energy requirements for foraging, where forage is scarce and widely dispersed (Heitschmidt and Taylor 1991). However, the linear ADG model is generally a good approximation of the relationship between stocking rate and animal performance (Morris *et al.* 1999).

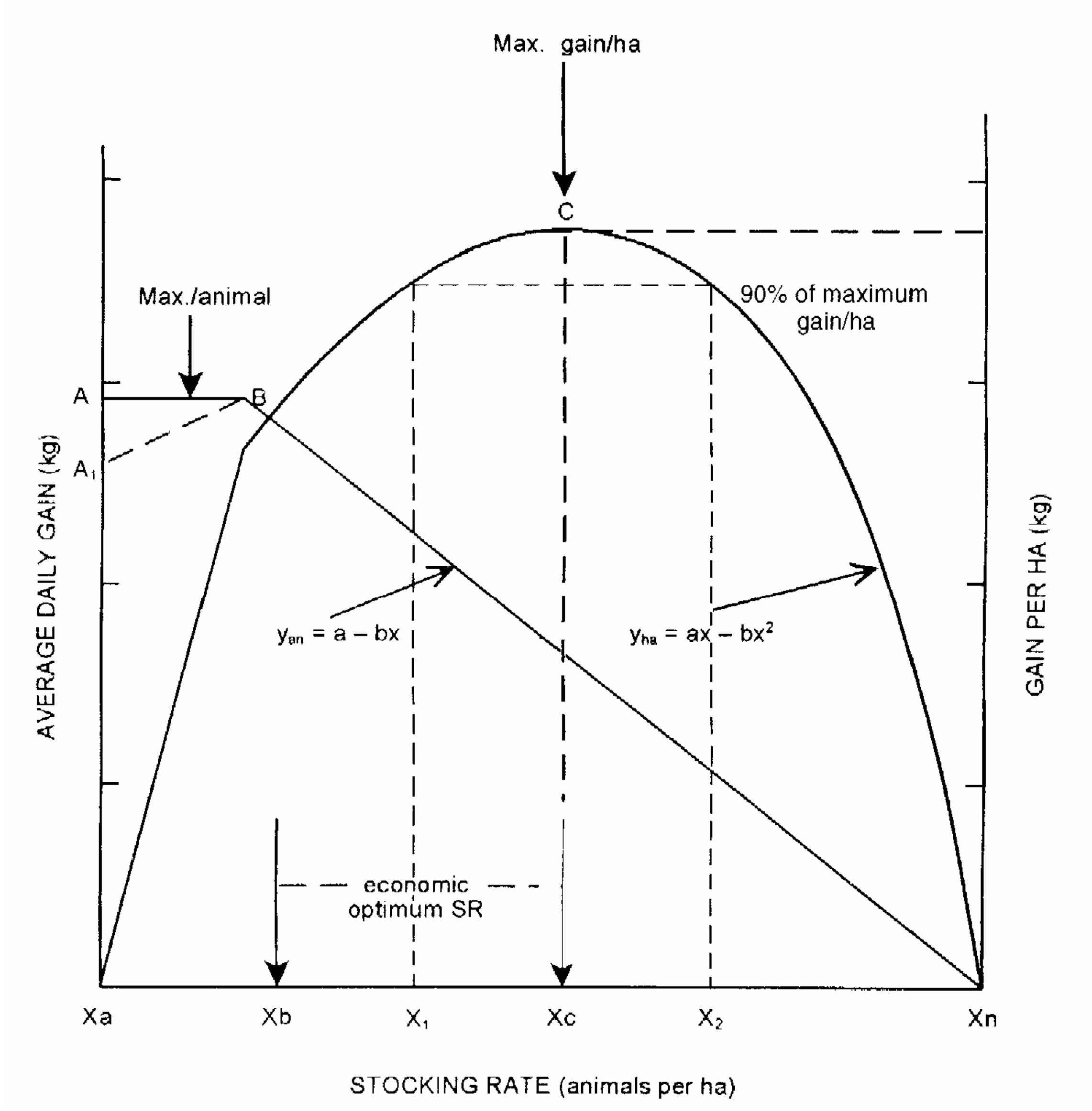


Figure 2-2: The relationship between stocking rate and ADG and gain per hectare (taken from Bartholomew 1991 cited by Morris *et al.* 1999).

2.2.2.2.The gain per hectare model

The relationship between stocking rate and gain per hectare can be described by the curvilinear equation $Y=ax-bx^2$, where a and b are constants and x is the stocking rate (Jones and Sandland 1974). The gain per hectare model is thus derived by multiplying the ADG equation (Y=a-bx) by the range of stocking rates applied (x) (Jones and Sandland 1974, Morris *et al.* 1999). The gain per hectare model shows a sharp increase in animal production/hectare with each unit increase in stocking rate from Xa to Xb (**Error! Reference source not found.**) (Morris *et al.* 1999). This is followed by a slower rate of increase at stocking rates beyond Xb, until a maximum gain per hectare is reached at Xc (**Error! Reference source not found.**) (Morris *et al.* 1999). The maximum gain per hectare is obtained where X=a/2b and this equation is derived by differentiating the gain per hectare equation with respect to x and then equating the first derivative to zero (Jones and Sandland 1974). After point Xc, there is an accelerated decline in gain per hectare at stocking rates beyond Xc (Morris *et al.* 1999). Finally, point Xn is reached, where the production per unit area is zero (**Error! Reference source not found.**) (Morris *et al.* 1999). The same production per hectare could be achieved at different stocking rates, but the higher stocking has a lower gain per animal, and the choice of at which stocking rate to apply, depends on the objectives of the farmer (Morris *et al.* 1999).

Morris *et al.* (1999) indicated that a number of points should be noted when using an empirical model for predicting animal performance and gain per hectare at various stocking rates. The models are empirical and their predictive ability depends on the quality of the data used to derive the models (Morris *et al.* 1999). Models are specific to a particular vegetation type, particular type and class of animal and cannot be extrapolated to predict animal performance under different conditions (Morris *et al.* 1999). The models results vary during the season as plant growth fluctuates within a season and years (Morris *et al.* 1999). Bartholomew (1985) cited by Morris *et al.* (1999) and Heitschmidt and Taylor (1991) suggested that the variation in biomass production results due to rainfall fluctuations. This will alter the intercept of the average daily gain line, rather than its slope and will shift the position of the maximum animal gain per hectare. It is thus recommended that a sensitivity analysis be performed to investigate what the effect of rainfall on animal production is and a range of rainfall levels representative of a period sufficiently long to incorporate climatic variation, should be used (Morris *et al.* 1999). The ADG model is not useful in semi-arid and arid areas as the rainfall is highly erratic and productivity more dependent on rainfall than stocking rate (Morris *et al.* 1999).

2.2.3. Long term effects of stocking rate on the vegetation, animal production and soil properties

Many rangelands are stocked at rates above the estimated carrying capacity, probably because land managers attempt to maximize income in the short-term, especially during times of financial difficulty (Danckwerts1989b). However, these high stocking rates can have drastic negative effects on veld condition and animal production in the long term and many have reported that it can even result in desertification.

Stocking rate has an effect on the quantity of available grazing and thus affects both intake and animal performance (Morris *et al.* 1999). Stocking rate has a long-term effect on the vegetation, which will in turn affect the productivity and economic viability of grazing systems (Morris *et al.* 1999). Some scientists have found that high stocking rates result in adverse impacts on both veld condition and animal production (Tainton 1972, Edwards and Nel 1973, Boultwood and Rodel 1981 cited by Fourie 1983 and Edwards 1980).

Severe overgrazing caused by high stocking rates will reduce the vigour of grasses and reduces the ability of the grass to produce and to continue producing herbage, as less energy is available for storage and growth (Chapman and Lemaire 1993 cited by Morris *et al.* 1999, Fourie 1983, Van Niekerk *et al.* 1984). Prolonged overgrazing can lead to an adverse change in species composition both in humid and semi-arid grasslands (Houston and Woodward 1966, Hazell 1967, Bryan and Evans 1973, Pearson and Whitaker 1974, Eng *et al.* 1978 cited by Fourie 1983, Hardy and Hurt 1989, Morris *et al.* 1992, Milchunas and Laurenroth 1993, Fynn 1998) and can result in bush encroachment (Frischknecht *et al.* 1953 cited by Fourie 1983) These adverse changes in vegetation dynamics can result in a reduction in the abundance of palatable species, basal cover and productivity and less productive grasses and forbs generally replace palatable species (O'Connor and Pickett 1992 cited by Fynn 1998, O'Reagain and Turner 1992 and O'Connor and Roux 1995). This decrease in veld condition ultimately results in reduced animal performance (Fynn 1998) and in a marked reduction in profitability per hectare (Danckwerts and King 1984, Van Niekerk *et al.* 1984). Experimental results from Hull *et al.* (1961) cited by Fourie (1983) support the above statement and indicated that low stocking rate treatments resulted in an ADG of 0.82kg/day and 17.1% of carcass fat, while the high stocking rate treatments had an ADG of 0.36kg/day and 13.4% carcass fat. At low stocking rates cattle selected for high quality material, while at high stocking rates, the forage had a high feeding value (e.g. high nitrogen content and digestibility), due to the high percentage of short green, growth of grasses (Demarchi 1973, Langlands and Bennet 1973b, Eng *et al.* 1978 cited by Fourie 1983). Piper *et al.* (1959) cited by Fourie (1983) however found that high stocking rates resulted in grasses with low protein and phosphorus content and high lignin percentages.

Danckwerts (1989c) reported that overstocking in sweetveld areas results in a reduction in forage production, rather than a reduction in forage quality. Hardy and Mentis (1986) cited by Morris *et al.* (1999) found contrasting results in humid grasslands, where overstocking resulted in small changes in biomass production, but a marked deterioration in the quality of forage on offer.

Stocking rate affects soil infiltration rates and soil water content (Rhoades *et al.* 1964, Rauzi and Hanson 1966, Rauzi and Smith 1973 cited by Fourie 1983). Rauzi and Smith (1973) cited by Fourie (1983) indicate that continuous high stocking rates will result in low infiltration rates and ultimately soil erosion. The reason why high stocking rates result in a decrease in infiltration rates is due to the decreased soil porosity with increases in stocking rate (Rauzi and Hanson 1966 cited by Fynn 1998), which has a negative effect on root development and increases in soil bulk density (Rhoades *et al.* 1964, Rauzi and Hanson 1966, Warren *et al.* 1986, Pluhar *et al.* 1987 cited by Fynn 1998). Decreases in infiltration rates therefore results in lower plant biomass and increased soil run-off (Le

Houerou 1989 cited by Fynn 1998), which results in high soil erosion levels (Fynn 1998). The effect of high stocking rates on sandy soils will be less when compared to areas with clay soils, as sandy soils have high porosity levels and are less prone to surface capping Sandy soils are thus not likely to have a lower infiltration rate (Fynn 1998). For example, 15 years of high stocking rates on sandy soils did not result in a significant lowering of animal production (Barnes 1965 cited by Fynn 1998), while a study done on clay soils found that high stocking rates resulted in lower animal production levels (Carew 1980 cited by Fynn 1998).

2.2.4. Studies that show the effects that stocking rate has on animal and grass production

Fourie *et al.* (1985a) found that stocking rate had a markedly greater influence on available grazing than the type of grazing system applied. Above ground biomass declined as stocking rate increased, but in some years no significant differences in above ground biomass between stocking rate treatments occurred, while during other years opposite trends emerged. For example in 1977/78 season, there were no significant differences in biomass production between the different stocking rate treatments. However, in the subsequent three seasons the light, medium and medium-heavy stocking rates all had a significantly higher biomass production than the high stocking rate treatments. The type of grazing system applied did not markedly influence the available grazing, but biomass production decreased and grazing pressure increased as stocking rate increased. Fourie *et al.* (1985a) concluded from their studies in the Kalahari Thornveld that if a stocking rate of 7ha/animal unit is applied, that the effect of droughts only becomes drastic, if the drought continues for more than a year, as at this stocking rate there is enough reserve grazing for 337days.

Fynn (1998) and Fynn and O'Connor (2000) found in a semi-arid savanna that stocking rate had a negative affect on production per hectare on poor condition rangeland during drought years. The combination of drought, high stocking rate and terrain morphology (e.g. steep slopes degraded far more rapidly than weakly slope areas) resulted in veld degradation. Long-term heavy grazing (e.g. high stocking rates) on sloping lands resulted in a decline in biomass production in both studies. These authors pointed out that the reduction in biomass production in a paddock was more severe, where species composition changes occurred due to drought and grazing. During high rainfall seasons, where light stocking rates were applied, grazing promoted the development of tufted perennial grasses. Under low rainfall conditions, annuals and weakly tufted perennials dominated the high stocking rate treatments. Annual species dominated at high stocking rates and when high rainfall prevailed. Long-term high stocking rates did not reduce cattle performance (measured in terms of gain per animal and gain per hectare). However, during dry conditions, cattle performance was the worse at high stocking rates on poor veld condition, than on veld in a good condition. Rainfall appeared to be a better indicator of cattle performance than both biomass production and stocking rate.

2.2.5. The importance and interactions of stocking rate and type of grazing system applied

Tainton (1984) cited by O'Reagain and Turner (1992), Tainton (1985) reported that stocking rate may be of secondary importance to the type of grazing system applied, especially when high stocking rates may be applied under rotational grazing systems, without detriment to range condition and animal performance (Booysen and Tainton 1978 and Savory 1978 cited by O'Reagain and Turner 1992, Acocks 1966). O'Reagain and Turner (1992) stated that the above-mentioned statement is refuted by available literature. All of the grazing trials reviewed by O'Reagain and Turner (1992), except one, showed that stocking rate had a greater effect on animal production, than the type of grazing system applied (Carew 1980, Gammon 1983b, Anon (1984), Anon 1985 cited by O'Reagain and Turner 1992, Fourie 1983, Kreuter *et al.* 1984, Donaldson 1986). Grof and Harding (1970), Robinson and Simpson (1975), Denny and Barnes (1977), Van Poolen and Lacey (1979) and Vorster and Visagie (1980) cited by Fourie (1983) also reported similar results.

Similarly, range condition appears to be more dependent upon stocking rate than grazing system applied (Walker and Scott 1968, Anon 1985 cited by O'Reagain and Turner 1992). The type of grazing system applied only has a significant effect at high stocking rates (Conway (1963) cited by Fourie (1983)). Higher animal gains are achieved with continuous grazing treatments for both light and medium stocking rates (Conway (1963) cited by Fourie (1983)). However, the high stocking rate and rotational grazing treatments experienced 49% higher animal gains, than the high stocking with continuous grazing treatment (Conway (1963) cited by Fourie (1983)).

2.2.6. The interaction between stocking rate and rainfall

Langlands and Bennet (1973) cited by Fourie (1983) illustrated throught their study that rainfall has a significant influence on stocking rate and on the digestibility of available forage. These authors indicated that in dry years (e.g. below the mean rainfall for area), grazing animals in low stocking rate treatments, selected high quality material. There was more material to select from relative to the high stocking rate treatments. However, during wet years, surplus grazing material in the low stocking treatments became moribund and lignified, and this decreased the ability of cattle to select for high quality material.

Hatch (1995) reported that conservative stocking in semi-arid savanna in KwaZulu-Natal decreased the risk of forage deficits, but increased the opportunity costs of lost financial returns during high rainfall seasons. In contrast, applying high stocking rates during high rainfall periods increased the farmer's returns, but the risk of forage deficits during periods of low rainfall increased and very low returns will occur under these conditions (Danckwerts and Drewes 1989, Hatch 1995, McCarthy 2001). Hatch (1995) proposed variable stocking rates (e.g. a mixture of conservative and high stocking rates), but recognized the danger of increasing stocking rates in a variable environment. Danckwerts and Drewes (1989) found that maximum income per hectare and maximum profitability per hectare occurred at a low stocking rates during the "dry" years, and they reported that there were more "dry" than "wet" years, It thus benefits farmers to stock conservatively over the long-term.

Fuhlendorf *et al.* (2001) found that drought had a greater effect on high grazing intensity treatments, than on low and intermediate grazing treatments. They found that there was a substantial decrease in biomass production in high grazing intensity treatments and plants had a small basal area, which resulted in greater drought mortality.

Walker *et al.* (1987) cited by Walker (1993) found in four game reserves in South Africa, that perennial plants and animals were able to withstand a severe drought for a single year. However, two successive years of well below average rainfall resulted in significant mortality in both plants and animals. The effect of drought was exuberated by heaving grazing prior and during the drought.

2.3. GRAZING SYSTEMS

2.3.1. Rotational grazing

Rotational grazing is a management strategy, which requires the allocation of grazing to a group or groups of animals for the entire grazeable period. The grazing area is subdivided into at least one (usually more) paddock more than the number of animal groups (Booysen 1967). Rotational grazing involves the successive grazing of paddocks by animals in rotation so that those animals are concentrated on a small part of the available grazing for a part of the grazeable period (Booysen 1967). Each paddock experiences successive periods of grazing and absence from grazing (Booysen 1967), resulting in the whole grazable area being utilized during the year.

Many scientists advocate that rotational grazing is the only system capable of maintaining long-term veld condition and animal production (Anon 1926, Botha and Malherbe 1945, Scott 1947, Roux 1968, Booysen and Tainton 1978 cited by O'Reagain and Turner 1992, Robinson and Simpson 1975 cited by Barnes 1977, Booysen *et al.* 1974) and it is recommended for all veld types (Roux 1968 cited by O'Reagain and Turner 1992, Barnes 1992, Danckwerts 1989a, Teague 1989). Rotational grazing has many advantages in controlling the grazing patterns and it can be used to facilitate the long-term maintenance of veld condition (Kreuter *et al.* 1984, Barnes 1992, Kirkman and Moore 1995). Rotational grazing results in a more even utilisation of the available grazing and as a result less selective grazing takes place and higher dry matter yields are achieved per season (Booysen 1966, Barnes 1992). Rotational grazing allegedly decreases or even eliminates selective grazing (Anon 1926, Rowland 1937, Pienaar 1968a, Booysen and Tainton 1978 cited by O'Reagain and Turner 1992, Barnes 1992), while by having a set period of occupation and absence from the paddock it prevents the regrowth of grazing (Pienaar 1968a cited by O'Reagain and Turner 1992, Booysen *et al.* 1974, Edwards 1981). Veld condition allegedly improves with a resultant increase in the grazing capacity and animal production off the veld (Rowland 1937, Preller 1947, Pienaar 1968a, Roux 1968, Savory 1978 cited by O'Reagain and Turner 1992, Acocks 1966, Barnes 1992, Gammon 1978).

Many authors have reported that rotational grazing allows the grasses to have a rest period during the critical growth periods and to help control selective grazing, which improves grass production and feeding value (Botha and Malherbe 1945, Coetzee 1948, Preller 1948, Booysen 1956, Grunow 1959, Hildyard 1960, Booysen *et al.* 1963, Booysen 1964, Pienaar 1968a, Venter and Drewes 1969, Rethman 1971, Grunow 1973, Vorster 1975, Van den Berg, *et al.* 1975, Van den Berg *et al.* 1976, Edwards 1975, Tainton *et al.* 1977, Vorster and Visagie 1980, Grunow 1980, Daines 1980 cited by Fourie 1983, Acocks 1966, Booysen *et al.* 1974, Booysen *et al.* 1975, Gammon and Roberts 1978a). O'Reagain and Turner (1992) however indicate that the above mentioned reasons are not supported by empirical evidence and animal production in continuous grazing systems may in fact be superior to rotational grazing systems (**Error! Reference source not found.**). Evidence from long-term grazing trials indicated that initial levels of animal production can be maintained for periods longer than 20 years. From the data in **Error! Reference source not found.**, it can be seen that continuous grazing does not necessarily impact adversely on the range condition. None of the trials reported improvements in carrying capacity under rotational grazing systems, either. Rotational grazing, in some cases, brought about significant range deterioration, even in as short a time-period as three years, but it should be noted that this was the veld was utilized by goats (Du Toit 1972 cited by O'Reagain and Turner 1992).

Table 2-1: Results of grazing trials, which compared rotational grazing systems with continuous grazing systems in terms of animal production and range condition (from O'Reagain and Turner 1992)

	Continuous Grazing superior	**Rotational Grazing superior**	**No difference**
Animal production	9	7	7
Range condition	3	5	14

Most researchers and advisors in South Africa advocate rotational grazing with multi-paddocks with at least six to eight paddocks per animal herd for most veld types (Kirkman and Moore 1995). Multi-paddock grazing systems are supposed to provide the manager with a means of controlling the frequency and intensity of grazing, but Barnes (1992) suggests this is a fallacy. The advantages of multi-paddock systems are as follows (Roberts 1970):

- The manager has greater flexibility as dense veld can be grazed intensively and denuded areas can be given special recovery treatment.
- The system allows for both highly selective light grazing and for less selective heavy grazing.
- The shorter grazing periods of paddocks is supposed to result in an increased vigour of grasses.
- Patch formation and the detrimental trampling around key resources areas can be prevented.
- Long periods of absence (e.g. longer rest periods) allows grasses to seed in these rested paddocks.
- Increased carrying capacity by allowing the recovery, seeding and establishment of grasses of denuded areas and this can be followed by grazing.
- More effective use of rainfall because of the high proportion of the veld that is rested and the system thus has greater drought reserves. Roberts (1970) however commented this in only true if the correct stocking rate is applied.
- The manager has to invest less in parasite control as animals are in paddocks for a very short time and parasites are not allowed to establish.

- Improved stock condition and more efficient animal management is possible due to regular handling and observation.
- Burning can be eliminated from the system.

Gammon (1978) found no conclusive evidence that any one form of rotational grazing was superior to any other. Barnes and Denny (1991) found that rotational grazing, whether with four or eight paddocks, did not increase the grazing capacity of veld. This contradicts the thoughts of Savory (1969), Howell (1976), Vaughan-Evans (1978) cited by Barnes and Denny (1991), who advocate that short duration grazing resulted in an increase in grass production and/or an increase in the proportion of desirable grass species.

Morris and Tainton (1996) concluded from their study in Southern Tall Grassveld that multi-paddock systems employing short periods of stay and long periods of absence/rest cannot be justified in terms of the ability of the system to improve plant production, basal cover and range condition. A possible reason for this is that the frequency and severity of defoliation of palatable species may not have differed, as widely suggested by the parameters of the system. The benefits of resting the veld could ameliorate the adverse effects of overgrazing. Barnes (1982), Gammon (1984), Tainton (1985) cited by Morris and Tainton (1996) questioned the cost and supposed increase in animal production that can be achieved by short duration grazing. Results of Morris and Tainton (1996) suggested that stocking rate cannot be increased in a short duration grazing system, because of the proposed increase in plant production in such systems. Denny and Steyn (1977) cited by Morris and Tainton (1996) reported that animal performance is in fact poorer for multi-paddock systems than a system with few paddocks. A possible reason for this is that animals have a decreased opportunity to select an optimum diet in multi-paddock systems. Morris and Tainton (1996), Morris and Fynn (2001) indicated that a multi-paddock rotational grazing system is not any better than a few paddock system in terms of increasing animal production and maintaining veld condition. Vorster and Visagie (1980) found similar facts in that the number of paddocks (three, six, 12 and 18) does not result in increases in animal production. These authors found that stocking rate and rest were more important in explaining variation in animal production, than grazing systems.

Barnes (1992) found that for rotational grazing systems to increase the carrying capacity of the veld, one or more of the following three changes need to occur:

- The first change is an increase in the proportion of more productive and palatable grass species relevative to unpalatable species.
- The second change is an increase in the biomass production due to a favourable change in defoliation patterns.
- The third and last change is increased utilization of less palatable species by the grazers. There is firm evidence that the above-mentioned changes are extremely unlikely.

Brockett *et al.* (1980) cited by (Fourie 1983) showed that higher animal gains where achieved with continuous grazing systems during spring, while the rotational grazing treatments had higher animal gains in summer and autumn. The rotational grazing system in this study had higher animal production per hectare, than continuous grazing systems.

There are two main approaches in the application of the rotational grazing concept (Booysen 1969). The main objective of both types of approaches is to increase animal production and to maintain veld condition (Kirkman and Moore 1995). The two approaches are called High Utilization Grazing (HUG) or Non-Selective Grazing (NSG) and High Production Grazing (HPG) or Controlled Selective Grazing (CSG) (Pienaar 1968b cited by Drewes 1991, Acocks 1966, Booysen 1969). Short Duration Grazing (SDG) is similar to NSG, but SDG has shorter rest periods (Beukes and Cowling 1999). The primary objective of HUG is to minimize selective grazing within the grass sward (Acocks 1966), while HPG attempts to maximize the seasonal production of high desirable or desirable plants (e.g. desirable species like *Themeda triandra*) (Pienaar 1968b cited by Drewes 1991, Booysen 1969).

HUG is achieved by "forcing" the animals to graze undesirable grass species (e.g. Increaser species like *Aristida junciformis*) and by increasing the utilization of the herbage of offer, even though desirable grass species are severely grazed (Booysen 1969, Kirkman and Moore 1995). This can be achieved by applying high stocking rates and keeping the period of stay "long" and the period of absence "long" (Acocks 1966, Booysen 1969, Kirkman and Moore 1995). The hypothesis that combats selective grazing is that defoliation is supposed to have a greater detrimental effect on undesirable grass species than on desirable grass species (Booysen 1969). This is not always true, as the severe grazing of desirable grass species may reduce their vigour and competitive ability (Booysen 1969). Jones *et a/.* (1967) cited by O'Reagain and Turner (1992) indicated that non-selective grazing in sourveld resulted in severe defoliation of palatable species and rapid range deterioration. Non-selective grazing allegedly improves range condition and herbage production, which allows for two to three-fold increases in carrying capacity (Roberts 1967a, Roberts 1967b and Simpson 1968 cited by O'Reagain and Turner 1992, Acocks 1966). However, O'Reagain and Turner (1992) clearly stated that the majority of evidence for non-selective grazing or HUG is anecdotal.

HPG or controlled selective grazing is achieved by leaving sufficient leaf material on desirable grass species within the sward to continue the fast growth rate of these plants. Undesirable plant species are rarely grazed and are supposed to become moribund and die (Booysen 1966, Pienaar 1968a cited by O'Reagain and Turner 1992, Booysen 1969, Kirkman and Moore 1995). By leaving sufficient leaf material on the desirable plant species, they can continue to grow at a faster rate and out-compete undesirable species (Booysen 1969). HPG can be achieved by applying low stocking rates and by keeping the period of stay and period of absence in the paddock "short" (Booysen 1969, Kirkman and Moore 1995). The hypothesis that combats selective grazing is that the lack of utilization of undesirable plant species is supposed to weaken their competitive ability against desirable grass species (Booysen 1969). Evidence for this grazing strategy is anecdotal (Pienaar 1968a cited by O'Reagain and Turner 1992) and the system is yet to be tested experimentally, but there is indirect experimental evidence to support this system (Pretorius *et al.* 1974, Burger *et al.* 1975 cited by O'Reagain and Turner 1992, Danckwerts 1984). O'Reagain and Turner (1992) agreed that lenient defoliation should favour dietary quality and intake as animals are removed from the paddock before species are excessively defoliated. Animal production may thus be higher in a HPG system than in a HUG system. Whether undesirable species become moribund and die through no utilisation, is however, questionable, because Increaser one species (i.e. *Hyparrhenia hirta*), increase when the veld is under-utilised and Increaser three species (i.e. *Aristida junciformis*) increase, if the veld is selectively grazed (Van Oudtshoorn 1999).

Booysen (1969) reported that it is not a question of one of these approaches being right and the other wrong. HUG results in a low initial production per animal, while animal production per hectare is higher than for HPG (Booysen 1969). The veld condition will deteriorate if undesirable grass species are less susceptible to defoliation than the desirable plant species and *vice versa* (Booysen 1969). HPG supports the point that undesirable grass species will die out, as the plant becomes more moribund over time (Booysen 1969). HPG is feasible where the undesirable plant is less susceptible to grazing than the desirable grass species (Booysen 1969). In areas where selective grazing is not a problem, HPG will result in greater production, but where selective grazing is a problem the method to use will depend on the plants in the grass sward. If the undesirable grass plants are more susceptible to grazing than the desirable grass species, then HUG is more suitable (Booysen 1969). If the undesirable grass plants are less susceptible to grazing than the desirable grass species, then HPG is more suitable (Booysen 1969). Tainton (1985) reported that there is a general view by of pastoralists is that HPG is more appropriate than HUG, but there are however a few exceptions to this, in the literature.

Tainton *et al.* (1977) found that the period of presence and absence is very important in a rotational grazing system when trying to obtain high animal production. They found that animal production increases with decreased periods of stay and increased period of absence. They concluded that the optimum grazing system for Tall Grassveld is a rotational grazing system with seven paddocks, with a period of stay of 10 days and a period of absence of 60 days.

2.3.2. Rotational resting

Rotational resting is a management strategy which requires the allocation of grazing to a group or groups of animals for the entire grazeable period to be sub-divided into at least one more paddock than animal groups and it involves the successive resting of the paddocks for specific purposes (e.g. seed production) (Booysen 1967). Rotational grazing and resting is a management strategy, which requires the allocation of grazing to a group of animals for the entire grazeable period to be sub-divided into at least two or more paddocks than groups of animals. This strategy involves the simultaneous incorporation of the principles of rotational resting and rotational grazing (Booysen 1967).

2.3.3. Continuous grazing

Continuous grazing is a management strategy whereby animals are placed in a paddock, when the forage is ready to be grazed at the start of the growing season and are left in that paddock for the entire grazeable period of a year. The number of animals in the enclosure during the grazing period may vary according to the growth rate of the grazing, but some animals must be present in the paddock at all times during the grazeable period (definition adapted from Booysen 1967, Tainton *et al.* 1999). Continuous grazing is free of management variables and it thus allows for an uncompounded evaluation of the inherent production patterns of the veld at any given time (Kreuter *et al.* 1984).

As with any type of grazing system, continuous grazing has different degrees of sophistication (Tainton *et al.* 1999). In its crudest form, continuous grazing comprises the whole farm as one paddock with all of the livestock in one herd (Tainton *et al.* 1999). The farm is stocked with the general grazing capacity of the area and vegetation (Tainton *et al.* 1999). It is suggested that this form of continuous grazing results in area and species selective grazing and unless stocking rates are manipulated to the production of the preferred areas, overgrazing of selected patches will result and veld deterioration and erosion may be inevitable (Fourie 1983, Tainton *et al.* 1999). Tainton *et al.* (1999) reported that the less preferred areas can be grazed only to the detriment of the preferred areas, by forcing the animals to graze these areas after they have utilised all the material on the preferred areas. Animal management (e.g. controlled mating, weaning and parasite control) is very difficult and animals do not easily or regularly come under the herdsman's eye (Tainton *et al.* 1999). This form of continuous grazing does not allow for the rationing of forage and peaks and troughs in animal production are exaggerated (Tainton *et al.* 1999). Resting of veld as to encourage the seeding of the more palatable species and to improve vigour is also not possible (Tainton *et al.* 1999).

The second form of continuous grazing is where there are many paddocks that are each stocked at the recommended grazing capacity for that paddock (Tainton *et al.* 1999). Each paddock has it own water points and herds or flocks are constituted to facilitate animal management. The animal numbers in each paddock may be regulated to try to maintain the preferred species composition, but in practise, this is difficult. If paddocks are well designed, area and species selection can be reduced significantly (Tainton *et al.* 1999). It is however hard to eliminate species selection and to ration forage if this form of continuous grazing is applied (Tainton *et al.* 1999). Rationing can be achieved by varying animal group sizes and in doing so changing the grazing pressure within the different paddocks throughout the season (Tainton *et al.* 1999). It is not possible to apply rests, unless there are more paddocks than there are animal groups (Tainton *et al*. 1999).

One of the major practical problems with continuous grazing is that it lacks flexibility. Booysen (1975) cited by Tainton *et al.* (1999) indicated that the optimum economic stocking rate for a continuously grazed pasture is lower than the same pasture grazed rotationally. Paddock size, placement of water points and adjustment of stocking rates to achieve the recommend grazing capacity is more critical in continuous than rotational grazing systems (Tainton *et al.* 1999). The economic advantage of a lower requirement for fencing and water points in a continuous grazing system decreases with increasing sophistication of the system (Tainton *et al.* 1999). However, Mentis *et al.* (1989) reported that continuous grazing systems are superior in terms of the financial returns, even in the long-term.

2.3.4. Studies that contradict the notion to continuous grazing system always results in poor veld condition and animal production

Barnes and Denny (1991) found in continuous grazing systems and low stocking rates treatments, high animal gains where achieved. It is often cited in the literature that continuous grazing results in veld degradation and ultimately desertification, in the long-term. However, there was no indication that continuous grazing had adverse effects on veld condition in this study. Edwards (1969) found similar results indicating that there was no conclusive scientific evidence in the literature to prove that continuous grazing systems of any veld type, resulted in lower animal production than rotational grazing systems.

O'Reagain and Turner (1992) reported that it has been widely accepted that continuous grazing is responsible for range deterioration and soil erosion in rangelands (e.g. Tidmarsh 1951, Booysen and Tainton 1978 cited by O'Reagain and Turner 1992, Edwards 1981, Vorster *et al.* 1983, Booysen 1969). The reason why is because continuous grazing allows for area and species selective grazing, which results in a decline in vigour and the eventual death of the preferred species (Booysen and Tainton 1978 cited by O'Reagain and Turner 1992, Booysen *et al.* 1974, Barnes 1977, Edwards 1981). While animal performance in continuous grazing systems is initially high, production allegedly declines with time, owing to the inevitable range deterioration associated with this system (Tidmarsh 1951, Booysen and Tainton 1978 cited by O'Reagain and Turner 1992, Kreuter *et al.* 1984).

However, Mckay (1968), Donaldson and Rootman (1983) cited by O'Reagain and Turner (1992) have shown, for semi-arid savannas, that range condition may be maintained even after years of continuous grazing with cattle. Generally, where degradation occurred under continuous grazing it appeared to be with sheep (Morris 1944, Roux 1964a, Roux 1964b cited by O'Reagain and Turner 1992, Donaldson 1986). Gammon and Roberts (1978a, 1978b and 1978c) found that area and selective grazing and the severity of tiller defoliation was nearly identical for continuous and six paddock rotationally grazed systems. Moore and Biddescombe (1964) cited by Roberts (1970) stated that there are no convincing economic advantages of having a rotational grazing system in semi-arid areas in Australia.

Kreuter *et al.* (1984) showed in their study that the continuous grazing treatments out-performed rotational grazing treatments in terms of both average daily gain and live mass production per hectare. Stocking rate appeared to only have a marginally greater effect on average daily gain, when compared to the type of grazing system applied. Beef production under continuous grazing was found to be 48 % higher at high stocking rates (2.2 animals/ha) compared to a rotational grazing system, but this marked difference was not evident at low stocking rate treatments. The maximum animal gain per hectare was higher under continuous grazing with high stocking rates. The maximum production/hectare and optimum stocking rate was greater under continuous than under rotational grazing. Possible reasons why continuous grazing were more superior to rotational grazing in this study are because animals had a greater ability to select for high nutritional value. There is less interference with animal behaviour, that possibly resulted in a less disturbed grazing pattern. The above average mean rainfall could also have resulted in an abundance of herbage and the advantage of conserving fodder in rotational grazing, was thus not realised. This trial was only conducted for a few years and the apparent short-term superiority of continuous grazing should not be viewed as a long-term advantage.

Archibald and Bond (2003) found that high stocking rates and continuous grazing resulted in the formation of grazing lawns. These areas are highly productive, usually consisting out of stoloniferous grass species, which support a high number and diversity of grasses. Huisman *et al.* (1999) and Swemmer (1998) cited by Archibald and Bond (2003), indicated that only when taller growing bunch grasses are kept short, are grazing lawn grass species able to spread and establish themselves.

Du Toit (2003) found in the False Thornveld of the Eastern Cape that the rotational grazing at a low stocking rate resulted in less than a third of the area being grazed and grazing was concentrated in small patches less than six meters in size. The continuous grazing at a low stocking rate treatment resulted in half the area being grazed and the patch size increased to 40 meters. The continuous grazing at a high stocking rate treatment resulted in two thirds of the area being grazed and animals grazed in both small and large patches. Patches had a significantly higher diversity than non-patches and the density of *Themeda triandra* was highly positively correlated to patch size. There was thus no evidence that rotational grazing reduced patch selective grazing and that rotationally grazed sites had better species composition than continuously grazed sites.

2.3.5. Studies that support the notion that continuous grazing systems usually results in poorer veld condition and animal production

Although continuous grazing has been proposed by Booysen (1975), Booysen and Tainton (1978) cited by Teague and Dowhover (2002) and Kirkman and Moore (1995), research comparing grazing systems has generally concluded that the effect of rotational grazing on defoliation patterns is weak or absent. Teague and Dowhover (2002, 2003) indicated that research comparing grazing systems have been chosen to be as uniform as possible and small paddocks (< 25 hectares and often five hectares) were mostly used. The above-mentioned factors significantly reduce the variability that causes patch selection and the associated deterioration in large paddocks (Norton 1998 cited by Teague and Dowhover 2002). Research by Stuth (1991) cited by Teague and Dowhover 2002, Bailey *et al.* (1996) and Senft *et al.* (1985) indicated that patch grazing increased as the area under consideration increased in size. Wallis DeVries and Schippers (1994) indicated that selection is only slightly affected by small-scale heterogeneity at the feeding stage, but it is profoundly affected by large-scale heterogeneity at the landscape level. Spatial and temporal variability in primary production localizes and intensifies herbivore impacts on the vegetation (Turner 1999 cited by Teague and Dowhover 2002, Illius and O’Connor 1999).

Teague and Dowhover (2002) showed that basal cover was significantly influenced by grazing treatment and that treatments interacted significantly with species composition. Grass basal cover increased significantly more under rotational grazing, compared to continuous grazing.

Results of Teague and Dowhover (2002) indicate that rotational grazing systems markedly increased basal cover of grass species and that rotational grazing treatments resulted in 33 % less bare ground than continuously grazed systems on the same soil type. It was concluded that weather, especially precipitation, had a significant effect on the basal cover within sites and on the biomass production for all of the species. There was also a significant interaction between rainfall and grazing system. In large paddocks under rotational grazing, perennial herb basal cover increased dramatically and there were lower proportions of bare ground than in continuous grazing systems. The type of grazing, but grazing systems did not influence biomass production, significantly.

If grazing takes place in a continuous way within patches in paddocks bigger than 25 hectares, then taller grass species gets replaced with shorter perennial grasses, followed by annual grasses and eventually bare ground (Archer and Smeins 1991 cited by Teague and Dowhover 2002, Milchunas and Laurenroth 1993). Species that are more productive are thus progressively replaced by less productive and palatable species. This can result in a decrease in the carrying capacity of the farm, decrease in infiltration rates and an increase in soil erosion and run off (Gifford and Hawkins 1978, Snyman and Fouche 1991 cited by Teague and Dowhover 2002, Thurow *et al.* 1986, Fuls 1992).

By using rotational grazing in large paddocks, land degradation will decline, as grass basal cover will increase, soil erosion and soil run off will decline (Teague and Dowhover 2003). To prevent the deterioration of heavily grazed areas, adequate periods of rest between successive defoliation must be provided (Teague and Dowhover 2003). Teague and Dowhover (2003) concluded that planned rotational grazing systems are the key for the sustainable use and conservation of rangelands.

Morris *et al.* (1992) found in Southern Tall Grassveld that continuous grazing at a high stocking rates treatment resulted in a grass sward dominated by *Aristida junciformis*. Even when stock was removed, veld rested and periodic burns implemented, the system was still dominated by this unproductive species. Tainton (1958), Tainton (1972) cited by

Morris and Fynn 2001 and Morris *et al*. (1992) reported on the superiority of rotationally grazing systems over continuously grazed systems for sheep production and in order to maintain a desirable species composition.

Bunting (2003) reported that the optimal grazing system for sourveld is a five paddock rotational grazing system. The paddocks in this author's study area were dominated by *Hyparrhenia hirta* before the grazing system was implemented. After the implementation, the author reported that the veld condition improved dramatically (e.g. dominated by *Themeda triandra*) and the mass gain of steers increased favourably. This five-paddock rotational system required that 40% of the veld be rested, maked use of the principles of both controlled selective grazing and non-selective grazing and aimed for 50% utilization in the reserve paddock. Veld that was rested during the previous year received controlled selective grazing during winter and were burned in August.

Venter and Drewes (1969) recommend a similar grazing system in which 25% of veld is rested, 50 % of veld is grazed short (e.g. non-selective grazing) and 25% is subjected to controlled selective grazing. Paddocks that are grazed selectively are rested and burnt the following season.

2.3.6. Optimum stocking rate for continuous and rotational grazing systems

Both continuous and rotational grazing systems have their own optimum-stocking rate (Booysen *et al.* 1975). Booysen *et al.* (1975) and Danckwerts and Drewes (1989) reported that the optimum stocking rate was found to lie between the biological optima of maximum production per animal and maximum production per hectare. Booysen (1969) reported that one of the main reasons for the poor veld condition in some continuously grazed systems is the application of incorrect stocking rates and not the actual grazing system itself.

2.4. THE EFFECT OF RAINFALL AND DROUGHTS ON ANIMAL PRODUCTION AND/OR VELD CONDITION

2.4.1. The effect of rainfall in semi-arid regions on animal production and veld condition

Rainfall is one of the most important variables explaining vegetation dynamics, variation in range production (e.g. animal and grass biomass production) and the profitability of livestock enterprises in semi-arid and arid environments (Frost *et al.* 1986 cited by Morris *et al.* 1999, O'Connor 1994, Hatch 1995, Hatch and Tainton 1995, Hatch *et al.* 1996). The rainfall in semi-arid and arid areas is highly erratic and unpredictable (Barnes and McNeil 1978, Aucamp and Barnard 1980, Mentis *et al* 1989, Behnke and Scoones 1993, Snyman and Fouche 1993, Fynn 1998, Fynn and O'Connor 2000, McCarthy 2001) and this can result in substantial and unpredictable fluctuations in plant production, adverse changes in basal cover and species composition, which ultimately results in poor animal production and veld condition (Snyman and Fouche 1993). An important relationship to consider are that there is the strong linear relationship between mean annual rainfall and vegetative biomass production (Deshmukh 1984, Milchunas and Laurenroth 1993). In addition, animal production is strongly linearly related to mean annual precipitation (Fritz and Duncan 1994 cited by Fynn 1998).

2.4.2. Contradictory views on the importance of rainfall on veld condition and/or animal production in semi-arid areas

The first viewpoint is that rainfall is more important than stocking rate and grazing system in vegetation dynamics and animal production in semi-arid areas. The authors in favour of the equilibrium vegetation dynamics model support the notion that the ecosystem has the capacity to regulate itself internally through the processes of intra- and inter-specific competition and plant-animal interactions (O'Neill *et al.* 1986 cited by Briske *et al.* 2003 and Behnke and Scoones 1993) (Chapter 2.5.1). The second viewpoint is the opposite of the above, namely that ecosystem has minimal capacity to regulate itself internally and external factors (especially rainfall) are the key components which regulate vegetation dynamics and animal production in these semi-arid areas (Milton and Hoffman 1994, Briske *et al.* 2003) (Chapter 2.5.2)

2.4.2.1.Studies that support the "non-equilibrium" paradigm

Plant species composition and animal production in semi-arid environments are largely driven by rainfall in the short term, while stocking rate becomes more important in the long-term (Hatch 1994 cited by Fynn 1998, O'Connor 1995, O'Connor and Roux 1995). Richter *et al.* (2001), found in three semi-arid savanna's that seasonal rainfall was the most important factor governing changes in species composition of the herbaceous layer. Animal production is more dependent on rainfall, than on stocking rate in these semi-arid regions (Ellis and Swift 1988). Fynn (1998) and Fynn and O'Connor (2000) showed that changes in botanical composition were strongly influenced by rainfall variability and that rainfall had the most marked effect on variability in biomass production. Behnke and Scoones (1993) concluded from their research that arid and semi-arid environments can be regarded as non-equilibrium systems and these systems are highly complex (Chapter 2.5).

O'Connor (1991) indicated that the annual rainfall variation in Sandveld savanna had an important overriding influence of the species compositional change and that this change is further mediated by the type of grazing regime applied (e.g. light or heavy grazing). The species composition and the abundance of the predominant species changed substantially, mainly due to variation in rainfall. The rainfall that occurred during the duration of this study, initially a couple of wet years and then successively drier years, had a greater influence on species compositional data, than the imposed grazing treatments.

2.4.2.2.Studies that support the "equilibrium" paradigm

Hoffman and Cowling (1990) cited by Hatch *et al.* (1996) and Riechers *et al.* (1989) indicated that forage production is determined largely by the stochastic nature of rainfall, that stocking rate is the major determinant of livestock production.

2.4.3. The effect of season of rainfall on species composition and veld condition

The season of rainfall affects the species composition and animal production of the veld. For example, Roux (1966) found, in Eastern Mixed Karoo veld, that when most of the rain falls in spring and summer the veld is dominated by grass species and shrubs are less abundant. If most of the rain falls in autumn and winter, then Karoo shrubs dominate the species composition and grass species are less abundant. Unpalatable shrubs also increased in abundance with autumn rainfall. When droughts occured in the region, both grass and shrubs species declined in abundance.

2.4.4. The effects of droughts in semi-arid regions on animal production and veld condition

Droughts occur regularly in arid and semi-arid areas and under these conditions, the available biomass for grazing is a major factor that influences animal production (Barnes and McNeil 1978, Fourie *et al.* 1985a). Barnes and McNeil (1978) indicated that droughts are likely to have disastrous effects on animal production and may cause long lasting damage to the environment. Livingstone (1991) cited by Fynn (1998) found that droughts decrease basal cover and biomass production of grasses, and that the first heavy rains after the drought resulted in high soil run-off, soil erosion and loss of seedbanks.

Single and multi-year droughts have major influences on the biomass production of veld and therefore on herbivore populations and their condition (Ellis and Swift 1988). Herbivore numbers remains relatively constant during short, year-long droughts although they might loose condition (e.g. decrease in mass), but plants experience a greater, but temporary setback (Ellis and Swift 1988). During multi-year droughts (two years or longer), the animal and plant population will decline rapidly and the animal population will take a long time to recover. This is assuming animals do not get fed substitutes for grazing (e.g. high levels of substitution of maize) during or after drought periods.

2.4.4.1. Studies that indicate the effect of drought on veld condition

Donaldson (1967) found in the Vryburg district, that the 1964-1966 drought lead to a highly significant mortality of *Stipagrostis uniplumis*, *Schmidtia pappophoroides* and *Eragrostis lehmanniana* which contributed to more than 80% of the grass species in the veld where woody species were not removed before the drought. In an area where woody species were removed before the drought, there was no significant mortality of these grass species and this veld also had a higher post-drought biomass than uncleared veld. The drought resulted in a significant decrease in basal cover in both well-managed areas and overgrazed areas. There was a significant increase of annual species (e.g. *Tragus racemosus*) within all treatment, after the drought had occurred. The high mortality of grass species resulted in low biomass production and a decrease in the carrying capacity of the veld, especially at the uncleared site.

O'Connor (1995) found, in a grassland savanna that drought had an overriding effect on species composition change, while grazing had a smaller additional effect. The drought resulted in a transformation in species composition of perennial palatable species (e.g. *Themeda triandra*) to unpalatable perennial (e.g. *Aristida bipartita*), annual and forb species in highly stocked grassland. Lightly stocked grassland maintained most of its palatable perennial species, but these species' relative abundances declined and a number of annual species were recorded for the first time after the drought (O'Connor 1995). The total basal cover and basal cover of preferred species declined in both highly stocked and lightly stocked treatments (O'Connor 1995). Post-drought recovery and past management practises help to explain species composition change after the drought. For example, sites that had light stocking rates before, during and after the drought had a better species composition and higher basal cover after the drought (O'Connor 1995).

Hatch and Tainton (1995) found similar results in the semi-arid Zululand Lowveld, where light stocking rates showed a less pronounced effect of drought and had a higher post-drought biomass in these sites. Fynn (1998) report that post drought management is important and the author used an example from Kelly (1973) to illustrate this point. In this example, a heavily stocked communal area had only a nine % lower biomass production than a commercial area in a normal year, but during a single year drought, the communal area had an 80% lower biomass production. Fynn (1998) and Fynn and O'Connor (2000) found that the 1991-92 drought in Zululand resulted in dramatical adverse shift in species composition, to a veld dominated by annual grasses, forbs and very weak perennial grasses.

Danckwerts and Stuart-Hill (1988) found, in the False Thornveld of the Eastern Cape, that the 1982/83 drought resulted in extensive grass mortality during the drought. After the drought, the recovery of the veld was particularly sensitive to the post-drought management applied. Veld that was grazed immediately after the drought recovered slower than veld that was rested after the drought. Increaser 1 species were more drought resistant than Decreaser species, while Decreaser species were more stable than Increaser II species. The ability of the grass species to recover after the drought followed an opposite trend. The species composition of the veld recovered rapidly following a drought, provided that the veld is rested after the drought. The authors recommended that veld be rested for as long as possible, after a drought to allow it to recover.

2.5. EQUILIBRIUM AND NON-EQULIBRIUM VEGETATION DYNAMICS

"The question of whether equilibrium and/or non-equilibrium vegetation dynamics occur in rangelands has been the source for many rangeland debates" (Briske *et al.* 2003). Egerton (1973) cited by Briske *et al.* (2003) and Wu and Loucks (1995) reported that the equilibrium paradigm has been in existence since the beginning of scientific inquiry, while the non-equilibrium paradigm is a more recent paradigm. These two paradigms represent unique interpretations of ecosystem behaviour in response to disturbance (e.g. grazing and rainfall) (Briske *et al.* 2003).

2.5.1. Equilibrium vegetation dynamics

The equilibrium paradigm is based on the assumption that ecosystems posses the capacity for internal regulation through negative feedback mechanisms (e.g. intra- and inter-specific competition and plant-animal interactions) (O'Neill *et al.* 1986 cited by Briske *et al.* 2003 and Behnke and Scoones 1993). Equilibrium vegetation dynamics usually occurs in areas (e.g. humid environments) where resource levels (e.g. rainfall) are relatively constant. Plant densities are high and symmetrical competition for available resources is important (Tainton *et al.* 1996). However, climate and ecosystems coupling may contribute directly to ecosystem behaviour, but climate is not the main factor driving ecosystem behaviour (Higgins *et al.* 2002 cited by Briske *et al.* 2003). Equilibrium systems are assumed to return to their pre-disturbance state or pre-disturbance trajectory when the disturbance has stopped (O'Neill *et al.* 1986 cited by Briske *et al.* 2003, Mentis *et al.* 1989, Wu and Loucks 1995, Tainton *et al*. 1996, Fernandez-Gimenez and Allen-Diaz 1999). The range model that was developed by Dyksterhuis (1949) is based on equilibrium vegetation dynamics and it emphasises the importance of plant competition and plant-herbivore interactions (Fernandez-Gimenez and Allen-Diaz 1999, Briske *et al.* 2003). The problem with the range model is that it assumes that if grazing pressure is decreased or eliminated, that the veld will return to its climax state (Friedel 1991). Friedel (1991) and Laycock (1991) indicated that this might be true for some systems, but in other systems, a threshold might have been crossed and the change in vegetation might be non-reversible (Chapter 2.5.2.1.1). An example of a non-reversible change occurred in a study by Morris *et al.* (1992) in Southern Tall Grassveld when *Aristida junciformis* occurred in high abundances under continuous grazing with a high stocking rate and a seasonal rest (rotational rest) treatment. When livestock where removed from the treatment and a periodic burn was introduced, *Aristida junciformis* abundances remained stable under the rest and burning regime (Morris *et al.* 1992). Laycock (1989) cited by Laycock (1991) called these non-reversible changes suspended stages of succession, in which communities remain constant for long periods of time. Laycock (1991) gave the following reasons for suspended stages or different trajectories of succession:

- The dominance of highly competitive species or life forms.
- Long generation times of dominant species.
- Lack of seed or a seed source.
- Specific physiological requirements that limit seedling establishment, except at infrequent intervals.
- Adverse climate change.
- Restriction of fire.

Another problem with the range model is that the climax community might not be the desirable vegetation type considering management objectives (Friedel 1991). The equilibrium paradigm assumes that ecological systems have a high degree of internal interactions and regulation of plants and herbivores are therefore strongly connected. Herbivores thus have a strong influence on plant populations in areas where this vegetation dynamics occurs (Chesson and Case 1986 cited by Briske *et al.* 2003, Tainton *et al.* 1996, Fernandez-Gimenez and Allen-Diaz 1999). Fernandez-Gimenez and Allen-Diaz (1999) and Briske *et al.* (2003) reported that grazing is assumed to internally regulate ecosystem behaviour, by imposing negative feedback mechanisms on the ecosystem. Fernandez-Gimenez and Allen-Diaz (1999) indicates that the range model predicts that as animal numbers increased, plant biomass and cover declines and species composition shifts from dominance of perennial grass and forbs (climax species), towards dominance by forbs and weedy annuals species (pioneer species). Many authors have argued for the equilibrium vegetation dynamics by recommending that there are multiple steady or equilibrium states, to account for dynamic behaviour of certain ecological systems (Holling 1973, Hurd and Wolf 1974, Sutherland 1974, Noy-Meir 1975, May 1977 cited by Briske *et al.* 2003). The above-mentioned authors stated that disturbances are assumed to force one stable community past the threshold to another subsequent stable community at the same site. Equilibrium paradigms has over-emphasised internal ecosystem regulation and stability, which has minimized the importance of climatic variability and episodic events on ecosystem behaviour (Wiens 1984 cited by Briske *et al.* 2003, Ellis and Swift 1988, Milton and Hoffman 1994, Wu and Loucks 1995).

2.5.2. Non-equilibrium vegetation dynamics

The non-equilibrium paradigm has minimised ecosystem regulation and stability and placed greater emphasis on external disturbances (e.g. rainfall), as key components that effect vegetation dynamics and therefore herbivore populations (Milton and Hoffman 1994, Briske *et al.* 2003). If an area has non-equilibrium vegetation dynamics, then it implies that ecosystems are less predictable than what the equilibrium paradigm suggests and that models other than the range model is required to try to account for this variability (Wiens 1984 cited by Briske *et al.* 2003, Ellis and Swift 1988, Wu and Loucks

1995). The non-equilibrium paradigm is based on the assumption that ecosystems possess a limited capacity for internal regulation (Ellis and Swift 1988, Wu and Loucks 1995) and there is thus a weak interaction between plants, the animals that graze them and their food source (Ellis and Swift 1988). Non-equilibrium systems are thus more vulnerable to external disturbances and these systems are thus more dynamic and less predictable than equilibrium systems (Hurt and Wolf 1974, Pickett *et al.* 1992, Pickett and Ostfeld 1995 cited by Briske *et al.* 2003 and Milton and Hoffman 1994). In non-equilibrium systems, climatic events and other abiotic factors (e.g. soil fertility) are assumed to be responsible for the greatest potential for vegetation and herbivore dynamics. (Walker 1993 and Watson *et al.* 1996 cited by Briske *et al.* 2003, Westoby *et al.* 1989, Behnke and Scoones 1993, O'Connor 1995 and Tainton *et al.* 1996). In these systems, herbivores are said to play a secondary and usually insignificant role in vegetation and herbivore dynamics (Tainton *et al.* 1996). Ellis and Swift (1988) proposed that rangeland areas with an inter-annual coefficient of variation of rainfall greater than 33% are non-equilibrium systems. The reason for this statement is because livestock would not experience density dependent effects as drought induced mortality would decrease animal numbers to such a level that density dependence effects can not be experienced and the herbivores can thus not influence the ecosystem deleteriously (Ellis and Swift 1988, Peel *et al.* 2000). Behnke and Scoones (1993) have used this argument in other semi-arid areas that support livestock production. The non-equilibrium paradigm has severe management implications as it challenges the traditional approaches for understanding and managing rangeland systems (Behnke *et al.* 1993, Scoones 1994 cited by Illius and O'Connor 1999). Scoones (1994) cited by Illius and O'Connor (1999) and Behnke *et al.* (1993) challenged the equilibrium concept of carrying capacity, the application of fixed stocking rates in variable environments, using species composition in assessing range condition and using insufficient experimental evidence (e.g. effects of defoliation intensity on vegetation structure, system functioning and animal production) to recommend fixed stocking rates.

According to (Fynn 1998) and Fynn and O'Connor (2000), results from their study in a semi-arid savanna indicate that density-dependent effects were present in their study, but it was mostly expressed on erodible landscapes during and following the drought. These authors concluded that grazing definitely had an effect on species composition and biomass production on erodible slopes, where supplementary feeding was necessary during the drought years on heavily stocked treatments and especially on poor condition rangeland. The results of this study contradicted the non-equilibrium paradigm as stocking rate influenced production per hectare on poor condition veld during the drought.

Beukes and Cowling (1999) found that changes in species composition and basal cover in a Nama-Karoo grassy shrubland are explained best by annual and short-term (quarterly) rainfall and not by grazing impacts and thus suggested that non-equilibrium dynamics occur in this region. The concentrated grazing and the effect of trampling, dung and urine did not influence perennial species composition in this shrubland.

Fuhlendorf *et al.* (2001) found that both grazing and rainfall were important in explaining vegetation dynamics in a semi-arid savanna. They reported that grazing influences the long-term species composition, but episodic climatic events substantially influence the short-term rate and trajectory of vegetation change. The drought that occurred during the study period resulted in a decrease in plant density, but the system recovered to become proportional with grazing intensity.

2.5.2.1.Non-equilibrium models

Three non-equilibrium models have been developed to account for the stochastic and discontinuous vegetation dynamics that occur in non-equilibrium areas (Fernandez-Gimenez and Allen-Diaz 1999).

2.5.2.1.1. Threshold model

A threshold refers to the boundaries that separate multiple equilibrium states in space and time and their existence determines if a system as experiencing non-equilibrium vegetation dynamics or not (Holling 1973, May 1977 cited by Briske *et al.* 2003, Friedel 1991). According to Briske *et al.* (2003) a stable state is assumed to persist until the disturbance exceeds the threshold limit, to induce an alternative stable state. The shift back to a previous state is not easily reversible without substantial intervention by range management (Friedel 1991). Chesson and Chase (1986) cited by Briske *et al.* (2003) reports that the threshold model is primarily applied to grassland and savannas that are experiencing bush encroachment. The reason for this is that thresholds are most apparent in these cases, because various growth forms track climatic changes at different rates and woody plants symptoms disappear less rapidly than in the case of herbaceous plants. When a threshold is passed, for example the change of a grassland state to a woodland state, the system defines the existence of a non-equilibrium system, but is does not imply that the ecosystem has shifted from a equilibrium to non-equilibrium system, because the capacity for internal regulation may be as great or greater than the previous state. The evaluation of thresholds, on the basis of disturbance regimes (e.g. fire regime) will identify the driver of vegetation change and provide additional insight into the ecological processes that establishes the occurrence of thresholds (Briske *et al.* 2003). Laycock (1991) indicated that it is necessary to understand the following factors in applying threshold models:

- Researchers need to know which vegetation types have relatively "stable successional states" and why these "stable states" exist.
- There is a need to develop criteria and methods to identify and monitor states.
- Thresholds must be identified to prevent the system moving out of desirable stable states.
- Fluctuations in species composition due to rainfall and other factors must be identified and included in model.
- Researchers must know whether the change to alternative states is cause by anthropogenic or natural factors.

2.5.2.1.2. The State and Transition model

State and transition models were specifically developed to overcome the limitations associated with the range model and for the evaluation of vegetation dynamics in variable environments (Westoby *et al.* 1989). The state and transition model of Westoby *et al.* (1989), is a stochastic model that proposes that unpredictable climatic (e.g. rainfall) or disturbance factors (e.g. grazing) can change vegetation from one state to another alternative state and alternative transitions between states can occur (Mentis *et al.* 1989). “New alternative states cannot always be reversed by successional processes, either because new dominants inhibit, rather than facilitate, establishment of original species assemblages, or because physical conditions have changed” (Walker 1993 cited by Milton and Hoffman 1994). Behnke and Scoones (1993) support the notion of a state and transition model as it allows for transitions from one state into a number of different states, or for the return of veld to its original state, which is along a transitional pathway and because of factors that are different from those which caused the original change, have occurred.

The state and transition model allows for a number of alternative states to develop that are not necessarily linked in any linear progression and the transition from one state to another is determined by a combination of stochastic and/or manipulated events (Fynn 1998). The state and transition model has been used to organise research and management in many types of arid and semi-arid rangelands (Walker 1993 cited by Milton and Hoffman 1994, Westoby *et al.* 1989, George *et al.* 1992). The state and transition model is a qualitative model that possesses the capacity to accommodate various types of knowledge and information associated with vegetation management (Westoby *et al.* 1989). This model was developed for ecosystems characterised by event driven systems, which were not addressed by the range model. The state and transition model was not developed with the objective to replace the range model in all ecosystems, as it can accommodate both equilibrium and non-equilibrium vegetation dynamics (Westoby 1979/80 cited by Briske *et al.* 2003, Westoby *et al.* 1989). Fynn (1998) indicates that this model still assumes strong biotic influences in determining vegetation dynamics and it is thus not intrinsically a non-equilibrium model, as it allows for both density dependent and density independent feedback mechanisms to occur. State and transition models were intended to function on the basis of managerial criteria, rather than ecological criteria (Briske *et al.* 2003). Briske *et al.* (2003) reported that the state and transition model requires knowledge of the potential alternative vegetation states of a site, potential transitions of the vegetation that can occurs at a site and the opportunities for managers of systems to achieve favourable transitions between vegetation states and hazards to avoids unfavourable transitions.

Meyer *et al.* (1996) proposed a state and transition model for the *Tarchonanthus* veld of the Ghaap Plateau, presented in **Error! Reference source not found.**. State one is characterised by mainly highly desirable species (e.g. *Themeda triandra)* and the basal cover and biomass production varies between medium and high. This state only occurs during periods characterised by consecutive years of favourable conditions. Meyer *et al.* (1996) reported that the potential for animal production is high, even under undesirable management conditions. The transition to state two is therefore caused by consecutive years of unfavourable climatic conditions.
State two is mainly characterised by desirable species (e.g. *Stipagrostis uniplumis)* and prevails during periods with average climatic conditions (e.g. small deviations from mean annual rainfall) (**Error! Reference source not found.**). The basal cover varies from medium to high and the biomass production varies from medium to low. The transition to state three can be caused by either consecutive years of unfavourable climatic conditions (large deviations from mean annual rainfall) and/or incorrect management (e.g. too high stocking rates and/or possibly prolonged periods of continuous grazing).

State three is characterised by mainly non-desirable species (e.g. *Aristida congesta*) (**Error! Reference source not found.**). The basal cover can fluctuate from low to medium and biomass production remains low, even under favourable climatic conditions. The animal production is low to medium and is determined by climatic conditions. For example, if the rainfall is far below the mean for the area, biomass production will be low and the vegetation will be predominated by annuals and animal production will thus be low. The problem with this state and transition model for the Armoedsvlakte Research Station is that the threshold is not quantified. For example, what is a high, medium and low biomass production in terms of kg/hectare of veld?

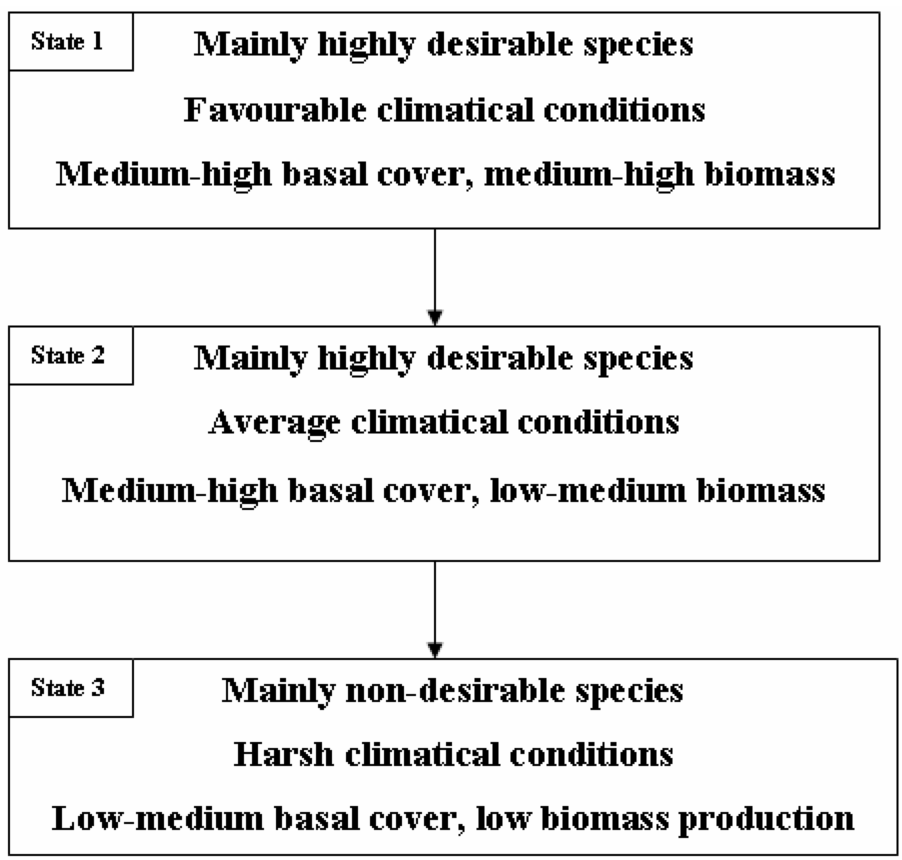


Figure 2-3: State and transition model for the *Tarchonanthus* veld of the Ghaap Plateau. (from Meyer *et al.* 1996/7).

Bestelmeyer *et al.* (2003) and Stringham *et al.* (2003) indicated that the evaluation of vegetation dynamics within states, in addition to between, and the application of the threshold concept to a state and transition model has represented important developments since the development of the model. Briske *et al.* (2003) reported that the state and transition model incorporates multiple dimensions (e.g. fire and climatic variability) in addition to grazing and this model relaxes the assumption concerning ecosystem predictability, stability and the potential number of equilibrium states. Fynn (1998) and Fynn and O'Connor (2000) concluded from their studies that the state and transition model was useful in explaining the composition change in semi-arid environment and to detect patterns of species composition change.

2.5.2.1.3. The persistent non-equilibrium model (Ellis and Swift 1988)

This model assumes that arid areas (<300 millimetres of rainfall per annum) are so constrained by the amount and variability of precipitation that rainfall events influence plant and animal interactions to a greater extent than plant competition and plant-herbivore interactions (Ellis and Swift 1988 and Briske *et al* 2003). In these ecosystems, there are large fluctuations in biomass production due to low and erratic rainfall regimes occurring, preventing herbivore populations from effectively tracking forage availability (Ellis and Swift 1988). This minimises the negative feedbacks between grazing intensity and vegetation dynamics (Ellis and Swift 1988). The occurrence of frequent multi-year droughts contributes to herbivore mortality and prevents herbivore numbers from ever reaching the ecological carrying capacity (Ellis and Swift 1988). In these non-equilibrium systems, herbivores have less of an impact on the vegetation than in equilibrium systems (Briske *et al.* 2003). However, Briske *et al.* (2003) reported that this model does not define the pattern of vegetation dynamics or the role of species composition on primary or secondary productivity.

An alternative interpretation may be that the impact of grazing is greater in equilibrium systems, because the grazing intensity increases prior to herbivore mortality during the multi-year droughts (Ellis and Swift 1988). The grazing effect can be magnified by the occurrence of "key resource areas" (e.g. high production zones such as wetlands), that can support high animal numbers and delay animal mortality during drought periods (Illius and O'Connor 2000 cited by Briske *et al.* 2003, Illius and O'Connor 1999 and Scoones 1992, Hary *et al.* 1996 cited by Fynn 1998). Illius and O'Connor (2000) cited in Briske *et al.* (2003) and Illius and O'Connor (1999) concluded from their studies that herbivores remain in equilibrium with key resource areas, even though they may not be in equilibrium with many other areas of the landscape. This implies that both equilibrium and non-equilibrium dynamics occur in rangelands characterized within low and highly variable rainfall areas (Illius and O'Connor 1999). The relative frequency of stress (e.g. droughts) and non-stress years and the degree of climatic variation will affect the relative importance of density dependent and density independent factors in an ecosystem (Illius and O'Connor 1999). Fuhlendorf *et al.* (2001) however report that the problem with commercial ranching systems is that herbivores are not free roaming (e.g. constrained by fences) and they might not be able to access key resource areas to optimise nutrient intake. To aggravate the situation commercial ranchers impose various management options (e.g. supplementary feeding and dipping) to minimise fluctuations in livestock numbers, which put added pressure on the system during dry years (Fuhlendorf *et al.* 2001).

2.6. THE RELATIVE IMPORTANCE OF EQUILIBRIUM AND NON-EQUILIBRIUM VEGETATION DYMAMICS

"Theoretical evidence clearly indicates that both equilibrium and non-equilibrium dynamics may operate in ecosystems at various temporal and spatial scales, to influence vegetation dynamics" (Tainton *et al.* 1996, Peel *et al.* 2000, Briske *et al.* 2003). Huston (1979) cited by Briske *et al.* (2003) indicates that communities thus have a combination of equilibrium and non-equilibrium dynamics and the balance between these two paradigms is constantly changing. The key questions then becomes "When do equilibrium and non-equilibrium systems apply?", and if there is a combination of both paradigms "What is the relative effect of equilibrium and non-equilibrium systems have on vegetation dynamics?" (Briske *et al.* 2003). "The less persistent the response of community composition to rainfall variability than to grazing intensity is partially a function of the non-selective, intermittent effects of droughts, compared with the more chronic, selective influence of grazing on individual species or species groups" (Illius and O'Connor 1999). The statements made above indicate that both climate and grazing influence vegetation dynamics, because intensive selective grazing often establishes the long term trajectory of vegetation change, while episodic climatic events often exert short term effects on this rate and trajectory (Fuhlendorf *et al.* 2001 cited by Briske *et al.* 2003). Illius and O'Connor (1999) warned that if an area experiences large climate variability, it does not necessarily mean that grazing has a negligible impact on vegetation dynamics. It is, however, difficult to measure the relative effect of rainfall and grazing because both occur at various spatial and temporal scales and they might have interactive effects (McNaughton 1983, Archer and Smeins 1991, Fuhlendorf and Smeins 1999 cited by Fuhlendorf *et al.* 2001, O'Connor 1995).

2.7. DIS-EQUILIBRIUM

Virtually all systems experience some non-equilibrium vegetation dynamics. Environmental variation and/or stochastic variation in factors like births or deaths are constantly redefining the equilibrium point, which may be at a rate faster than what the system can respond too (Illius and O'Connor 1999). This system will never have a single equilibrium point and this failure to reach equilibrium, is termed dis-equilibrium (Illius and O'Connor 1999). Caughley (1987) cited in Illius and O'Connor (1999) showed that even with an inter-annual rainfall coefficient of 45%, these highly variable systems show some equilibrium vegetation dynamics, with consumer resource coupling and that the system is not an entirely non-equilibrium system, where consumer resource coupling is absent.

2.8. CONCLUSIONS

The animal performance models that describe the relationship between stocking rate and animal performance were found to be useful, but these models have their limitations. Some authors reported that the animal performance models are not useful in semi-arid areas, as production is more dependent on rainfall than on stocking rate. Stocking rate was found by most authors to explain more of the variation in animal production and veld condition, than what grazing systems did.

The main reason why rotational grazing was advocated was because it is suppose to minimise selection, encourage a more even utilisation of the veld and it is suppose to increase both the carrying capacity and range condition of the area. However, the two approaches to rotational grazing are based on anecdotal evidence and the supposed benefits have yet to be demonstrated empirically. Continuous grazing, which is supposed to result in a poor veld condition and animal production was actually found to outperform rotational grazing systems in terms of animal production for some systems. The veld condition for rotationally and continuously grazed areas was very similar, with rotational grazing systems being only slightly superior. Both grazing systems have their own optimum stocking rate and this point lies between the maximum production per animal and maximum production per hectare.

The literature reviewed indicated that both equilibrium and non-equilibrium systems occur in semi-arid areas. It is now important to find a quantitative measure of the relative abundance of non-stress and stress factors that affects density dependent factors and density-independent factors. There is thus a continuum of equilibrium and non-equilibrium factors in semi-arid environments.

3. Literature review of the statistical techniques and procedures that are relevant and appropriate for the grazing trial data set

3.1. INTRODUCTION

This chapter is an overview of the literature that deals with multivariate statistical methods that may be used to understand the vegetation dynamics of the Armoedsvlakte grazing trials. An introduction to ordination is presented and reasons why this analytical tool is useful in understanding ecological data is explained. The use of appropriate models and ordination techniques are discussed. A section is included on how to interpret the different ordination techniques and their associated ordination diagrams. An important part of this chapter is how to remove the variation in a data set resulting from spatial and temporal effects and not treatment effects. The problem of repeated measures of experimental units is discussed with reference to the Armoedsvlakte grazing trial.

3.2. ORDINATION

Ordination is the collective term for multivariate techniques that arrange sites along two axes on the basis of species compositional data (Ter Braak 1987). An ordination diagram is a graph with two axes that explains most of the variation in the data set, in which sites are represented by points in two-dimensional space and points are arranged in such a manner that sites which are situated close together are similar to each other in terms of species composition, while points that are far apart correspond to sites, are dissimilar in terms of species composition (Ter Braak 1987, Leps and Smilauer 2003). Similarly, the close proximity of species with particular reference to a sample indicates that these species are likely to occur more often within these sites and with a higher abundance than species that those that are further away from these sites (Leps and Smilauer 2003). Ordinations can calculate correlations between species and environmental variables and correlations of environmental to other environmental variables (Leps and Smilauer 1999).

Ecologists use ordinations because it can turn large data sets that are difficult to analyse into meaningful information (Ter Braak and Smilauer 1998). Since the number of species observed within the data set is usually large, ordination can be used to summarize and arrange the data in an ordination diagram (Ter Braak 1987).

Ordination diagrams can be interpreted in terms of the environment at the different sites (Ter Braak 1987). The ordination axes might coincide with some of the measured environmental variables and these variables can then be correlated with the ordination axes (Leps and Smilauer 2003). If environmental data is lacking, then this interpretation can be done in an informal way (Leps and Smilauer 1999), but if environmental data has been collected for the sites, it can be done in a formal manner (Ter Braak 1987). This two-step approach is called indirect gradient analysis or unconstrained ordination (Ter Braak 1987, Leps and Smilauer 1999). Indirect gradient analysis searches for the variation that best explains the patterns of species composition in a data set (Leps and Smilauer 2003). Unconstrained ordination axes correspond to the directions of the greatest variability in the data set (Leps and Smilauer 2003). Advantages of indirect gradient analysis are that species compositional data is easier to collect than environmental data, since there are many different ways to collect environmental data and the sampler might be unsure which one or more variables species react to (Ter Braak 1987). Species compositional data may thus be a more informative indicator of environmental dynamics, than any set of environmental variables (Ter Braak 1987). Ordination can be used to indicate whether important environmental variables have been overlooked (Ter Braak 1987). This can be seen if there are no relations between the positioning of sites in the ordination diagram and the measured environmental variables (Ter Braak 1987). The occurrence of individual species might be so unpredictable that is a difficult to pick up any relationship between species and environmental conditions and general patterns of coincidence of several species may be of greater use in detecting species and environmental relationships (Ter Braak 1987). Indirect gradient analysis techniques that can be used in Canoco 4.5 are Principal Component Analysis (PCA), Correspondence Analysis (CA) and Detrended Correspondence Analysis (DCA).

Direct gradient analysis or constrained ordination occurs when environmental variables are included from the beginning of the analysis and this analysis cannot be done without environmental data (Ter Braak 1987). Direct gradient analysis aims to find variation in species composition that can be explained by measured environmental variables (Leps and Smilauer 2003). Constrained ordination axes correspond to the directions of the greatest variation in the data set that can be explained due to environmental variations (Leps and Smilauer 2003). Direct gradient analysis techniques that can be used in Canoco 4.5 are Redundancy Analysis (RDA), Canonical Correspondence Analysis (CCA) and Detrended Canonical Correspondence Analysis (DCCA).

3.2.1. Choice of ordination techniques

Ordination techniques that are most widely used among community ecologists are Principal Component Analysis (PCA), Correspondence Analysis (CA) and Detrended Correspondence Analysis (DCA) (Ter Braak 1987). PCA assumes a linear response model, while CA and DCA assumes a unimodal response model (Ter Braak 1987). A PCA works well when gradients are short (low species diversity or turnover), but over long gradients the approximation by the linear function is poor and the opposite trend applies to CA (Leps and Smilauer 2003). Length of gradients can be checked by running a DCA or a DCCA (Leps and Smilauer 2003, Leps and Smilauer 1999). If the lengths of gradients are shorter than two standard deviations, then a PCA or an RDA are more suitable techniques (Ter Braak 1987, Leps and Smilauer 1999 and Leps and Smilauer 2003), because there are few absences in the data, little species turnover and a linear model would thus be more appropriate. The choice between an RDA and PCA depends if the user wants to constrain the axes with environmental variables, if this is the case, then a RDA will be used and not a PCA.

If the lengths of gradients are bigger than three standard deviations, then a CA, CCA or DCA is more appropriate (Ter Braak 1987), because species responses are more complex (e.g. more likely to be unimodal than linear) and there are greater species turnover and lots of zeros in the data set. The choice between the use of a CA or a DCA can be solved by looking for an arch effect in the CA ordination and at the lengths of gradients. If there is no clear evidence of an arch effect in the CA, then CA is the more appropriate technique. If there is an arch effect, the lengths of gradients need to be consulted, as DCA gradient lengths of greater than four standard deviations, indicate that there is high species turnover and probably an arch effect. A DCA is used when there is an arch effect in the CA (Ter Braak 1987) and this removes the arch effect by detrending by segments (Leps and Smilauer 2003). Leps and Smilauer (1999, 2003) do not recommend the use of detrending by segments for unimodal ordination techniques where either covariables or environmental variables are present, but rather recommend that detrending should be by polynomials for such data sets. The arch effect arises from the ends of the axes of the ordination diagram being compressed, relative to the middle and because the second axis (Y-Axis) frequently shows a systematic, often-quadratic relation with the first axis (X-axis) (Ter Braak 1987). Detrending is not necessary when a constrained unimodal ordination is used (CCA), as an arch effect in this type of analysis indicates redundant environmental variables (Leps and Smilauer 1999, 2003). For example, there might be two or more environmental variables that are strongly correlated (either positively or negatively) with each other. If one of these variables from such a group is removed, the arch effect will often disappear (Leps and Smilauer 2003).

3.2.2. Interpreting an ordination diagram

The direction of the arrow in an ordination diagram indicates the direction in which the abundance of a species or environmental variable increases the most (Ter Braak 1987). The length of the arrow in an ordination diagram equals the rate of change in the above-mentioned direction (Ter Braak 1987). The longer the length of the arrow, the greater the rate of change for the variable in concern. If the angle between two species, sites and/or environmental variables is less than 90 degrees, then the two variables are positively correlated with each other (Leps and Smilauer 2003). If the angle is between 90-180 degrees, then the variables are negatively correlated and if the angle is exactly 90 degrees, then the variables have no correlation (Leps and Smilauer 2003).

An eigenvalue is a measure of how much of the variation of the data set an axis can explain (Leps and Smilauer 2003). Each axis is constructed so that it explains as much of the variation in the data set as possible, while under the constraint of being independent of the previous axes (Leps and Smilauer 2003). As a result, the eigenvalues decrease with the order of the axis (Leps and Smilauer 2003).

3.2.2.1.Interpreting a Correspondence Analysis (CA) and Detrended Correspondence Analysis (DCA)

Ter Braak (1987) warns the user, when interpreting CA and DCA ordination diagrams, that rare species are often on the edge of the diagram, because they prefer extreme conditions and/or because their few occurrences by chance happen to be at sites with extreme conditions. A CA is sensitive to species that occur in only a few species-poor sites. These species can however be removed from the ordination diagram on the basis of information from a summary table of the frequency of species, mean abundance and mean local abundance of species in the data set. An alternative option is the down-weighting option, which gives rare species a low weighting, thus minimizing their influence on the analysis (Ter Braak 1987).

In a CA ordination diagram, species and samples are represented as points, environmental variables are represented as arrows and dummy variables are represented as points (Leps and Smilauer 1999). The abundance of species with reference to sites is discussed in Chapter 3.2. The length, direction and angle of environmental arrows can be interpreted in the same way as discussed in Chapter 3.2.2. The perpendicular projection of sample points onto an environmental variable, gives the user an ordering of samples in order of increasing value of the environmental variable (Leps and Smilauer 1999). If species are situated closed to where an environmental variable is increasing (seen by the direction of the arrow), it indicates that the species with the highest abundance will be at higher values of that environmental variable (Leps and Smilauer 2003). If species are found to be close to a dummy variable, then that species is said to have a high abundance in the samples for that class and *vice versa* (Leps and Smilauer 2003). The distance rule is used to investigate the relationship between dummy variables and sample sites (Leps and Smilauer 2003). The relationship between environmental variables and dummy variables can be investigated by using the projection rule (Leps and Smilauer 2003). The centroid of the nominal environmental variable can be projected on a quantitative environmental variable and in this way the user can get an order of the average value in that class. The distance rule is used to investigate the relationship between two dummy variables (Leps and Smilauer 1999).

3.2.2.2. Principal Component Analysis (PCA)

Centring and standardizing is an option in linear ordination methods (e.g. PCA) and it refers to manipulations with the species data matrix before the ordination is calculated (Leps and Smilauer 2003). Centring by species is obligatory for any partial linear ordination method (e.g. data set where a co-variable matrix was used) (Leps and Smilauer 2003). Centring refers to the subtraction of the mean so that the resulting species or sample has a mean of zero (Leps and Smilauer 2003). Standardizing usually means the division of each value by the standard deviation (Leps and Smilauer 2003). Leps and Smilauer (2003) reports that the user should be careful with standardization by species, with or without centring, because the intention of this procedure is to give all of the species in the data set the same weight, but some species with a low frequency might be very influential. Standardizing is also used if there are variables that have different units or scales (Leps and Smilauer 2003).

An ordination diagram based on a linear model (e.g. PCA or RDA) displays samples as symbols, species as arrows, environmental variables as arrows and dummy variables as points (Leps and Smilauer 2003). The length and direction of the arrows for species and environmental data on a linear ordination diagram can be interpreted as discussed in Chapter 3.2.2. The angle between species, sites and environmental data gives the user an indication of the correlation between these variables (Chapter 3.2.2). The position of species and sites relative to each other explains how similar or dissimilar species are (Chapter 3.2.2).

3.3. CANONICAL ORDINATION

Canonical ordination techniques are ordination techniques that are converted into multivariate direct gradient analysis and they deal with many species and many environmental variables (Ter Braak 1987). The main aim of canonical ordination is to detect the main patterns and the relationships between species and the environment (Ter Braak 1987). Canonical ordination techniques are designed to detect patterns of variation in species data that can be explained "best" by the observed environmental variables (Ter Braak 1987). The ordination diagram that results not only expresses variations in species composition, but also the relationship between the species and each of the environmental variables. The canonical form of PCA, CA and DCA is called Redundancy Analysis (RDA), Canonical Correspondence Analysis (CCA) and Detrended Canonical Correspondence Analysis (DCCA), respectively.

3.3.1. Canonical Correspondence Analysis (CCA)

CCA is restricted correspondence analysis in the sense that the site scores are restricted to be a linear combination of measured environment variables (Ter Braak 1987). A CCA calculates the species-environment correlation, which is a correlation between the site scores that are weighted averages of the species scores and the site scores that are a linear combination of the environmental variables (Ter Braak 1987). The species environment correlation is thus a measure of the association between species and the environment (Ter Braak 1987). The importance of the association is expressed by the eigenvalue, as the eigenvalue measures how much variation in the species data is explained by the axes and therefore by the environmental variables (Ter Braak 1987). Environmental variables with long arrows indicate a stronger correlation with the ordination axes than those with short arrows and these variables are therefore more closely related to the pattern of variation in species composition shown in the ordination diagram (Ter Braak 1987).

3.3.2. Redundancy analysis (RDA)

Redundancy analysis (RDA) is the canonical form of a PCA and appears to be useful if used in combination with a PCA (Ter Braak 1987). RDA is the technique that selects the linear combination of environmental variables that returns the smallest total residual sum of squares, as this combination will explain more of the variation in the data set (Ter Braak 1987). PCA minimizes the total residual sum of squares, but it does not account for the variation from environmental variables (Ter Braak 1987). A RDA is simply a PCA with the restriction of environmental variables on the site scores (Ter Braak 1987). In a RDA, species and sites are represented, as in a PCA, and environment variables are indicated by arrows (Ter Braak 1987).

3.3.3. The use of a combination of ordination and canonical ordination techniques

Canonical ordination and ordination followed by environmental interpretation can be useful in combination (Ter Braak 1987). If the results from these analyses do not differ largely, then the user knows that no important environmental variables have been overlooked in the study (Ter Braak 1987). If the result of the ordination and the Canonical ordination do differ significantly, than the user may have overlooked important environmental variables (Ter Braak 1987).

3.3.4. Partialling out effects other than treatment effects

The user of Canoco usually only wants to study the treatment effect and not other effects in his data set. For example, in the current study, if the user wanted to study the effect of stocking rate on species composition and not the effect of spatial, temporal and rainfall variation, the user can partial out the effects of these variables by using co-variables. Another example given in Leps and Smilauer (1999) that is relevant to the Armoedsvlakte data set, is where experimental design results in samples being grouped into logical and physical blocks (e.g. in our case paddocks). The values of the response variables (e.g. species composition) might be similar due to their close proximity in space and this results in spatial auto-correlation (Leps and Smilauer 1999). The user must thus model this influence and account for spatial variation in the data set (Leps and Smilauer 1999). The differences in the response variables that are due to membership of samples in different blocks can be partialled out from the model and the analysis can be performed on the residual variation (e.g. variation due to treatment effect) (Leps and Smilauer 1999). Anderson and Gribble (1998) explained the process of partitioning variation among the spatial, temporal and environmental components within a multivariate data set in detail. The method of Anderson and Gribble (1998) is an extension of an existing method for partialling out the spatial component of environmental variation (Borchard *et* *al*. 1992), using canonical analysis, as it includes temporal variability in the analysis. In this study, plot identifiers can be used to resolve this issue and a spatial matrix that uses dummy variables are required to relate observations to samples.

3.3.5. Partial ordination

Partial ordination is the process of combining ordination and canonical ordination in a single analysis (Ter Braak 1987). The eigenvalues of the extra axes that measure residual variation in the data set (e.g. variation that is not explained by the linear combinations of environmental variables already included in the analysis) are analysed (Ter Braak 1987). A partial ordination is being used if the user has subtracted variability explained in species composition by a co-variable before an ordination is performed (Leps and Smilauer 2003).

3.3.6. Partial Canonical ordination

Partial Canonical ordination is the process of partialling out the effects of co-variables and to relate the residual variation to the impact variables (Ter Braak 1987, Leps and Smilauer 2003). The usual environmental variables are simply replaced by the residuals obtained by regressing each of the treatment or impact variables on the co-variable (Ter Braak 1987). The Monte Carlo permutation procedure can be used to investigate the statistical significance of the species relationships with environmental variables (Ter Braak 1987, Leps and Smilauer 1999). The console version of Canoco allows the user to specify the arrangements of samples in terms of spatial and temporal structure and/or general split-plot design (Leps and Smilauer 1999).

3.3.7. The problem of repeated measures

If response variables (e.g. species composition) get repeatedly sampled for different sites over time, then spatial and temporal autocorrelation arises from these samples. This can however be corrected for by using a split-plot Analysis of variance (ANOVA) with time representing the spilt-plots within the treatment whole plots (Chapter 3.3.4) (Leps and Smilauer 2003). This type of analysis implies that the repeated measures are in fact the within plot factors (Leps and Smilauer 2003). The interaction between treatment and time reflects the difference in the development of sampled units between the different treatments. Plot identifiers can be used as co-variables because the interaction between treatment and time is of importance and corresponds to the effect of experimental manipulation and can be included into the data set by using them as dummy variables and the average over years of each site is subtracted from the variation in the data set and only the changes within each plot are analysed. (Leps and Smilauer 2003). Time can be included into the analysis as follows: 0, 1, 2, 3 etc. for year 1977, 1978, 1979, 1980 (Leps and Smilauer 2003). The user of Canoco must in this case restrict for spatial and temporal structure or split-plot design. Interactions between treatment and time are introduced to account for the way in which each treatment alters the response variables measured. For Armoedsvlakte Research Station, the following interactions are used:

- ✓ Time×stocking rate
- ✓ Time×seasonal current rainfall
- ✓ Time×seasonal past rainfall
- ✓ Time×grazing system (both rotational and continuous)
- ✓ Grazing system×stocking rate

The restriction of the permutation type to be applied allows for two options within the Canoco program (Ter Braak and Smilauer 1998). The first option requires the user to know the number of split-plots and second option requires information on the treatment type (e.g. whole plot level) and the split-plot level (Ter Braak and Smilauer 1998). The effect of environmental variables that differs from treatment type can be tested by permuting whole plots, while keeping split-plots of each whole plot together (Ter Braak and Smilauer 1998). If whole plot factors form a time series that their permutations can be restricted to cyclic or toroidal shifts to account for temporal auto-correlation (Ter Braak and Smilauer 1998). The effect of environmental variables within the whole plot factor can be assessed by permuting the split-plots, without permuting the whole plots (Ter Braak and Smilauer 1998). If the split-plots form a time series, their permutations can be restricted to cyclic or toroidal shifts to account for autocorrelation (Ter Braak and Smilauer 1998).

3.3.8. Treatment structure

The Armoedsvlakte Research Station grazing trials during phase one (1977-1991) have two combinations of grazing systems and four stocking rate applications. During phase two (1992-1999) there was only one grazing system applied (e.g. rotational grazing system) and there were three stocking rate applications. Phase three had a similar treatment structure to phase two, but the stocking rates were higher.

4. The effect and interactions of stocking rate, grazing system applied and seasonal rainfall on veld condition

4.1. Introduction

This chapter illustrates the methods that were used to sample the different variables that are used as indicators of veld condition at the Armoedsvlakte Research Station and the statistical procedures that were used in helping us to understand the vegetation dynamics that occur at this site. The chapter investigates the effect and interactions of stocking rate, grazing system applied and seasonal rainfall on three veld condition indicators, namely species composition, residual biomass and basal cover for the different phases of the grazing trial. It is important to note that the different phases of the trial were analysed separately, because both stocking rate and grazing system treatments were different for different phases.

The importance of stocking rate and its effect on veld condition according to the literature has been discussed in Chapter 2.2, while the interactions of stocking rate with grazing system and rainfall were discussed in Chapter 2.2.5 and Chapter 2.2.6. The different types and approaches of grazing systems and its effect on veld condition were discussed in Chapter 2.3. The current recommendation to farmers in the Vryburg area is to apply a rotational grazing system with six paddocks and to have a week long grazing period for each paddock (Venter 1991). This allows for a rest period of five weeks, but this system results in a decline in veld condition. It is thus recommended to apply a similar rotational system, but with a two-week grazing period, which allows for a 10-week rest period which might be more effective in preventing veld degradation (Venter 1991). The effect of rainfall and droughts on veld condition was discussed in Chapter 2.4.

4.2. SPECIES COMPOSITION

4.2.1. Methods and materials

Tainton (1986) cited by O'Reagain (1996) reported that species composition is a major determinant of animal production on South African rangelands. The species composition assessment was performed every third year and was done by the technician and six co-workers at the research farm. The Wheel-Point method as described by Tidmarsh and Havenga (1955) was used to calculate basal cover and species composition, but only the species composition component will be discussed in this chapter (refer to Chapter 4.3 for a description on the calculation of basal cover was calculated and for the advantages and disadvantages of using the Wheel-point method). The Wheel-Point that was used is three meters in circumference and 3000 points were taken within all of the treatments. At each point, a hit or a miss is recorded. Where a hit is recorded, the grass species was also identified. The abundance of each species was then calculated as follows:

Relative abundance of species A= No of species A encountered/ Total no of hits*100

The relative abundance data was used to study what the effect of different stocking rates on the abundance of different species and the Veld Condition Scores (VCS) were used to quantify the effect of stocking rate on veld condition.

Two types of Veld Condition Scores (VCS) were calculated for all of the treatments using an adaptation of the Ecological Index Method of Hardy *et al.* (1999). The relative index values that were assigned to each group, was a value of 10 for the highly desirable group, a value of seven for the desirable group, a value of four for the less desirable group and a value of one for the undesirable group (Hardy *et al.* 1999) (**Error! Reference source not found.**). The first VCS was based on basal cover (%) of grass species (Chapter 4.3) and was calculated as follows:

VCS one= (∑All species basal cover that belong to the highly desirable group*10) + (∑All species basal cover that belong to the desirable group*7) + (∑All species basal cover that belong to the less-desirable group*4) + (∑All species basal cover that belong to the undesirable group*1).

The second VCS was based on the relative abundance (%) of different species and calculated as follows:

VCS two= (∑All species relative abundances in the highly desirable group*10) + (∑All species relative abundances in the desirable group*7) + (∑All species relative abundances in the less-desirable group*4) + (∑All species relative abundances in the undesirable group*1)

VCS two score will vary between 1000 and 100. A sward with a score of 1000, will have 100 percent highly desirable species (100*10). A sward with a score of 100, will have 100 percent undesirable species (100*1) (Tainton 1982 cited by Hardy *et al.* 1999). A major shortcoming of this method is the subjective allocation of species to the groups and the assumption that all species are equally sensitive to defoliation (Hardy *et al.* 1999).

All of the treatments were sampled during phase one (1977-1991) of the grazing trial, but during phase two (1992-1999) only replication one, three and six for the rotational grazing with low, medium and high stocking rates treatments were sampled with the Wheelpoint method. Continuous grazing treatments were no longer part of the grazing trial during phase two (1992-1999) and phase three (2000 to present) and these paddocks were thus not sampled. During phase three (2000 to present) only replication one, three and six rotational grazing with low, medium and high stocking rates treatments were sampled with the Wheelpoint method.

The relative abundances of individual species were grouped into their ecological groups (**Error! Reference source not found.**) to analyse how the ecological groups have increased, decreased or remained constant due to different stocking rate treatments. The calculation for all of the ecological groups' abundances follows below:

Relative abundance (%) for the highly desirable group= (∑All the species relative abundances that are in the highly desirable group)

Relative abundance (%) for the desirable group= (∑All the species relative abundances that are in the desirable group)

Relative abundance (%) for the less-desirable group= (∑All the species relative abundances that are in the less- desirable group)

Relative abundance (%) for the undesirable group= (∑All the species relative abundances that are in the undesirable group)

4.2.2. Statiscal analysis for phase one (1977-1991)

Relative species abundance and veld condition data were analysed using ordination techniques with Canoco 4.5 (Ter Braak and Smilauer 2003). A Principal Component Analysis (PCA) was performed to identify and remove any clear outliers in the data set. Following this, a Detrended Correspondence Analysis (DCA) was carried out to determine the lengths of gradient (e.g. species turnover or diversity in the data set). These lengths of gradients were less than 2.5 standard deviations (SD), which suggested that the species turnover is small. Linear models like PCA and/or RDA were thus the most appropriate techniques to analyse the data. A partial RDA was chosen to constrain the axes with environmental variables (e.g. stocking rate, type of grazing system applied and seasonal rainfall) and to remove spatial and temporal autocorrelation. Following this, manual forward selection of environmental variables and interactions were performed to test the significance of environmental variables and interactions between them. It should be noted that only rotational grazing interactions were permutated, because continuous grazing interactions are the exact opposite (i.e. grazing system environmental variables are nominal variables) and it would have been unneccassary to analyse both. Non-significant environmental variables and interactions (P>0.1) were excluded from the analysis. The interaction between current seasonal rainfall and past seasonal rainfall were not tested, as this interaction resulted in large inflation factors. It was, however, important to perform this analysis to investigate why the time-effect was so large. When the seasonal rainfall interaction was included, the time-effect in the analyses decreased substantially and this suggests that most of the time-effect was due to the interaction of seasonal current and past rainfall.

Two types of Euclidean distances were calculated using PRIMER 4.5, namely, change in species abundance from beginning of the trial and the change in species abundance from year to year (**Error! Reference source not found.**, **Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**). The Euclidean distances for the rotationally grazed sites and continuously grazed sites were shown on different graphs and it should be noted that an average across the six paddocks for the rotationally grazed sites were taken to make comparisons between different grazing systems, easier (**Error! Reference source not found.**, **Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**).

4.2.3. Statiscal analysis for phase two (1992-1999)

Relative species abundance and veld condition data were analysed using ordination techniques with Canoco 4.5 (Ter Braak and Smilauer 2003). A PCA was performed to identify and remove any clear outliers in the data set. Following this, a DCA was carried out to determine the lengths of gradients (e.g. species turnover or diversity in the data set). These lengths of gradients were less than 1.5 SD, which suggested that the species turnover is small. Linear models like PCA and/or RDA were thus the most appropriate techniques to use to analyse the data. A RDA was chosen to constrain the axes with environmental variables (e.g. stocking rate and seasonal rainfall). Following this, manual forward selection of environmental variables and interactions were performed to test the significance of environmental variables and interactions between them. Non-significant environmental variables and interactions ($P>0.1$) were excluded from the analysis. It is important to note that continuously grazed treatments were discontinued at the start of phase two. The variation in the data set due to grazing systems could not be analysed because of this. The RDA model only included seasonal current rainfall and not seasonal past rainfall into the analysis, as there were only two sampling periods. Therefore, Euclidean distances could not be calculated for the analyses of phase two.

4.2.4. Statistical analysis for phase three (2000 to present)

Relative species abundance and veld condition data were analysed, using ordination techniques with Canoco 4.5 (Ter Braak and Smilauer 2003). A PCA was performed to identify and remove any clear outliers in the data set. Following this, a DCA was carried out to determine the lengths of gradients (e.g. species turnover or diversity in the data set). These lengths of gradients were less than two SD, which suggested that the species turnover is small. Linear models like PCA and RDA were thus the most appropriate techniques to use to analyse the data. A RDA was chosen to constrain the axes with an environmental variable (e.g. stocking rate). It is important to note that continuously grazed treatments were discontinued at the start of phase two. Because of this, the variation in the data set due to grazing system could not be analysed. There was only one sampling period during phase three and as result, Euclidean distances could not be calculated for the analyses. The effect of seasonal rainfall will not vary within a single season and this variable could therefore not be included.

4.2.5. Results and discussion

4.2.5.1.Phase one (1977-1991)

The results of the Monte Carlo permutation test indicates that there is a statistically significant effect ($P<0.002$) of the environmental variables and the interactions of these variables on the first and all of the canonical axes (**Error! Reference source not found.**). The statiscally signicant environmental variables were time, seasonal past rainfall and seasonal current rainfall, while the statistically significant interactions include the time by seasonal past rainfall, stocking rate by time and stocking rate by seasonal current rainfall interactions (**Error! Reference source not found.**). The species-environmental relationship for axes one and two explains 97.9 percent of the explainable variation in the data set, which indicated that the variation in the data set is well explained by the measured environmental variables (**Error! Reference source not found.**). Axes one and two of the RDA explained 57.7 percent of the total variation in the data set (**Error! Reference source not found.**). Eigenvalues are 0.447 and 0.032 for axes one and two, which represents 53.8 and 57.7 percent of the total variance, respectively.

Table 4-1 A summary of the results of the Monte Carlo permutation test for the partial RDA for relative species abundance and veld condition data for phase one (1977-1991)

Test of significance of first canonical axis

F-ratio = 157.329

P-value = 0.002

Test of significance of all canonical axes

F-ratio = 38.719

P-value = 0.002

Table 4-2: Significance of environmental variables and interactions for the species abundance and veld condition data for phase one (1977-1991)

Environmental variable/Interaction	**P-Value**	**Significant**
Time	0.002	Highly significant
SP	0.004	Highly significant
SC	0.002	Highly significant
Time*SP	0.004	Highly significant
Time*SC	0.320	Non-significant
Rot*time	0.510	Non-significant
Rot*SP	0.720	Non-significant
Rot*SC	0.210	Non-significant
SR*time	0.002	Highly significant
SR*SP	0.950	Non-significant
SR*SC	0.002	Highly significant

Table 4-3: Summary of the partial RDA for species composition and veld condition data from phase one with only significant environmental variables and interactions included

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.447	0.032	0.007	0.003
Species-environment correlations	0.907	0.603	0.356	0.291
Cumulative percentage variance				
of species data	53.8	57.7	58.5	58.8
of species-environment relation	91.3	97.9	99.3	99.9
Sum of all eigenvalues				0.83
Sum of all canonical eigenvalues				0.489

Most of the time variable variance could be explained by the rainfall interaction (explained earlier), but it is important to see how species and the veld condition of sites changed over time. From **Error! Reference source not found.** and **Error! Reference source not found.**, it was concluded that highest rate of change in species composition occurred during the period 1982 to 1985, in which the system experienced four years of below average seasonal rainfall (**Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**). The most changes (from year to year) in terms of species composition and veld condition occurred in 1985, which occurred directly after the two consecutive years of very low seasonal rainfall (**Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**). The species composition before this period was dominated mostly by *Themeda triandra* and sites had high veld condition scores (indicated by the close proximity of sites to *Themeda triandra* and supplementary environmental variables) (**Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**). The Generlized Additive Model (GAM) was highly statistically significant (F-value=103.08 and $P<0.001$), when looking the probability of finding *Themeda triandra* over time. After the drought the species composition was dominated by *Eragrostis lehmanniana* (**Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**) even though the system experienced above mean seasonal rainfall following the multi-year drought (**Error! Reference source not found.**). The GAM was highly statistically significant (F-value=116.82 and $P<0.001$), when looking at the probability of finding *Eragrostis lehmanniana* over time. The system did not recover from the two consecutive dry years, although some convergence of sites occurred late in phase one (**Error! Reference source not found.** and **Error! Reference source not found.**). It seems as though the system can recover from single year droughts (e.g. of seasonal rainfall of 182 mm in 1991), but multi-year droughts (seasonal rainfall of 319 and 284 mm in 1984 and 1985 respectively), resulted in adverse changes in veld dynamics. It is important to note that the significant interactions of stocking rate by seasonal current rainfall and seasonal past rainfall by time indicated that the effect of rainfall on species composition and veld condition is dependent on stocking rate and time (**Error! Reference source not found.**).

The length of the arrows in **Error! Reference source not found.** for the environmental variables and the interactions between them indicated their importance in explaining variation in the data set. Time was very strongly negatively correlated with axes one (-0.8444) and this is due to the interaction of seasonal current and seasonal past rainfall (explanation given above). Seasonal current rainfall (-0.4816) was relatively weakly negatively correlated to axes two.

These results indicated that stocking rate and grazing system are not important in terms of explaining variation in species abundance and veld condition of the system, but that seasonal rainfall (both past and current) was. From these results, it can be concluded that the system can recover from single year droughts (1991), but multi-year droughts result (1984 and 1985) in an adverse change in species composition and veld condition. These results indicated that the system is a non-equilibrium system as rainfall explains vegetation dynamics better than both stocking rate and grazing system.

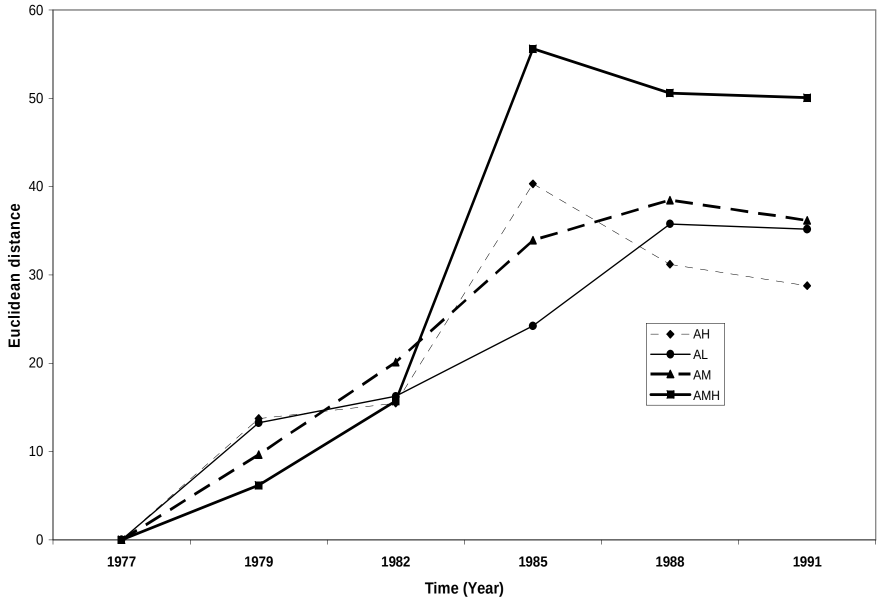


Figure 4-1: Euclidean distance for the continuously grazed sites illustrating change in species abundance from 1977-1991. Treatments were: AH=Continuous grazing at a high stocking rate, AL= Continuous grazing at a low stocking rate, AM= Continuous grazing at a medium stocking rate and AMH= Continuous grazing at a medium-heavy stocking rate.

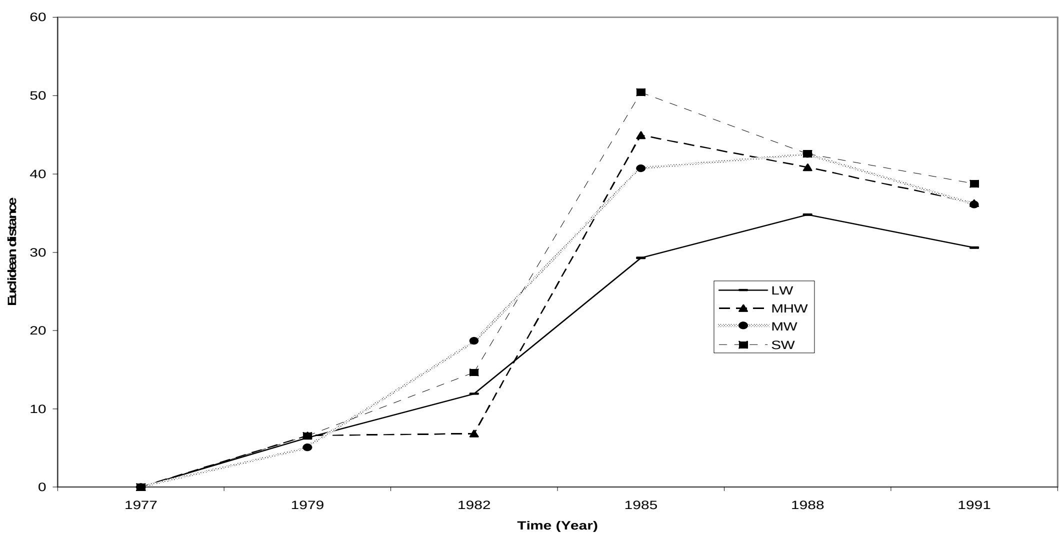


Figure 4-2: Euclidean distances for the rotationally grazed sites illustrating change in species abundance from 1977-1991. Treatments are: LW=Rotational grazing at a low stocking rate, MHW= Rotational grazing at a medium-heavy stocking rate, MW= Rotational grazing at a medium stocking rate.

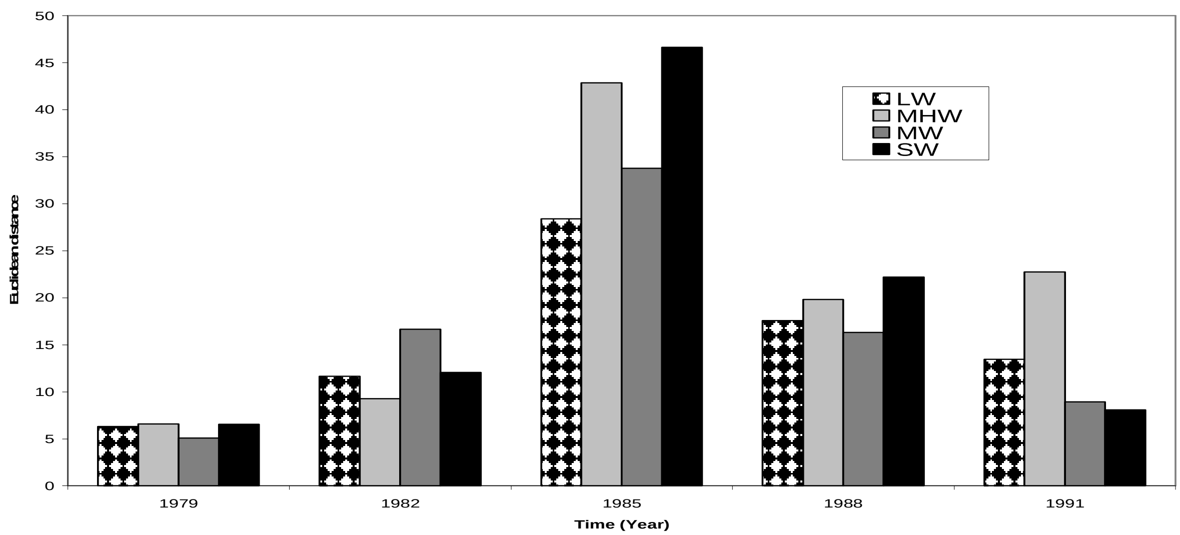


Figure 4-3: Euclidean distances for the rotationally grazed sites illustrating change in species abundance from year to year. Treatments were: Rotational grazing at a low stocking rate, MHW= Rotational grazing at a medium-heavy stocking rate, MW= Rotational grazing at a medium stocking rate.

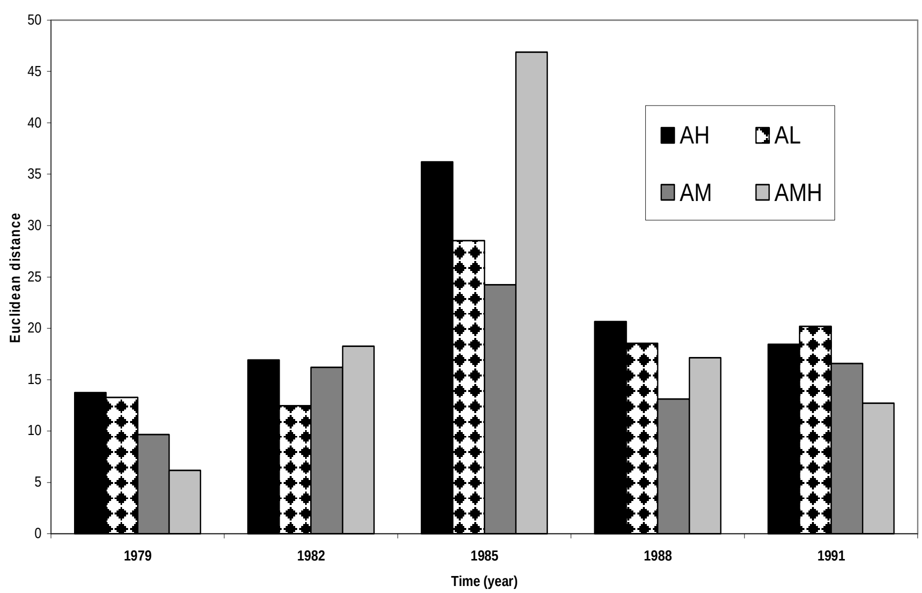


Figure 4-4: Euclidean distances for the continuously grazed sites illustrating change in species abundance from year to year. Treatments were: AH=Continuous grazing at a high stocking rate, AL= Continuous grazing at a low stocking rate, AM= Continuous grazing

at a medium stocking rate and AMH= Continuous grazing at a medium-heavy stocking rate.

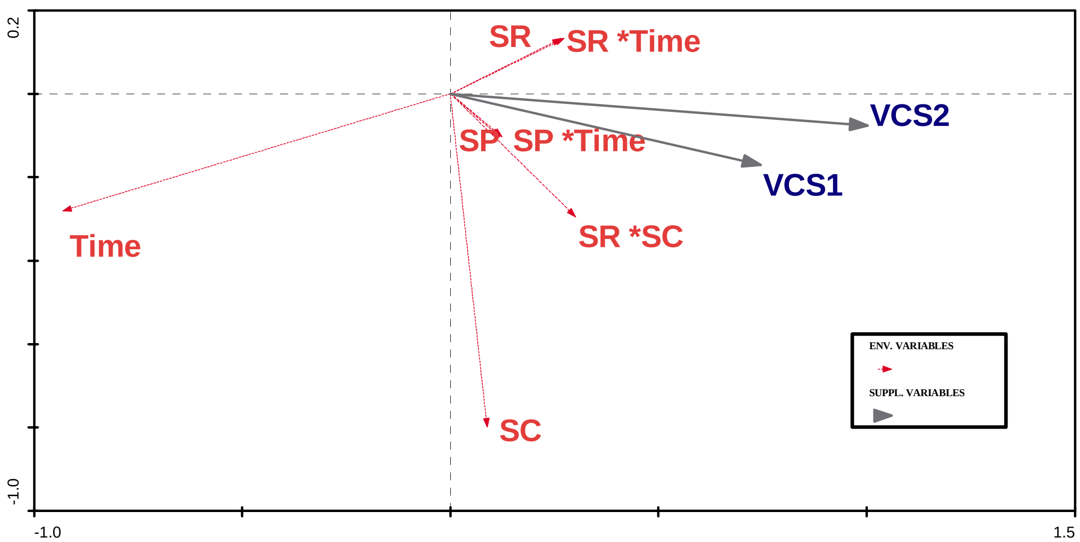


Figure 4-5: Biplot of environmental variables and supplementary environmental variables along the first two axes of a partial RDA illustrating the effect of environmental variables and interactions between them on species relative abundance's and veld condition for phase one. Eigenvalues are 0.447 and 0.032 for axes one and two, which represents 53.8 and 57.7 of the total variance, respectively. Environmental variables were: SC=Seasonal current rainfall (mm), SR=Stocking rate (LSU/ha), SP=Last year's seasonal rainfall and Time=Year that survey was performed. Supplementary environmental variables are: VCS1=Veld condition score one, which is based on basal cover and VCS2=Veld condition score two, which is based on species composition.

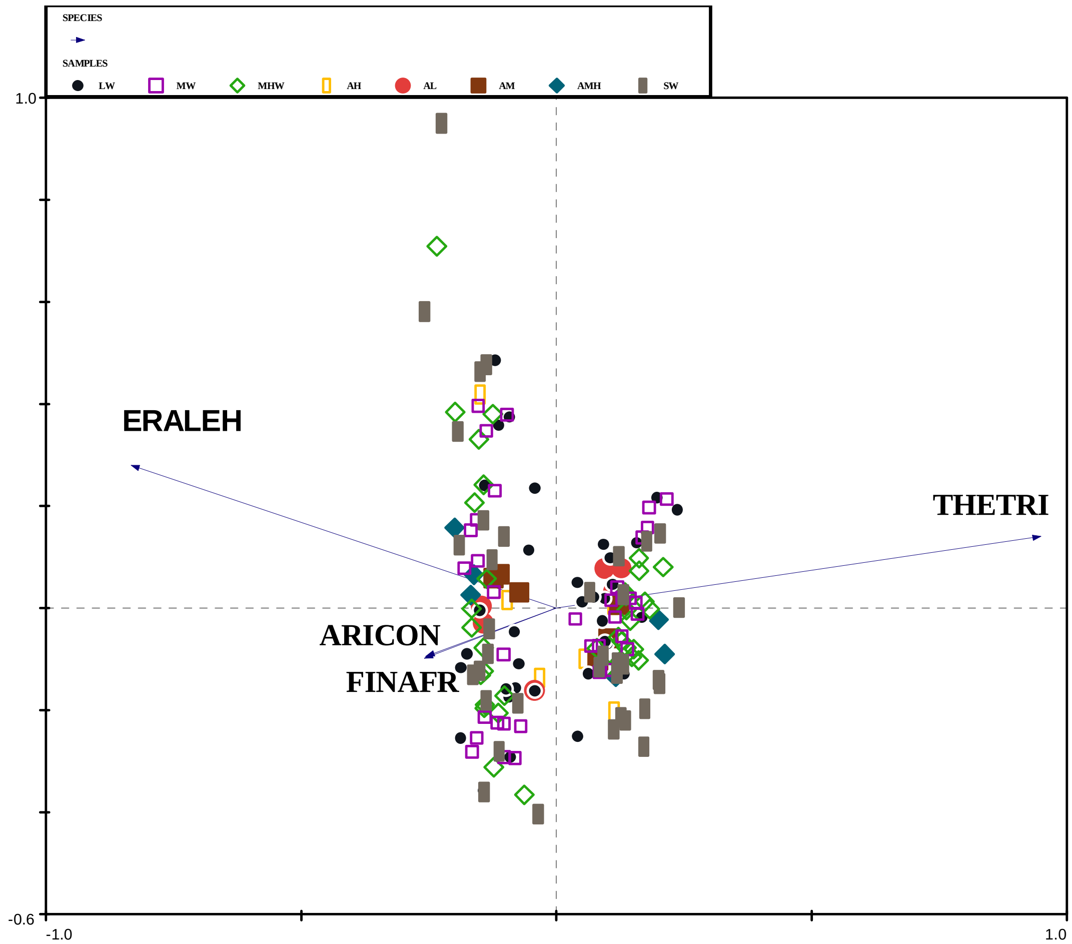


Figure 4-6: Biplot of species and samples along the first two axes of a partial RDA showing species relative abundances within sites for the grazing trial at the Armoedsvlakte Research Station. Treatments are: LW=Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate, MHW= Rotational grazing at a medium-heavy stocking rate, SW= Rotational grazing at a high stocking rate, AL= Continuous grazing at a low stocking rate, AM= Continuous grazing at a medium stocking rate, AMH= Continuous grazing at a medium-heavy stocking rate and AH= Continuous grazing at a high stocking rate. Species with less than 30 percent of their variance explained by the biplot are not shown.

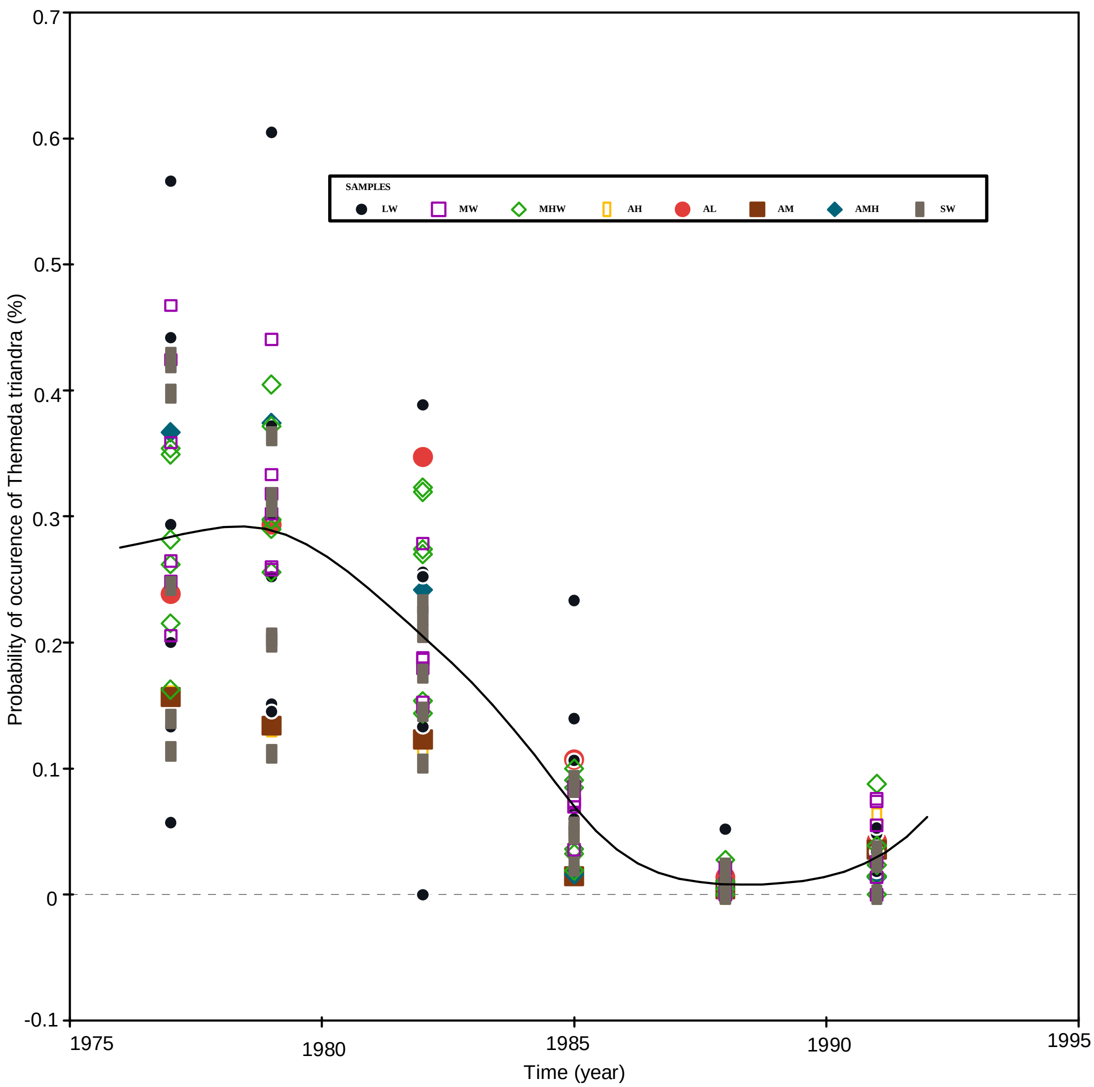


Figure 4-7: Generalized Additive Model (GAM) illustrating the probability of finding *Themeda triandra* over time, across all treatments. Treatments are LW=Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate, MHW= Rotational grazing at a medium-heavy stocking rate, SW= Rotational grazing at a high stocking rate, AL= Continuous grazing at a low stocking rate, AM= Continuous grazing at a medium stocking rate, AMH= Continuous grazing at a medium-heavy stocking rate and AH= Continuous grazing at a high stocking rate.

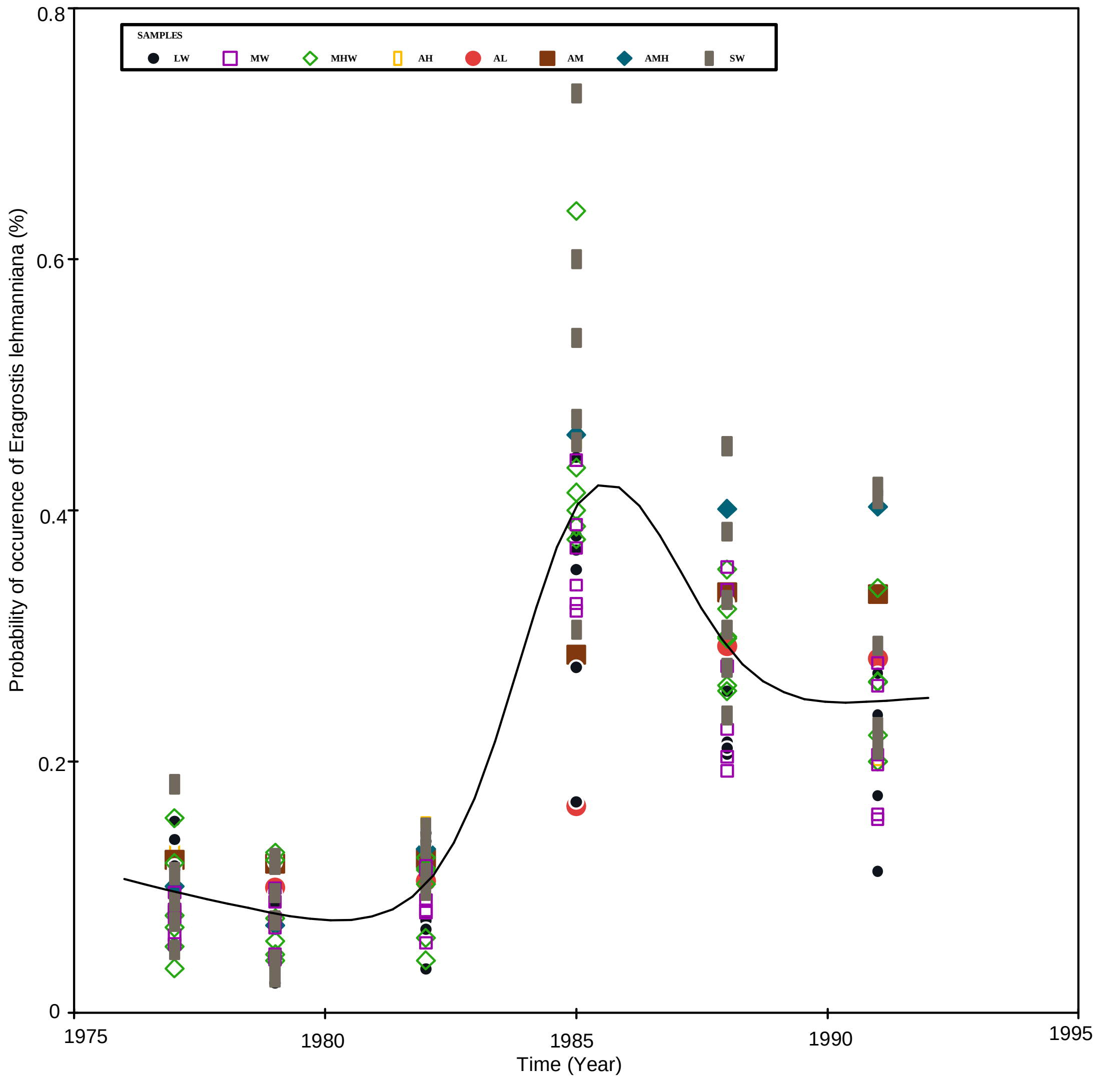


Figure 4-8: Generalized Additive Model (GAM) indicating the probability of finding *Eragrostis lehmanniana* over time, across all treatments.. Treatments are LW=Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate, MHW= Rotational grazing at a medium-heavy stocking rate, SW= Rotational grazing at a high stocking rate, AL= Continuous grazing at a low stocking rate, AM= Continuous grazing at a medium stocking rate, AMH= Continuous grazing at a medium-heavy stocking rate and AH= Continuous grazing at a high stocking rate.

4.2.5.2.Phase two (1992-1999)

The results of the Monte Carlo permutation test indicated that there is a statistically significant effect (P=0.01) of the environmental variables and the interactions of these variables on the first and all of the canonical axes (**Error! Reference source not found.**). The only significant environmental variable was stocking rate (**Error! Reference source not found.**). The species-environmental relationship for axes one and two explained 95.5 percent of the explainable variation in the data set, which showed that the variation in the data set is well explained by the measured environmental variables (**Error! Reference source not found.**). Axes one and two of the RDA explained 36 percent of the total variation in the species data set (**Error! Reference source not found.**). Eigenvalues are 0.259 and 0.102 for axes one and two, which represents 25.9 and 36 percent of the total variance, respectively.

The general trend was that as stocking rate increased the relative abundances of *Digitaria eriantha* decreased substantially, while the abundances of *Cymbopogon plurinodis* decreased to a lesser extent (**Error! Reference source not found.**). However, the relative abundances of *Schmidtia pappophoroides* increases substantially, while the relative abundances of *Eragrostis pseudo-obtusa* and *Tragus racemosus* increased to a lesser extent with increasing stocking rates. Both types of veld condition scores decreases substantially with an increase in stocking rates, especially the second veld condition scores. The veld condition score improved greatly as current seasonal rainfall increases, especially the second veld condition score (**Error! Reference source not found.**). It is important to note that the significant interaction between stocking rate and seasonal current rainfall, indicated that the effect of stocking rate is dependant on current seasonal rainfall.

The length of the arrows in **Error! Reference source not found.**, for the environmental variables and the interactions between them, indicated their importance in explaining variation. Axis one was very strongly positively correlated to stocking rate (0.9063) and to the stocking rate by seasonal current rainfall interaction (0.8665), which suggested that stocking rate explained most of the variation in axis one. However, season rainfall explained an additional amount of variation along axis one. Seasonal current rainfall have a strong positive correlation (0.6224) with axis two, which indicated that seasonal current rainfall explains most of the variation in axis two.

The light and medium stocking rates treatments were strongly associated with *Digitaria eriantha* and both types of veld condition scores, while the high stocking rate treatments were strongly associated with less palatable species (*Eragrostis pseudo-obtusa* and *Schmidtia pappophoroides*). This indicates that high stocking rates seems to decrease veld condition scores.

These results indicated that stocking rate is more important explaining variation in species abundances and veld condition, although seasonal current rainfall explained an important part of the variation in the data set. These results suggested that there is continuum of non-equilibrium and equilibrium vegetation dynamics in the system.

Table 4-4 Summary of the results of the Monte Carlo permutation test for the RDA for species abundance and veld condition data for phase two

Test of significance of first canonical axis F-ratio = 4.187 P-value = 0.008 Test of significance of all canonical axes F-ratio = 2.424 P-value = 0.01

Table 4-5: Significance of the environmental variables and interactions between them on species relative abundance and veld condition for phase two (1992-1999).

Environmental Variable / Interaction	**P-Value**	**Significance**
SC	0.188	Non-significant
SR	0.002	Highly significant
SR*SC	0.104	Significant

Table 4-6: Summary of the RDA for data from phase two (1992-1999) with only significant environmental variables and interactions included.

Eigenvalues	0.259	0.102	0.017	0.214
Species-environment correlations	0.921	0.724	0.401	
Cumulative percentage variance				
of species data	25.9	36	37.7	59.2
of species-environment relation	68.5	95.5	100	
Sum of all eigenvalues				1
Sum of all canonical eigenvalues				0.377

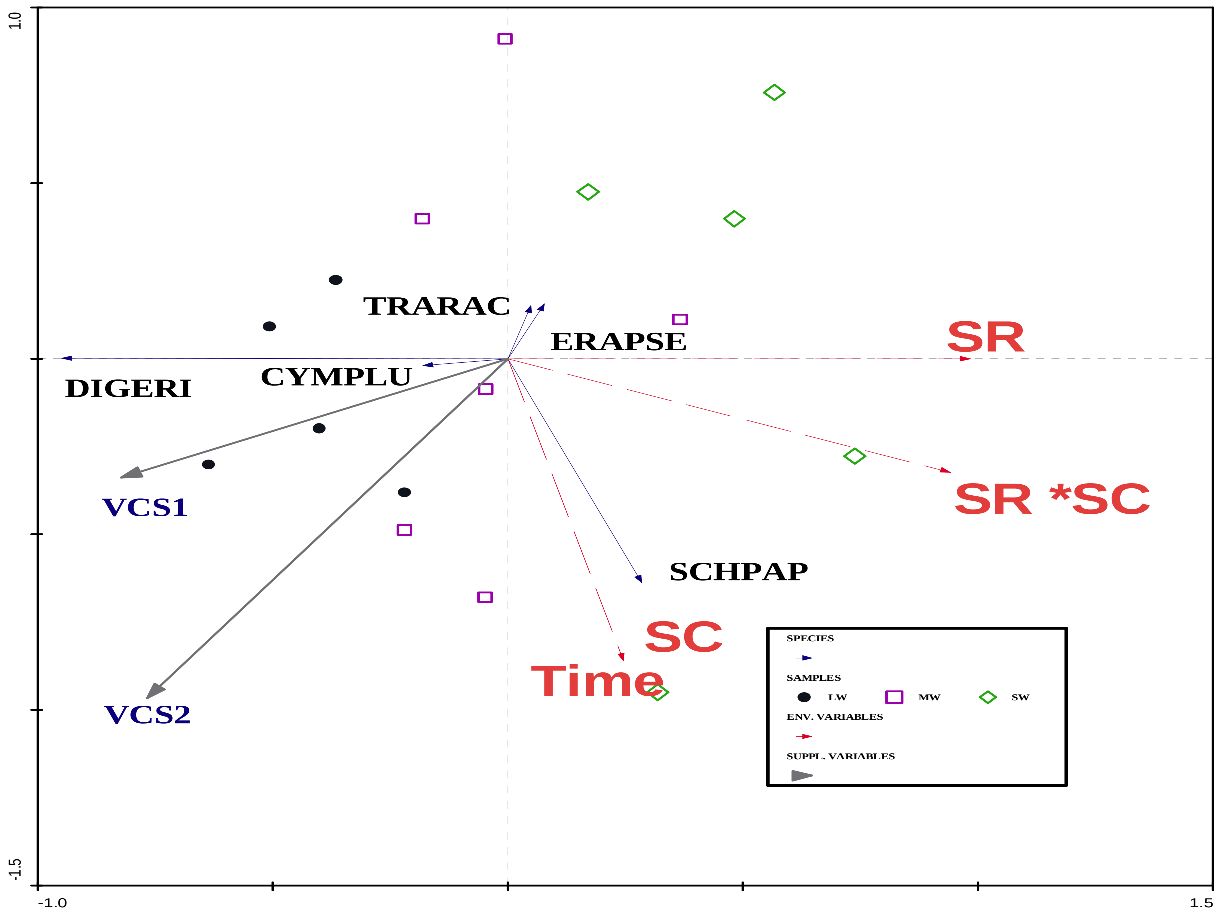


Figure 4-9: Tri-plot of species, environmental variables, supplementary environmental variables and samples along the first two axes of a RDA showing species relative abundances and veld condition scores for sites at the Armoedsvlakte Research Station. Species with less than 40 percent of their variance explained by the tri-plot are not shown. Treatments are: LW=Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate and SW= Rotational grazing at a high stocking rate. The environmental variables are: SR=Stocking rate (LSU/ha), SC=Seasonal current rainfall (mm) and Time (year). The supplementary environmental variables are VCS1=Veld condition score one, which is based on basal cover and VCS2=Veld condition score two, which is based on species composition. Species are: Digeri=*Digitaria eriantha*, Schpap=*Schmidtia pappophoroides*, Cymplu=*Cymbopogon plurinodis*, Trarac=*Tragus racemosus* and Erapse=*Eragrostis pseudo-obtusa*.

4.2.5.3. Phase three (2000-present)

The results of the Monte Carlo permutation test indicated that there is a statistically significant effect (P=0.004) of stocking rate on the first canonical axis (Table 4-7). The species-environmental relationship for axis one explained 100 percent of the explainable variation in the data set, because stocking rate was the only environmental variable included in the analysis (Table 4-8). Axes one and two of the RDA explained 55.3 percent of the total variation in the data set (Table 4-8). Eigenvalues are 0.286 and 0.267 for axes one and two, which represents 28.6 and 55.3 percent of the total variance, respectively.

The general trend is that as stocking rate increased the relative abundance of *Digitaria eriantha* decreased substantially, while the relative abundances of *Themeda triandra* and *Fingerhuthia africana* decreased to a lesser extent (**Error! Reference source not found.**). The relative abundance of *Eragrostis lehmanniana* increased substantially, while the relative abundance of *Eragrostis superba* increased to a lesser extent with increasing stocking rates. Both types of veld condition scores decreased with an increase in stocking rates, especially the first veld condition scores (**Error! Reference source not found.**).

The length of the arrows of the environmental variables and the interactions between them indicated their importance in explaining variation. Axis one was very strongly positive correlated to stocking rate (0.94), which suggested that stocking rate explained most of the variation in axis one (**Error! Reference source not found.**).

Table 4-7 Summary of the results of the Monte Carlo permutation test for the RDA for species abundance and veld condition data for phase two

Test of significance of all canonical axes
F-ratio = 2.805
P-value = 0.004

Table 4-8: Summary of the RDA for relative species composition and veld condition data from phase three (2000 to present) with stocking rate as the only environmental

Axes	1	2	3	4
Eigenvalues	0.286	0.267	0.144	0.131
Species-environment correlations	0.94			
Cumulative percentage variance				
of species data	28.6	55.3	69.7	82.8
of species-environment relation	100			
Sum of all eigenvalues				1
Sum of all canonical eigenvalues				0.286

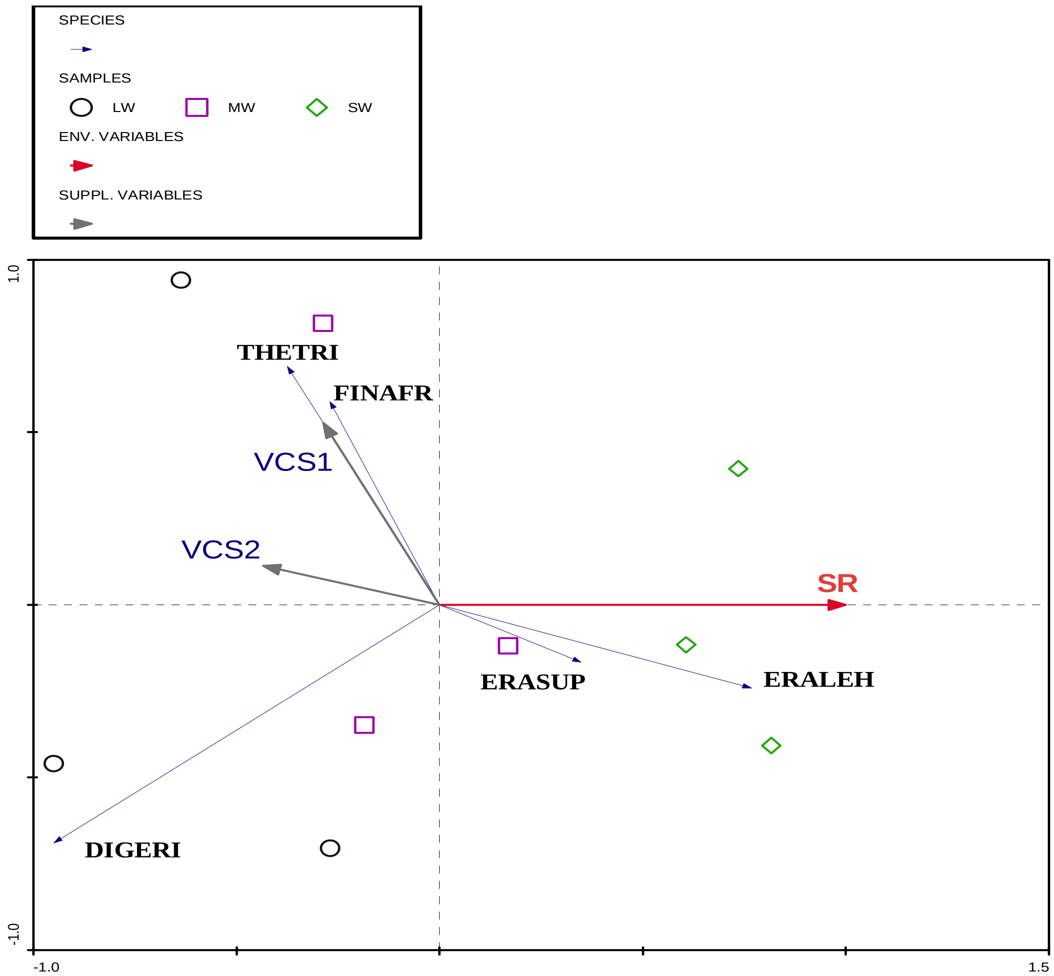


Figure 4-10: Tri-plot of species, environmental variables, supplementary environmental variables and samples along the first two axes of a RDA illustrating species abundance and veld condition for sites from the grazing trial at the Armoedsvlakte Research Station. Species with less than 55 percent of the total variance explained by the tri-plot are not shown. Treatments are: LW=Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate and SW= Rotational grazing at a high stocking rate. The environmental variable is SR=Stocking rate (LSU/ha). The supplementary environmental variables are VCS1=Veld condition score one, which is based on basal cover and VCS2=Veld condition score two which is based on species composition. Species are: Digeri=*Digitaria eriantha*, *Thetri=Themeda triandra*, Eraleh=*Eragrostis lehmanniana*, Finafr=*Fingerhuthia africana* and Erasup=*Eragrostis superba*.

4.2.6. Conclusions

4.2.6.1.Phase one (1977-1991)

Most of the variation in time is explained by the interaction of seasonal current rainfall and seasonal past rainfall. The multi-year drought (1984-1985) caused an adverse shift in species composition from a *Themeda triandra* dominated system to an *Eragrostis lehmanniana* dominated system, with a resultant decrease in the veld condition of all treatments. High seasonal rainfall followed the drought, but the change in species composition persisted, although some convergence did occur. These results indicated that stocking rate and the type of grazing system applied are less important in explaining vegetation dynamics, than seasonal current and seasonal past rainfall are. These results suggested that the system can recover from single year droughts, but multi-year droughts result in adverse changes in species composition, that persist for a number of years. These results indicate that non-equilibrium vegetation dynamics occurred during phase one, as rainfall was more important than stocking rate in explaining vegetation dynamics.

4.2.6.2.Phase two (1992-1999)

High stocking rates resulted in an adverse change in species composition and a resultant decrease in veld condition. The opposite trend existed for rainfall as high seasonal current rainfall resulted in an improvement in veld condition. These results indicate that stocking rate was more important than rainfall in explaining variation in the data set, but rainfall explains an additional part of the variation in the data set. This indicated that the vegetation dynamics within the system is a continuum of non-equilibrium and equilibrium effects in the system.

4.2.6.3.Phase three (2000 to present)

High stocking rates resulted in adverse changes in species composition and resultant decrease in veld condition scores. It is important to notice that rainfall could not be included in these analyses as there was only one sampling period and rainfall thus does not contribute to explaining, variation within the data set.

4.3. BASAL COVER OF SPECIES

4.3.1. Introduction

Tidmarsh and Havenga (1955) defined the basal cover of grasses as the rooted cover of grasses at ground level. Basal cover varies from season to season and within seasons and this variation can be attributed to the incidence of defoliation (e.g. grazing and fire) and/or rainfall. It is important to monitor the basal cover of an area, as a decline in basal cover can result in increased soil run-off and soil erosion levels (Kincaid and Williams 1966 cited by Fynn 1998), but Kennan (1969) cited by Fynn (1998) reported that this will not happen in areas with very sandy soils (reasons for this are given in Chapter 2.2). Fourie (1983) reported that high stocking rates in both the rotational and continuously grazed systems resulted in a decrease in basal cover and the aim of this chapter is to see if this trend has continued to occur at Armoedsvlakte Research Station. In contrast to this, Fuhlendorf *et al.* (2001) concluded from their studies that basal cover is not a good indicator of grazing intensity and its use may lead to the interpretation that vegetation change is more responsive to climate than to grazing. They recommend that species composition should be used as an indicator of veld condition.

4.3.2. Methods and materials

A basal cover assessment at the Armoedsvlakte Research Station is conducted every third year. The Wheelpoint method (Tidmarsh and Havenga 1955) is used to calculate the basal cover (%) and species composition (Chapter 4.2.1) of grasses, but only the basal cover component will be discussed in this chapter.

The main advantage of point methods like the Wheelpoint method is that they are free of problems associated with quadrat size (Everson and Clarke 1987 cited by Brockett 2001). A point based method may be able to avoid the problem of the biased placement that is experienced with quadrats in tall grass and on rocky terrain (Brockett 2001). Everson and Clarke (1987) cited by Brockett (2001) indicated that the Wheelpoint method was the most consistent in its relative accuracy and discriminatory ability. Everson *et al.* (1990) reported that the Wheelpoint method shows good results between the observed and expected frequencies for all the species that they sampled, but more than 1200 points are required in detecting a change in species with a frequency of less than five percent to achieve a 20 percent precision, where precision was defined as the degree of variability in estimates obtained with repeated samples.

The disadvantages of the Wheelpoint method are that the operator and sampling costs are higher than other point methods like the step-point method. This is because the Wheelpoint requires two people, one operator to push the wheel and the other as an observer and recorder, whereas the step-point method equipment is much cheaper and only one sampler is required. Two sources of error result due to the use of the Wheelpoint method (Tidmarsh and Havenga 1955, Mentis *et al.* 1980, Hardy and Tainton 1982, Mentis 1982, Friedel and Shaw 1987). The first is that the probability of recording a strike is extremely low and large sample sizes are thus required to achieve acceptable levels of precision of basal cover. The second is that there is a considerable amount of variability between and within operators in the identification of what constitutes a strike.

The Wheelpoint that is used at the Armoedsvlakte Research Station is three meters in circumference and 3000 points are taken within all of the treatments. At each point a hit or a miss is recorded and if a hit is recorded then the grass species is identified by the observer and recorder. This allows for the calculation of total grass basal cover for each of the stocking rate treatments, individual basal cover of all of the grass species within each stocking rate treatment and basal cover of each of the ecological groups (**Error! Reference source not found.**)(calculations shown below).

All of the stocking rate and grazing system treatments for phase one (1977-1991) were sampled. During phase two (1992-1999) only replications one, three and six for the rotational grazing at a low, medium and high stocking rates treatments, were sampled. Continuous grazing treatments were no longer part of the grazing trial and as a result, these paddocks were thus not sampled. During phase three (2000 to present) only replication one, three and six for the rotational grazing at a low, medium and high stocking rates treatments, were sampled.

The basal cover of each of the grass species was calculated from the number of strikes recorded as a percentage of the total number of point observations for a sample site:

Basal cover of a species (%) = Number of hits for that species/total number of points taken (3000)*100

Total basal cover for a treatment (%) = Number of hits for the treatment/total number of points taken (3000)*100

The basal cover data were used to study the effect and interactions of stocking rate, type of grazing system applied and seasonal rainfall on different species basal cover, on the total basal cover within each treatment and on the basal cover of different ecological groups (**Error! Reference source not found.**).

The basal cover of individual species were grouped into their ecological groups (**Error! Reference source not found.**) to analyse how the ecological groups' basal cover have changed due to different stocking rate treatments. The calculations for all of the ecological group basal cover follow below:

Basal cover (%) for the highly desirable group= (∑All the species basal cover that were in the highly desirable group)

Basal cover (%) for the desirable group= (∑All the species basal cover that were in the desirable group)

Basal cover (%) for the less-desirable group= (∑All the species basal cover that were in the less- desirable group)

Basal cover (%) for the undesirable group= (∑All the species basal cover that were in the undesirable group)

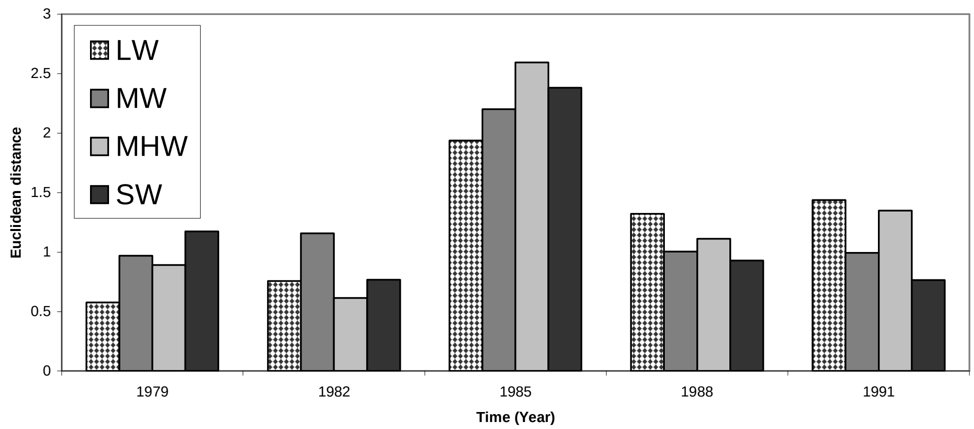
The total basal cover for each of the different stocking rate treatments were calculated as follows:

Total basal cover for a stocking rate treatment=∑basal cover for the highly desirable group for the relevant stocking rate treatment + ∑basal cover for the desirable group for the relevant stocking rate treatment + ∑basal cover for the less desirable group for the relevant stocking rate treatment + ∑basal cover for the undesirable group for the relevant stocking rate treatment.

4.3.3. Statistical analysis for phase one (1977-1991)

Relative species basal cover data was analysed using ordination techniques with Canoco 4.5 (Ter Braak and Smilauer 2003). A PCA was performed to identify and remove any outliers in the data set. Following this, a DCA was carried out to determine the lengths of gradient (e.g. species turnover or diversity in the data set). These lengths of gradients were less than 2.5 Standard Deviations (SD), which suggested that the species turnover was small. Linear models like a PCA and/or a RDA was thus the most appropriate techniques to analyse the data. A partial RDA was chosen to constrain the axes with environmental variables (e.g. stocking rate, type of grazing system applied and seasonal rainfall) and to remove spatial and temporal autocorrelation. Following this, manual forward selection of environmental variables and interactions were performed to test the significance of environmental variables and interactions between them. Only rotational grazing interactions were permutated, because continuous grazing interactions were the exact opposite (e.g. grazing system environmental variables were nominal variables) and it would have been unnecessary to analyse both. Non-significant environmental variables and interactions ($P>0.1$) were excluded from the analysis. The interaction between current seasonal rainfall and past seasonal rainfall were not tested as this interaction resulted in large inflation factors. It was however important to perform this analysis to investigate why the time effect was so large. When the season rainfall interaction was included, the time effect in the analyses decreases substantially and this suggested that most of time effect was due to the interaction of seasonal current and past rainfall.

Two types of Euclidean distances were calculated for both grazing systems using PRIMER 4.5. These were the change in basal cover from the beginning of the trial (**Error! Reference source not found.** and **Error! Reference source not found.**) and the change in basal cover from year to year



(

Figure 4-13 and

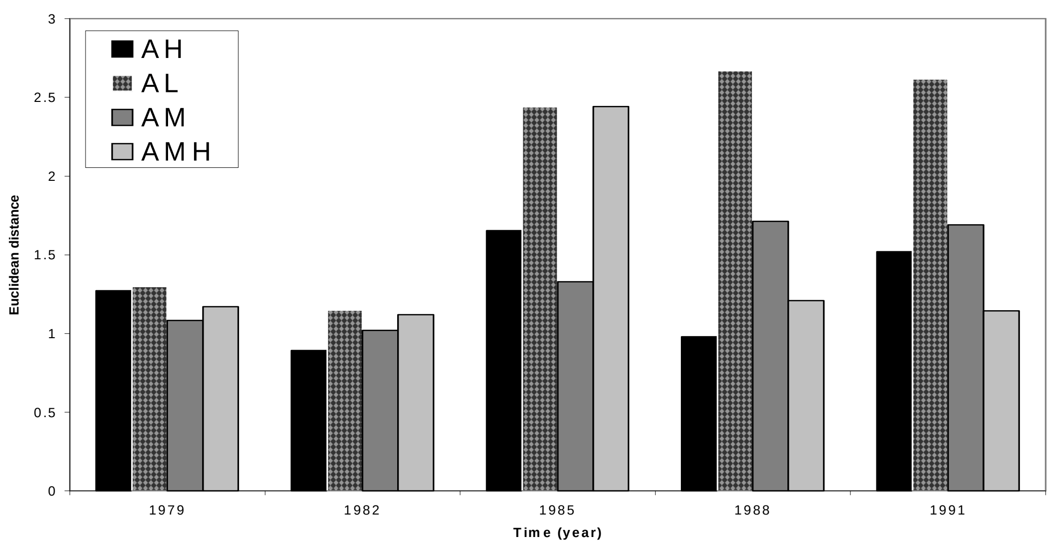


Figure 4-14). The Euclidean distances for the rotationally grazed sites and continuously grazed sites were shown on different graphs. It is important to note that an average across the six paddocks for the rotationally grazed sites was taken to make comparisons between grazing systems, easier (**Error! Reference source not found.**, **Error! Reference source**

not **found.**,

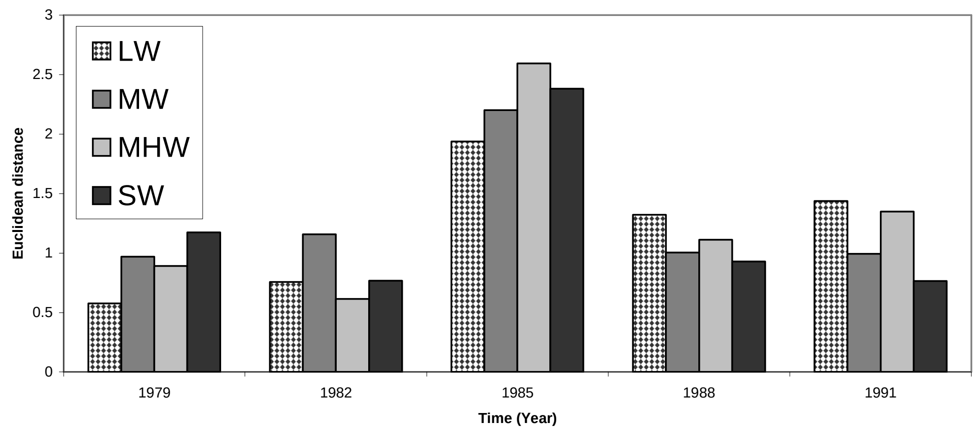


Figure 4-13 and

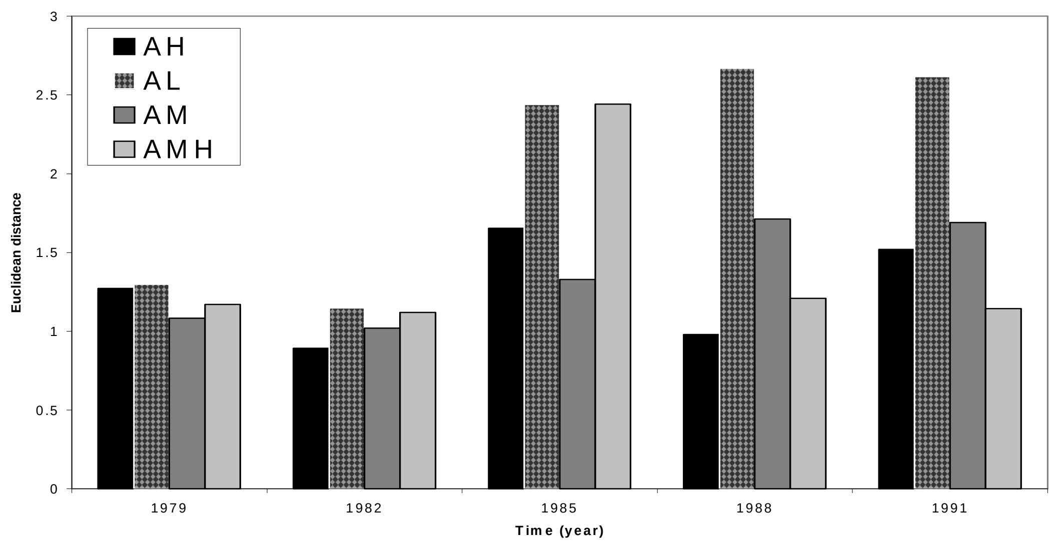


Figure 4-14).

4.3.4. Statistical analysis for phase two (1992-1991)

Relative species basal cover data were analysed, using ordination techniques with Canoco 4.5 (Ter Braak and Smilauer 2003). A PCA was performed to identify and remove any clear outliers in the data set. Following this, a DCA was carried out to determine the lengths of gradients (e.g. species turnover or diversity in the data set). These lengths of gradients were less than 1.5 SD, which suggested that the species turnover was small.

Linear models like PCA's and/or RDA's were thus the most appropriate techniques to use to analyse the data. A RDA was chosen to constrain the axes with environmental variables (e.g. stocking rate and seasonal rainfall). Following this, manual forward selection of environmental variables and interactions were performed to test the significance of environmental variables and interactions between them. Non-significant environmental variables and interactions (P>0.1) were excluded from the analysis. It is important to note that continuously grazed treatments were discontinued at the start of phase two and the variation in the data set due to grazing system could not be analysed because of this. The RDA model only had seasonal current rainfall and not seasonal past rainfall included into the analysis, as there was only two sampling periods. As a result, Euclidean distances could not be calculated for the analyses.

4.3.5. Statistical analysis for phase three (2000 to present)

Relative species basal cover data were analysed, using ordination techniques with Canoco 4.5 (Ter Braak and Smilauer 2003). A PCA was performed to identify and remove any clear outliers in the data set. Following this, a DCA was carried out to determine the lengths of gradients (e.g. species turnover or diversity in the data set). These lengths of gradients were less than two SD, which suggested that the species turnover was small. Linear models like PCA and/or RDA are thus the most appropriate techniques to use to analyse the data. A RDA was chosen to constrain the axes with the only environmental variable (stocking rate). It is important to note that continuously grazed treatments were discontinued at the start of phase two and the variation in the data set due to grazing system could not be analysed because of this. There was only sampling period during phase three and because of this Euclidean distance, could not be calculated for the analyses. Seasonal rainfall (both past and current) could not be included in the analysis, as these variables will not vary within a single season.

4.3.6. Results and discussion

4.3.6.1.Phase one (1977-1991)

The results of the Monte Carlo permutation test illustrated a statistically significant effect (P=0.002) of the environmental variables and the interactions of these variables on the first and all of the canonical axes (Table 4-9).

The environmental variables that had a statistically signicant effect on the basal cover of species were time, seasonal past rainfall and seasonal current rainfall, while signicant interactions were the time by seasonal past and stocking rate by time interactions (Table 4-10). The species-environmental relationship for axes one and two explained 95.9 percent of the explainable variation in the data set, which showed that the variation in the data set was well explained by the measured environmental variables (Table 4-11). Axes one and two of the RDA explained 54.7 percent of the total variation in the data set (Table 4-11).

Most of the time variable variance were explained by the rainfall interaction (explained earlier), but it is important to see how the basal cover of species have changed over time. From **Error! Reference source not found.** and **Error! Reference source not found.** it can be concluded that the highest rate of change in the basal cover of species occurred during the period 1982 to 1985, when the system experienced four years of below average seasonal rainfall (**Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**). The most change in basal cover (from year to year) occurred in 1985, which is immediate after the two consecutive years of well below mean seasonal rainfall (**Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**). This change persisted longer in the continuously grazed sites. All treatments before the multi-year drought was dominated mostly by *Themeda triandra* (**Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**), while *Eragrostis lehmanniana* dominated the basal cover of all treatments following the drought (**Error! Reference source not found.**, **Error! Reference source not found.** and

Error! Reference source not found.). The system did not recover from two consecutive low rainfalln years, despite high seasonal rainfall after the multi-year drought, although some convergence of sites occurred late in phase one (**Error! Reference source not found.** and **Error! Reference source not found.**). The single year drought (182 mm rainfall during 1991), did not result in an adverse change in basal cover as *Themeda triandra* basal cover actually improved, while *Eragrostis lehmanniana* basal cover declined (**Error! Reference source not found.** and **Error! Reference source not found.**).

The length of the arrows for the environmental variables and the interactions between them indicates their importance in explaining variation in the data set. Time was strongly negatively correlated with axes one (-0.8583) and this is due to the interaction of seasonal current and seasonal past rainfall (explanation given above). Seasonal past rainfall (0.6285) and the interaction of time by seasonal past rainfall (0.6291) is relatively strongly positively correlated to axes two.

These results indicated that stocking rate and grazing system were less important in terms of explaining variation in the basal cover of species within the system, than seasonal rainfall (both past and current) was. It is important to note that the significant interactions of stocking rate by seasonal current rainfall and stocking rate by time, indicated that the effect of seasonal rainfall on species composition and veld condition is dependent on stocking rate and time. From these results, it was concluded that the system can recover from single year droughts, but multi-year droughts results in an adverse change in basal cover of sites. These results indicated that the system is a non-equilibrium system as rainfall explains vegetation dynamics better than both stocking rate and grazing system, but the interaction of stocking rate with time explained additional amount of variation of basal cover.

Table 4-9 A summary of the results of the Monte Carlo permutation test for the partial RDA for species basal cover data for phase one (1977-1991)

Test of significance of first canonical axis

F-ratio = 133.028

P-value = 0.002

Test of significance of all canonical axes

F-ratio = 43.158

P-value = 0.002

Table 4-10 Significance of the environmental variables and interactions between them for species basal cover during phase one (1977-1991)

Environmental variables/interactions	P-value	Significance
Time	0.002	Highly significant
SP	0.002	Highly significant
SC	0.002	Highly significant
Time*SP	0.002	Highly significant
Time*SC	0.492	Non-significant
Rot*Time	0.568	Non-significant
Rot*SP	0.248	Non-significant
Rot*SC	0.044	Significant
SR*Time	0.002	Highly significant
SR*SP	0.996	Non-significant
SR*SC	0.022	Significant

Table 4-11 Summary of the results of the Monte Carlo permutation test for the partial RDA for species basal cover data for phase one (1977-1991)

Axes	1	2	3	4
Eigenvalues	0.42	0.04	0.01	
Species-environment correlations	0.88	0.72	0.5	0.31
Cumulative percentage variance				
of species data	49.7	54.7	56.4	56.9
of species-environment relation	87.1	95.9	98.8	99.7
Sum of all eigenvalues				0.84
Sum of all canonical eigenvalues				0.48

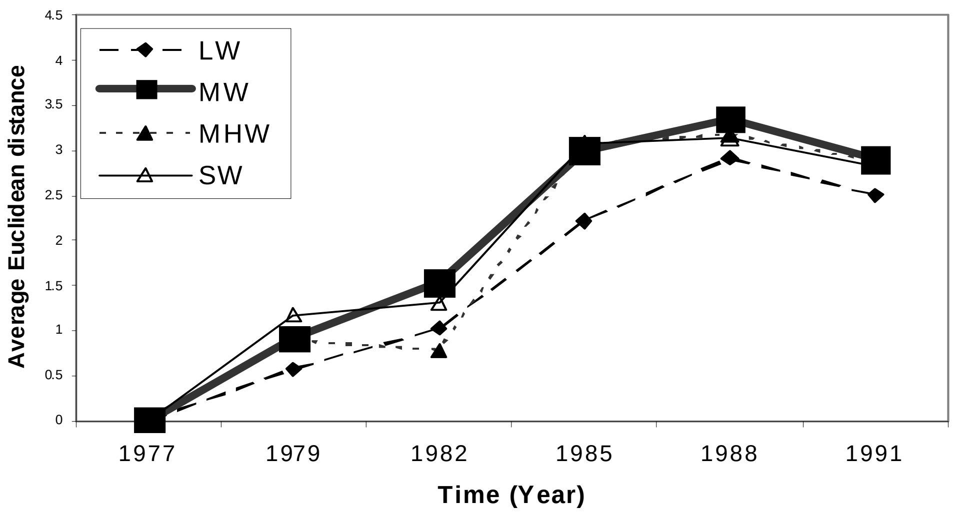


Figure 4-11: Euclidean distance for the rotationally grazed sites illustrating change in the basal cover of species from 1977. Treatments are: LW=Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate, MHW= Rotational grazing at a medium=heavy stocking rate and SW= Rotational grazing at a high stocking rate.

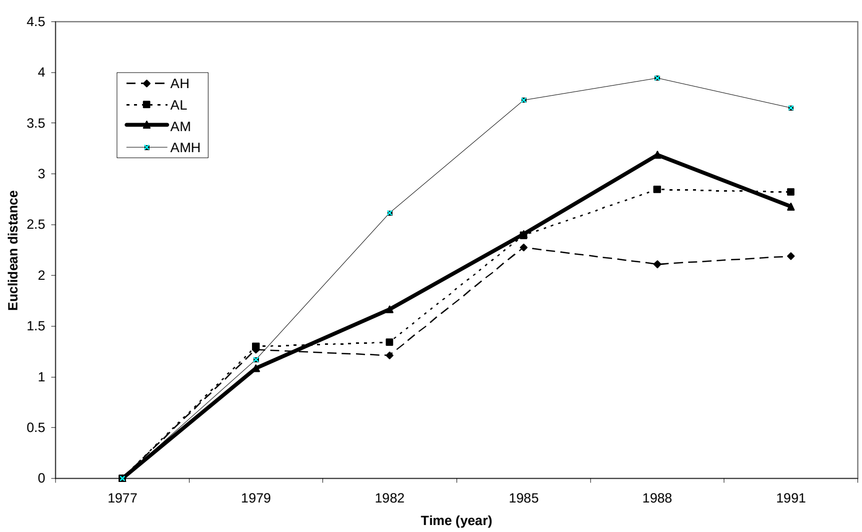


Figure 4-12: Euclidean distance for the continuously grazed sites illustrating change in the basal cover of species from 1977. Treatments are: AH=Continuous grazing at a high stocking rate, AL= Continuous grazing at a low stocking rate, AM= Continuous grazing at a medium stocking rate and AMH= Continuous grazing at a medium-heavy stocking rate.

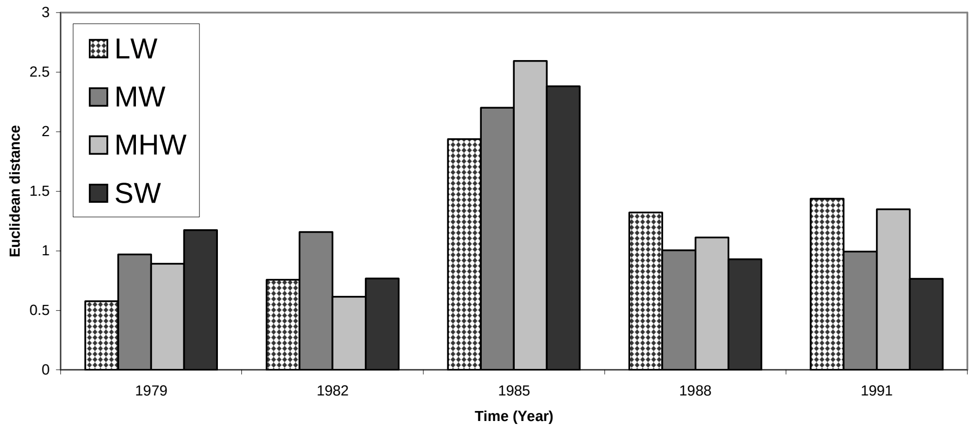


Figure 4-13: Euclidean distance for the rotationally grazed sites illustrating change in the basal cover of species from year to year. Treatments are: LW=Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate, MHW= Rotational grazing at a medium=heavy stocking rate and SW= Rotational grazing at a high stocking rate.

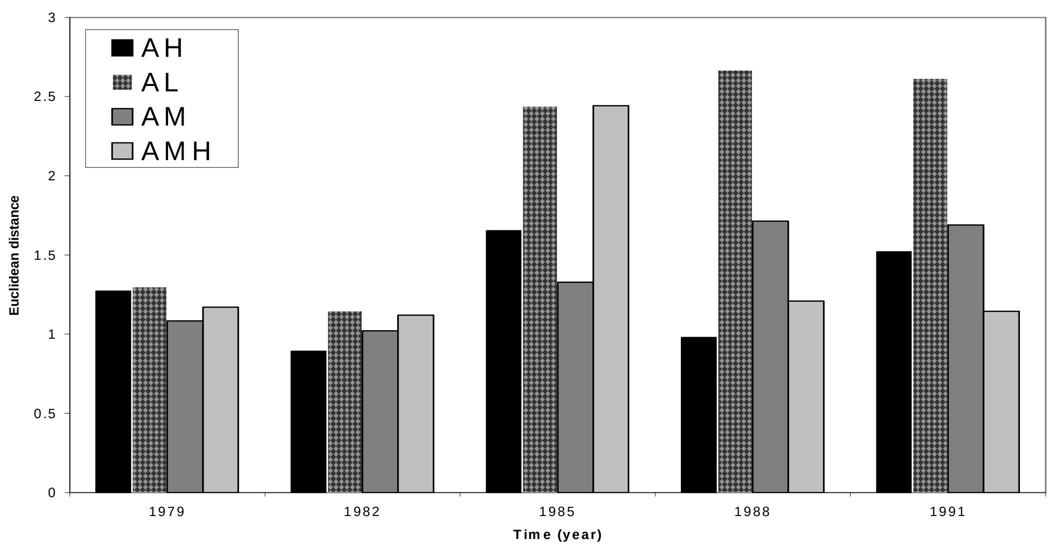


Figure 4-14: Euclidean distances for the continuously grazed sites illustrating change in the basal cover of species from year to year. Treatments are: AH=Continuous grazing at a high stocking rate, AL= Continuous grazing at a low stocking rate, AM= Continuous grazing at a medium stocking rate and AMH= Continuous grazing at a medium-heavy stocking rate.

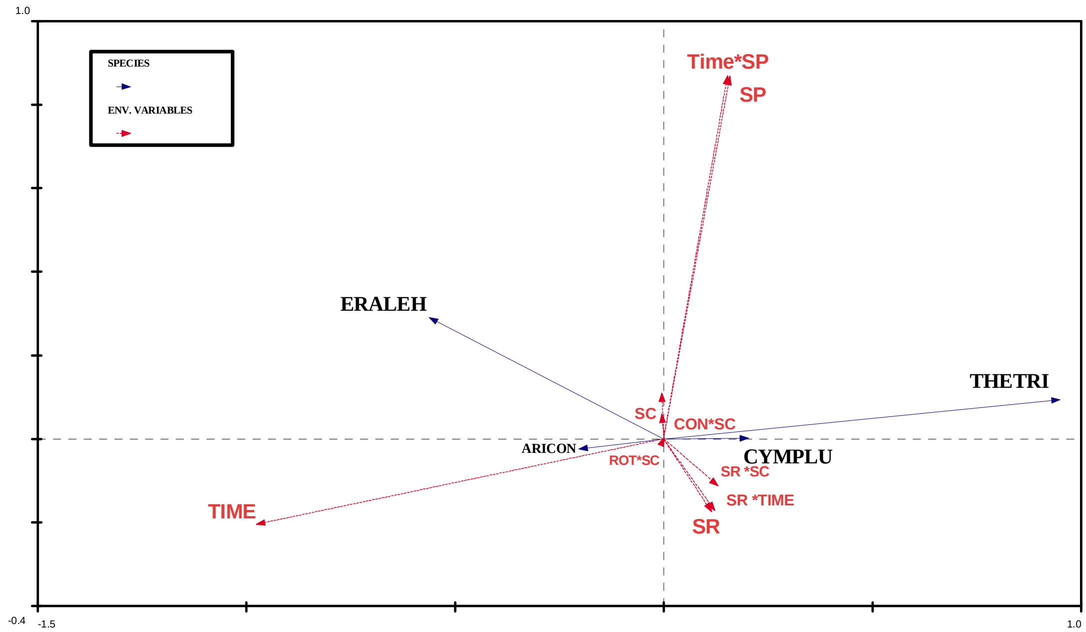


Figure 4-15: Bi-plot of species and environmental variables along the first two axes of a partial RDA showing the effect of environmental variables and the interactions between them on species basal cover of sites, from the grazing trial at the Armoedsvlakte Research Station. Eigenvalues are 0.42 and 0.04 for axes one and two, which represents 49.4 and 54.7 percent of the total variance, respectively. Species with less than 33 percent of their variance explained by the bi-plot are not shown. Environmental variable are SR=Stocking rate (LSU/ha), Time (year), SC=Seasonal current rainfall (mm), SP=Seasonal past rainfall (mm), CON=Continuous grazing system and ROT=Rotational grazing system. Species are: Thetri=*Themeda triandra*, Eraleh=*Eragrostis lehmanniana*, Cymplu=*Cymbopogon plurinodis* and Aricon=*Aristida congesta*.

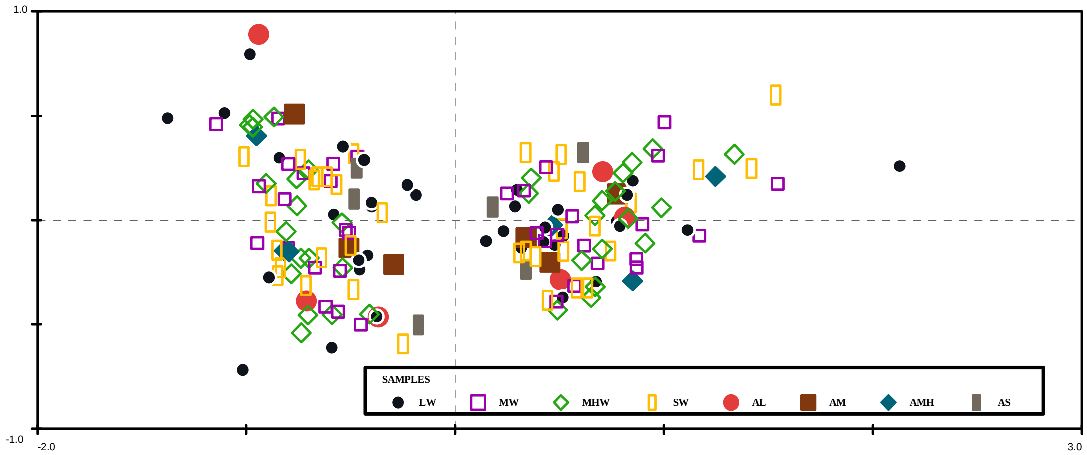


Figure 4-16: Scatter-plot of samples along the first two axes of a partial RDA with species basal cover from sites from the grazing trial at the Armoedsvlakte Research Station. Eigenvalues are 0.42 and 0.04 for axes one and two, which represents 49.4 and 54.7 percent of the total variance, respectively. Treatments are: LW= Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate, MHW= Rotational grazing at a medium-heavy stocking rate, SW= Rotational grazing at a high stocking rate, AL= Continuous grazing at a low stocking rate, AM= Continuous grazing at a medium stocking rate, AMH= Continuous grazing at a medium-heavy stocking rate and AH= Continuous grazing at a high stocking rate.

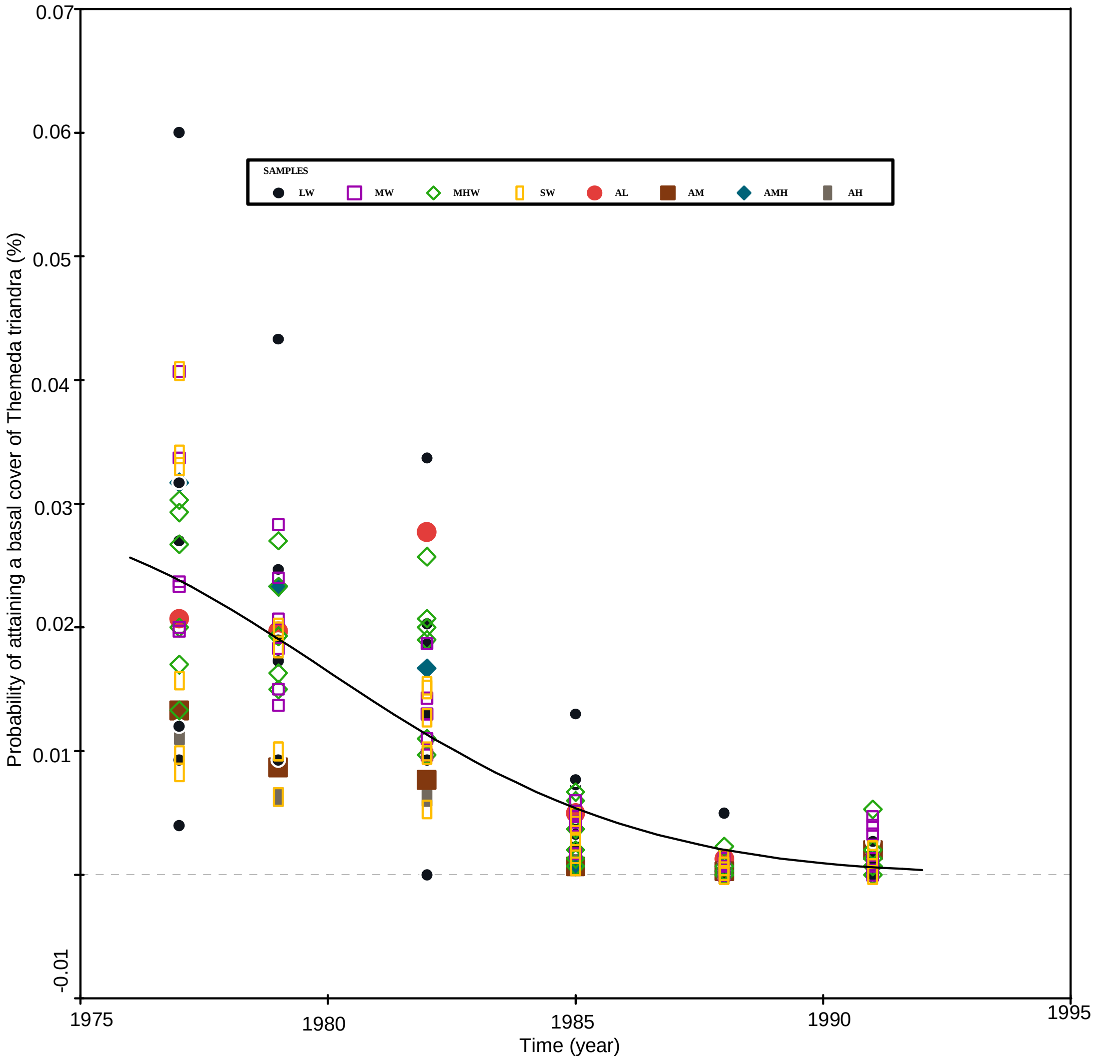


Figure 4-17: Generalized Linear Model (GLM) illustrating the probability of attaining a basal cover of *Themeda triandra* over time across all treatments. The GLM was very highly statistically significant (P<0.001, F-ratio=171.54). The logistic regression equation was $Y=-48481+49.1298x-0.0124486x^2$, where Y=predicted basal cover of *Themeda triandra* (%) and x=time (year). Treatments are: LW= Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate, MHW= Rotational grazing at a medium-heavy stocking rate, SW= Rotational grazing at a high stocking rate, AL= Continuous grazing at a low stocking rate, AM= Continuous grazing at a medium stocking rate, AMH= Continuous grazing at a medium-heavy stocking rate and AH= Continuous grazing at a high stocking rate.

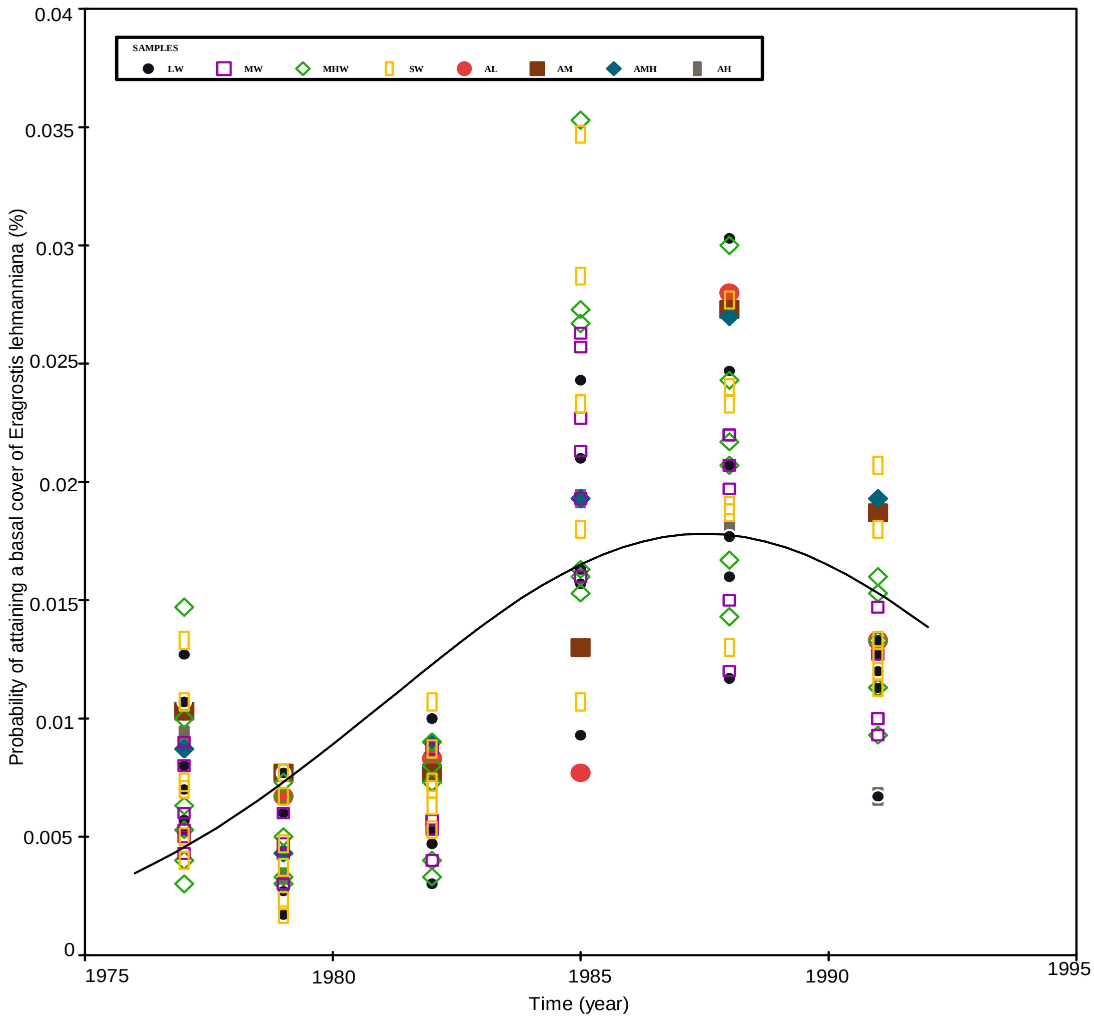


Figure 4-18: Generalized Linear Model (GLM) illustrating the probability of attaining a basal cover of *Eragrostis lehmanniana* over time across all treatments. The GLM was highly statistically significant (P<0.001, F-ratio=68.59). The logistic regression equation was $Y=-49465.5+49.7729x-0.0125224x^2$, where Y=predicted basal cover of *Themeda triandra* (%) and x=time (year). Treatments are LW= Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate, MHW= Rotational grazing at a medium-heavy stocking rate, SW= Rotational grazing at a high stocking rate, AL= Continuous grazing at a low stocking rate, AM= Continuous grazing at a medium stocking rate, AMH= Continuous grazing at a medium-heavy stocking rate and AH= Continuous grazing at a high stocking rate.

4.3.6.2. Phase two (1992-1999)

The results of the Monte Carlo permutation test were highly statistically significant (P=0.004) for the environmental variables and the interactions of these variables on the first and all the canonical axes (Table 4-12) and the only signicant environmental variable was stocking rate (Table 4-13). The species-environmental relationship for axes one and two explained 100 percent of the explainable variation in the data set, which showed that the variation in the data set is well explained by the measured environmental variables. Axes one and two of the RDA explained 33.7 percent of the total variation in the basal cover data set (Table 4-14).

The general trend was that as stocking rate increased, basal cover of *Digitaria eriantha* decreased substantially, while the basal cover of *Cymbopogon plurinodis* and *Heteropogon contortus* decreased to a lesser extent. However, the basal cover of *Eragrostis pseudo-obtusa* and *Tragus racemosus* increased with increasing stocking rates (**Error! Reference source not found.** and **Error! Reference source not found.**).

The length of the arrows in **Error! Reference source not found.** for the environmental variables and the interactions between them indicated their importance in explaining variation. Axis one was very strongly positive correlated to stocking rate (0.7886), which suggested that stocking rate explained most of the variation in axis one. Seasonal current rainfall had a relatively weak negative correlation (-0.5876) with axis two, which indicates that seasonal current rainfall explained most of the variation in axis two.

These results indicated that stocking rate was more important than seasonal rainfall in explaining variation in basal cover, but seasonal current rainfall explained an important part of the variation in the data set. These results thus suggested that there was a continuum of non-equilibrium and equilibrium vegetation dynamics in the system.

Table 4-12 A summary of the results of the Monte Carlo permutation test for the RDA for species basal cover data for phase two (1992-1999)

Test of significance of first canonical axis

F-ratio = 4.847

P-value = 0.004

Test of significance of all canonical axes

F-ratio = 3.308

P-value = 0.002

Table 4-13 Significance of the environmental variables and interactions between them for species basal cover during phase two (1992-1999**)**

Environmental variables/interactions	P-value	Significance
SC	0.118	Non-significant
SR	0.002	Highly significant
SR*SC	0.134	Non-significant

Table 4-14 Summary of the RDA for the basal cover of species during phase two (1992-1999)

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.272	0.066	0.265	0.114
Species-environment correlations	0.833	0.671		
Cumulative percentage variance				
of species data	27.2	33.7	60.3	71.6
of species-environment relation	80.5	100		
Sum of all eigenvalues				1
Sum of all canonical eigenvalues				0.337

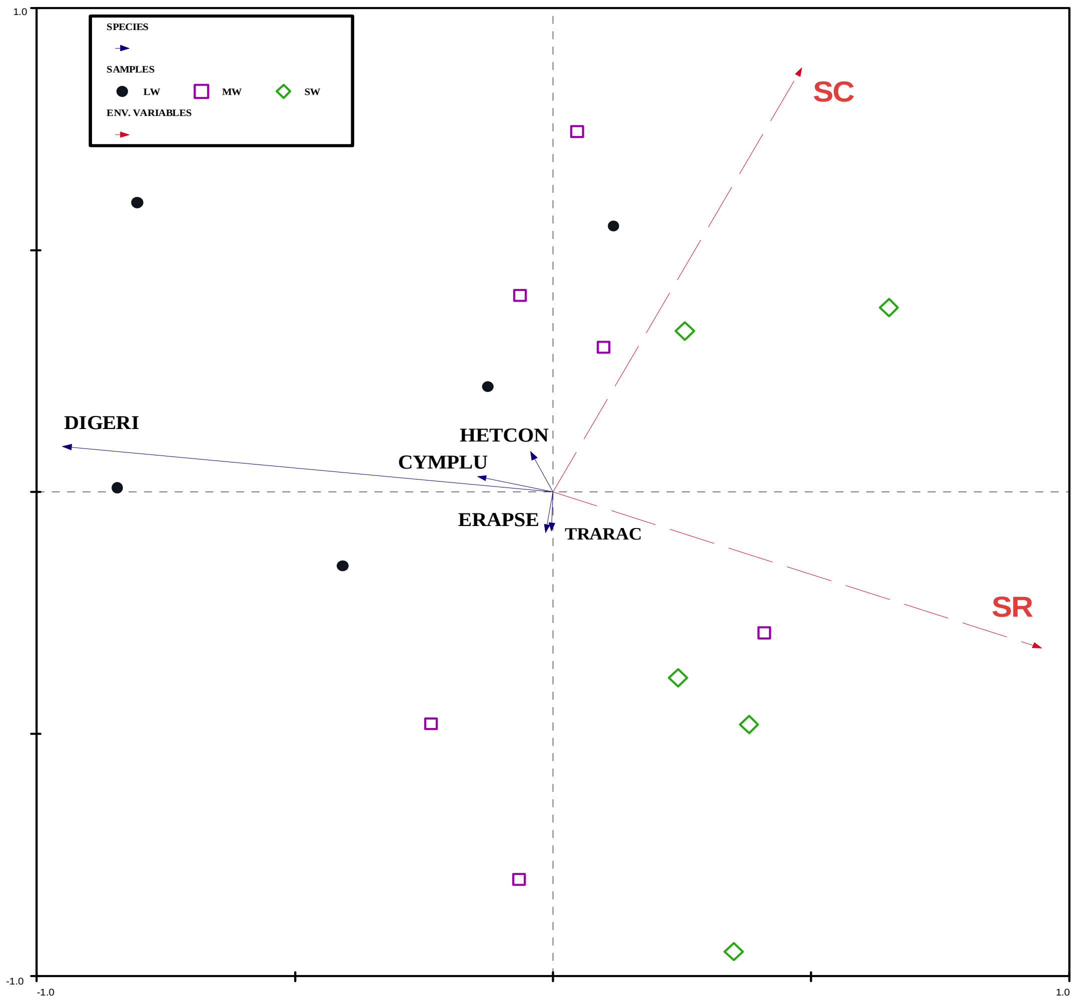


Figure 4-19: Tri-plot of species, environmental variables, the interactions between and sites along the first two axes of a RDA showing the effect of environmental variables on species basal cover from sites, from the grazing trial at the Armoedsvlakte Research Station. Eigenvalues are 0.272 and 0.066 for axes one and two, which represents 27.2 and 33.7 percent of the total variance, respectively. Species with less than 55 percent of their variance explained by the tri-plot are not shown. The environmental variables are SR=Stocking rate (LSU/ha) and SC=Seasonal current rainfall (mm). Treatments are LW=Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate, and SW= Rotational grazing at a high stocking rate. Species are: Digeri=*Digitaria eriantha*, Cymplu=*Cymbopogon plurinodis*, Erapse=*Eragrostis pseudo-obtusa*, Trarac=*Tragus racemosus* and Hetcon=*Heteropogon contortus*.

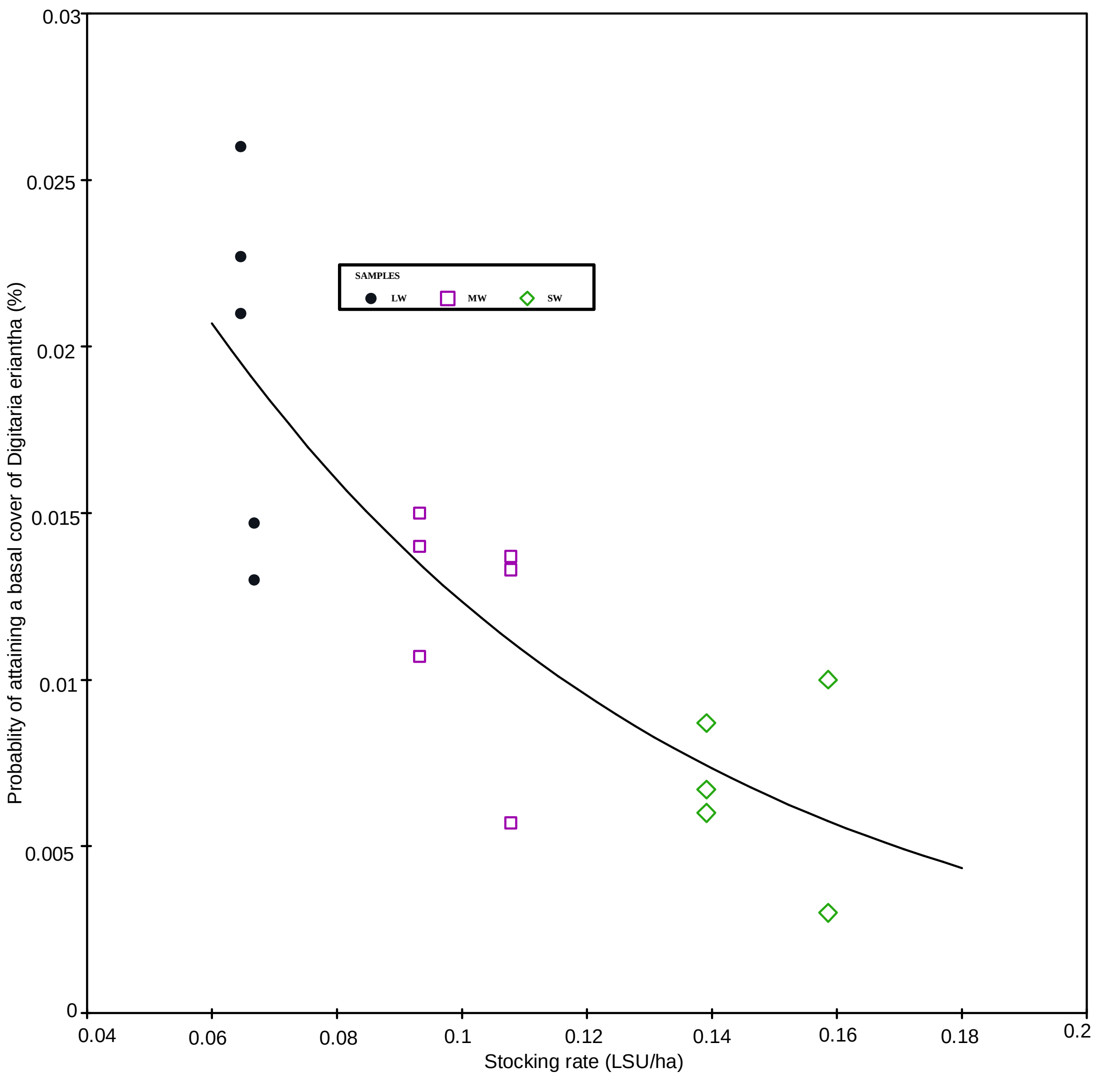


Figure 4-20: GLM illustrating the probability of attaining a basal cover of *Digitaria eriantha* over time across all treatments. The GLM was highly significant (P<0.001, F-value=32.03). The logistic regression equation was Y=-3.06778-13.1427X, where Y=predicted basal cover of *Digitaria eriantha* (%) and X=stocking rate (LSU/ha). Treatments are LW= Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate, and SW= Rotational grazing at a high stocking rate.

4.3.6.3.Phase three (2000 to present)

The results of the Monte Carlo permutation test indicated that there was statistically significant effects (P=0.042) of the environmental variables on the first canonical axis (Table 4-15). The species-environmental relationship for axis one explained 100 percent of the explainable variation in the data set, because stocking rate was the only environmental variable included into the analysis (Table 4-16). Axes one and two of the RDA explained 52.1 percent of the total variation in the data set (Table 4-16).

The general trend was that, as stocking rate increased, the basal cover of *Digitaria eriantha* decreased substantially, while the basal cover of *Eragrostis lehmanniana* increaseds substantially. The basal cover of E. *superba*, *E. nindensis* and *Chrysopogon serrulatus* increased to a lesser extent (**Error! Reference source not found.** and **Error! Reference source not found.**).

The length of the arrows for the environmental variables indicated their importance in explaining variation. Axis one was very strongly positively correlated to stocking rate (0.863735), which suggested that stocking rate explains most of the variation in axis one (**Error! Reference source not found.**).

Table 4-15 A summary of the results of the Monte Carlo permutation test for the RDA for species basal cover data for phase three (2000 to present)

Test of significance of first canonical axes
F-ratio= 2.183
P-value= 0.042

Table 4-16 Summary of the RDA for the basal cover of species during phase three (2000 to present)

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.238	0.286	0.217	0.098
Species-environment correlations	0.874			
Cumulative percentage variance				
of species data	23.6	52.1	73.7	83.6
of species-environment relation	100			
Sum of all eigenvalues				1
Sum of all canonical eigenvalues				0.238

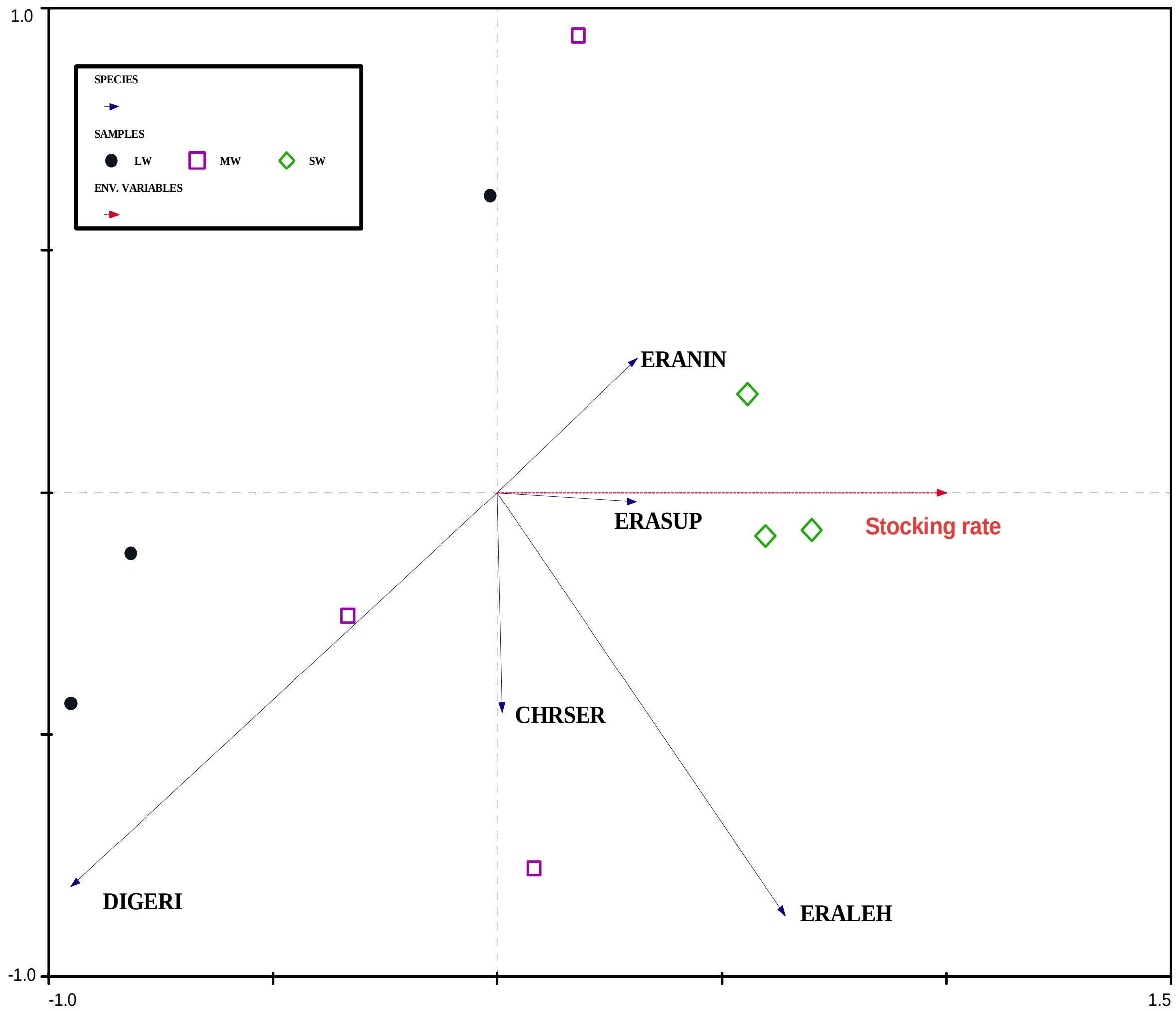


Figure 4-21: Tri-plot of species, sites and environmental variables along the first two axes of a RDA showing the effect of environmental variables on species basal cover from sites, from the grazing trial at the Armoedsvlakte Research Station. Eigenvalues are 0.238 and 0.286 for axes one and two, which represents 23.8 and 52.3 percent of the total variance, respectively. Species with less than 55 percent of their variance explained by the tri-plot are not shown. The only environmental variable is SR=Stocking rate (LSU/ha). Treatments are: LW= Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate, and SW= Rotational grazing at a high stocking rate. Species are: Digeri: *Digitaria eriantha*, Eraleh=*Eragrostis lehmanniana*, Chrser=*Chrysopogon serrulatus*, Erasup=*Eragrostis superba* and Eranin=*Eragrostis nindensis*.

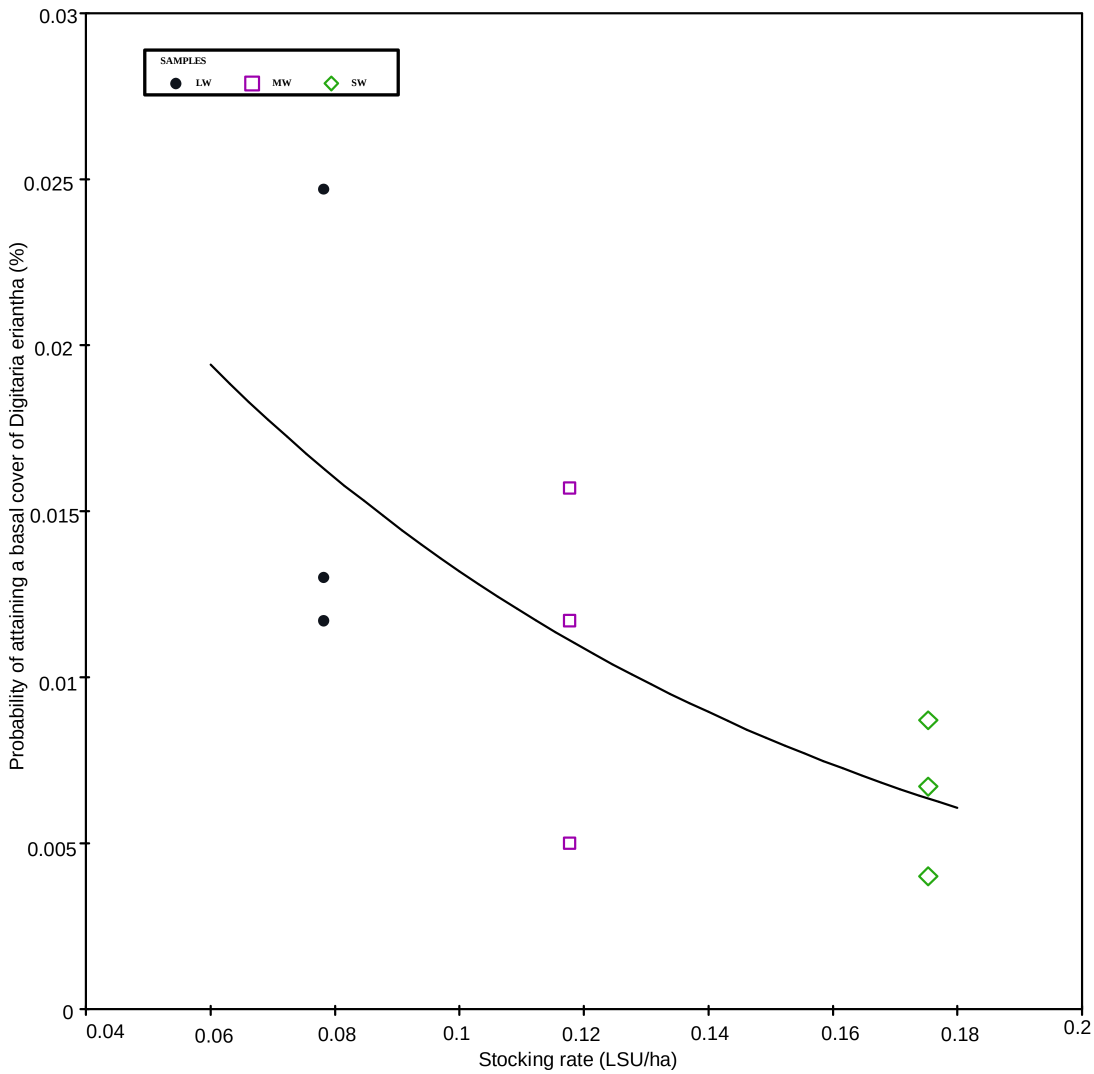


Figure 4-22: GLM illustrating the probability of attaining a basal cover of *Digitaria eriantha* over time across all treatments. The GLM was statistically significant (P=0.03, F-value=7.92). The logistic regression equation was Y=-3.33311-9.81648X, where Y=predicted basal cover of *Digitaria eriantha* (%) and X=Stocking rate (LSU/ha). Treatments are: LW= Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate, and SW= Rotational grazing at a high stocking rate.

4.3.7. Conclusions

4.3.7.1.Phase one (1977-1991)

During phase one the system experienced large variations in basal cover and most of this variation in the basal cover across all treatments could be explained by the interaction of seasonal current and seasonal past rainfall. Most of the changes in basal cover occurred during the multi-year drought in the system and this change in basal cover seems to persist longer in continuously grazed treatments. The main change in the basal cover of species was in that the basal cover of sites were dominated by *Themeda triandra* before the drought and by *Eragrostis lehmanniana* after the drought, although some convergence did occur late in phase one. These results indicated that seasonal rainfall is more important than stocking rate and grazing system in explaining variation in the data set. This indicates that non-equilibrium vegetation dynamics are occurring in the area. These results also suggested that the system can recover from single year droughts, but not from multi-year droughts.

4.3.7.2.Phase two (1992-1999)

High stocking rates resulted in a decrease in total basal cover of sites. The basal cover of highly desirable species like *Digitaria eriantha* decreased, while overstocking increased the basal cover of less-desirable and undesirable species like *Eragrostis pseudo-obtusa* and *Tragus racemosus*. Stocking rate explained more variation in basal cover than seasonal rainfall, but seasonal rainfall explained an additional amount of variation in basal cover. This suggested that there is a continuum of non-equilibrium and equilibrium vegetation dynamics in the system.

4.3.7.3.Phase three (2000 to present)

The application of high stocking rates resulted in a decrease in total basal cover of sites and in a decrease in the basal cover of highly desirable species like *Digitaria eriantha*, while the basal cover of desirable species like *Eragrostis lehmanniana* and *Eragrostis superba* and less-desirable species like *Eragrostis nindensis*, increased. It is important to note that the effect of rainfall could not be investigated, as there was only one sampling period and rainfall is thus not explaining variation in the data set.

4.4. RESIDUAL BIOMASS

4.4.1. Methods and materials

The methods for calculating residual biomass for the different stocking rate treatments at the Armoedsvlakte Research Station have changed over time. The quadrat method was used from 1977 to 1998. From 1999 to present, the Dry Weight Rank (DWR) method was used to calculate biomass production.

4.4.1.1.The quadrat method for calculating biomass production

The residual biomass assessment was performed four times a year between 1977-1981, and twice a year thereafter. A one square meter quadrat was placed along the line transect. The dry matter material within the quadrat was clipped to a height of two centimeters from the ground. Moribund material was removed, since material below this height did not contribute to available biomass production. The grass species were harvested on an individual basis. 30 quadrats were harvested per line during 1981-1992. Species were then grouped into highly desirable, desirable, less desirable and undesirable groups (**Error! Reference source not found.**). In 1993/94, the same method was applied, but the thirty quadrats were pseudo-replicated twice, giving a total of 60 (1993-1996). The reason why these “replications” were termed pseudoreplications was because the first replication and second replication were sampled close together and they thus do not represent true “replications”. In 1997/98, 50 quadrats instead of 30 were harvested in the same way as described above. Samples were weighed on a species basis and oven-dried for two days at 38°C. The total grass biomass production ($kg.ha^{-1}$), individual species biomass production ($kg.ha^{-1}$) and the biomass for each of the ecological groups ($kg.ha^{-1}$) were then calculated. In 1999, the method of calculating biomass production, changed from the quadrat method to the DWR method.

4.4.1.2.The Dry Weight Rank (DWR) method

The DWR method was mainly developed to eliminate the need for clipping a large amount of grass and to sort the vegetation to determine the relative contributions of species to total biomass production, on a dry weight basis (Dowhover *et al.* 2001). The DWR method involves the following (adapted from Barnes *et al.* 1982):

1. Quadrats are placed in a homogenous area to be surveyed and this requires that the sample should be representative of the area to be sampled. It is important to consider quadrat size and each quadrat should include at least three species in the majority of the quadrats, but the quadrat should still be small enough to enable the operator to allocate ranks quickly and accurately (Kirkman *et al.* 1994, Kirkman 1999). The number of quadrats required is linked to the level of accuracy desired (Kirkman *et al.* 1994, Kirkman 1999).
2. Each of the quadrat sampled requires the operator to allocate which species contribute the most, second most and least amount to dry weight production (Kirkman *et al.* 1994 and Kirkman 1999).
3. A rank of one is allocated to the species that contributes the most to dry weight production, a rank of two is allocated to the species that contributes the second most to dry weight production and a rank of three is allocated to the species that contributes the least to dry weight production (Kirkman 1999). This process is known as normal ranking.
4. If only one species is present in the quadrat, all three ranks are allocated to this species and this is called cumulative ranking (Kirkman *et al.* 1994, Kirkman 1999). Cumulative ranking is used where there are less than three species in a quadrat. (described by Jones and Hargreaves 1979).
5. If only two species are present in a quadrat, a rank of one and two are allocated to the clearly dominant species and a rank of three to the other species. This is also an example of cumulative ranking (Kirkman *et al.* 1994, Kirkman 1999).
6. Another example of cumulative ranking is where only two species are present in a quadrat, but the dominant species is only slightly more than the other species than a rank of one is given to the dominant species and a rank of two and three to the other species (Kirkman *et al.* 1994, Kirkman 1999).

7. If two species appear to contribute equal amounts to dry weight production then the relevant rank is allocated equally to the species concerned and this is called shared ranking (Barnes *et al.* 1992). This allows for more than three species to be included in a quadrat (Kirkman 1999). If a rank of one was allocated to the two dominant species, a rank of two and three are allocated to the next two dominant species (Kirkman 1999). The data are recorded on the data sheet as follows: species A and species B are both allocated a rank of one, species C is allocated a rank of two and species D is a rank of three. It is suggested by Kirkman (1999), that shared ranks should be circled on the data sheet for ease of entering them into the spreadsheet (discussed in Chapter 4.4.1.4).

8. It is suggested that non-grasses like forbs, sedges and weeds should be grouped together (Kirkman *et al.* 1994, Kirkman 1999).

The precision of the DWR method can be increased by weighting the ranks for each of the quadrats sampled on the basis of the dry matter production, before the summation by ranks (Jones and Hargreaves 1979, Kelly and McNeil 1980, Barnes *et al.* 1982, Dowhover *et al.* 2001). A non-destructive method of estimating biomass production for each of the quadrats used in the DWR analysis is thus required (Kirkman *et al.* 1994, Kirkman 1999). Several non-destructive techniques for estimating dry matter yield have proposed, of which the disc meter is probably the most well known in South Africa (Kirkman *et al.* 1994, Kirkman 1999). The disc meter may not give accurate results on veld that has been grazed selectively or on veld that is short, particularly where this occurs on stony or uneven ground (Kirkman *et al.* 1994, Kirkman 1999). The comparative yield method that was proposed by Haydock and Shaw (1975) cited by Kirkman *et al.* (1994) and Kirkman (1999) and the double sampling technique that was proposed by Reich *et al.* (1993) are non-destructive methods of estimating biomass production. The double sampling technique appears to be the most suitable in providing a rapid means of estimating the biomass production of each quadrat used in the dry weight rank analysis (Kirkman *et al.* 1994, Kirkman 1999). This method requires the yield of each quadrat to be estimated, while simultaneously allocating ranks to each of the species within the quadrat (Kirkman *et al.* 1994, Kirkman 1999). The double sampling technique estimates the biomass of grass in a series of quadrats by visual estimation on a suitable scale (Kirkman *et al.* 1994, Kirkman 1999). A proportion of the quadrats need to be clipped and weighted and a linear regression can then established between the biomass estimates and the corresponding actual dry mass of the grass in the harvested quadrats (Kirkman *et al.* 1994, Kirkman 1999). It is important to note that the calibration is specific to each operator and that it is necessary to re-calibrate on each sampling occasion (Kirkman *et al.* 1994, Kirkman 1999).

At the Armoedsvlakte Research Station the following steps were used in applying the DWR technique:

The volumes of grasses within quadrats were subjectively estimated to have varying degrees of biomasses and are accordingly ranked on a scale from 1-5 (low to high biomass) and three replicates of a five, four, three, two and one are cut. This material is weighed before being dried for two days at 38°C. Senesced material is removed from the tuft before it is clipped, as this material does not contribute to available dry matter, as cattle will very rarely utilize this material. The grass is harvested to a height of two centimeters from the soil, to accommodate the grazing height of cattle. Reich *et al.* (1993) recommend that fresh weight should be used instead of dry weights due to the similarities in their weight distribution. These authors recommend that if need be, the fresh weights could be converted to dry weights. The sampling then proceeds as follows along the transect:

1. A nested quadrat is placed along the transect and a production value is given to each of the four sub-quadrats within the quadrat (Figure 4-23).

2. The three most prominent species, in terms of their contribution to dry matter production, in each of the sub-quadrats are identified. A value of one is given to the species, which contributes the most to biomass production and a value of three to the species, which contributes the least. A value of one, two and three is given to a single species if it is the only species contributing to dry matter production for the sub-quadrat. The production value can also be shared between two or more species. For example, species A and species B can contribute equally to dry matter production within a sub-quadrat and both species are thus awarded a one, two and three.

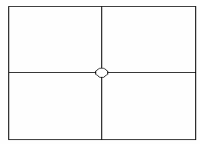


Figure 4-23 The quadrat used during the Dry-Weight Rank (DWR) sampling method at the Armoedsvlakte Research Station.

4.4.1.3.DWR data processing

4.4.1.3.1. Normal ranking

Ranks one, two and three are allocated to the three dominant species in terms of their contribution to dry matter yield. The three species are then allocated the ranks of one, two and three on the data entry sheet and on the spreadsheet (Kirkman unpublished).

4.4.1.3.2. Cumulative ranking (suggested by Jones and Hargreaves 1979)

This is used where the quadrat has less than three species. In this case, more than one rank is allocated to a species. For example, species A is allocated a rank of one, two and three. This is entered into the spreadsheet as 123. Another example of cumulative ranking is where species A is allocated a rank of one and two, with species B being allocated a rank of three. This is entered as 12 for species A and 3 for species B on the spreadsheet (Kirkman unpublished).

4.4.1.3.3. Shared ranking (suggested by Barnes et al. *1982)*

Shared ranks are used when two or more species contribute equally to the dry matter within the quadrat. Each of the two species is then allocated their ranks equally. This type of ranking allows for more than three species to be included in a particular quadrat (Kirkman unpublished). If there was a quadrat with four species within it and the two dominant species contributed equally to dry matter production and the other two species where the next dominant species, then the ranks will be allocated in the following way (Kirkman unpublished). Species A and species B will both receive a rank of one, species

C will get a rank of two and species D will get a rank of three (Kirkman unpublished). It is convenient to circle the shared ranks on the data sheet, which makes the process of data capturing faster and easier. Kirkman (unpublished) reports that the shared ranks are differentiated in the spreadsheet by adding 0.5. In the above-mentioned example, the rank for species A and B will be 1.5, species C will be two and species D will be three (Kirkman unpublished).

4.4.1.4. Explanation of spreadsheet that is used to calculate total residual biomass and individual species residual biomass (Kirkman unpublished)

The estimated value of the dry weight production of each quadrat is entered on the right hand side of the spreadsheet for each of the quadrats sampled. Kirkman (unpublished) reports that the spreadsheet has been configured for a linear regression equation in the form Y=a+bX, where Y=residual biomass ($kg.ha^{-1}$), X=rank of production and a and b=regression coefficients. The regression coefficients (a and b) are entered at the top of the spreadsheet, along with the amount of quadrats sampled and the size of the quadrats used. The model can however be adjusted to accommodate quadratic regressions in the form of $Y=ae^{bx}$, where Y=residual biomass ($kg.ha^{-1}$), x=rank of production, a and b=regression coefficients and e=natural log.

The details of the site sampled and the data collected is entered in the yellow shaded areas of the spreadsheet, as the rest of the spreadsheet has been protected to maintain the integrity of the calculations. However, the formulas are visible for the user and for others that want to examine them (Kirkman unpublished).

The results from the DWR method can be seen at the bottom of the data sheet (Kirkman unpublished). The program gives the user a total biomass production and the amounts that individual species contribute to total biomass as a value and as a percentage of total biomass.

Kirkman (unpublished) reports that an integrity test has been included on the right hand side of the spreadsheet. If the data for each quadrat has been entered correctly then there should be a three in the "DO" column and an one in each of the next three columns, corresponding to the ranks of one, two and three from each quadrat. Kirkman (unpublished) reports that if a mistake has been made, then the user can track the error easily and it can be corrected.

4.4.1.5.Advantages and disadvantages of the Dry Weight Rank (DWR) method

Friedel *et al.* (1988) showed from their studies that the comparative yield method (alternative method for non-destructive determination of biomass) shows large differences in biomass production between operators and the procedure of standard selection and calibration is slow. The DWR technique resulted in constant biomass and species composition estimation, but initial training is still required. t'Mannetjie and Haydock (1963) reported that if ranking was done correctly, that the dry weight rank method provided an accurate estimation of species composition by weight and that great levels of accuracy can be achieved, where observers encountered a restricted group of species. Dowhover *et al.* (2001) found that the DWR was preferred to visual quadrat estimation because ranking was easier, quicker and less likely to be biased between evaluators.

Sandland *et al.* (1982) criticized the DWR method, as it relies on a pre-determined set of multipliers to pastures and/or veld of different homogeneity and spatial distribution. Gillen and Smith (1986) also criticized the DWR method as it over-estimates the abundances of abundant species, while under-estimating less abundant species.

4.4.2. Statistical analysis for phase one (1977-1991)

Residual biomass data were analysed, using ordination techniques with Canoco 4.5 (Ter Braak and Smilauer 2003). A PCA was performed to identify and remove any clear outliers in the data set. Following this, a DCA was carried out to determine the lengths of gradient (e.g. species turnover or diversity in the data set). These lengths of gradients were less than one SD, which suggested that the species turnover was very small. Linear models like PCA and/or RDA were thus the most appropriate techniques to use to analyse the data. A partial RDA was chosen to constrain the axes with environmental variables (i.e. stocking rate, type of grazing system applied and seasonal rainfall) and to remove the spatial and temporal autocorrelation. Following this, manual forward selection of environmental variables and interactions were performed to test the significance of environmental variables and interactions between them. Only rotational grazing interactions were permutated, because continuous grazing interactions were the exact opposite (i.e. grazing system environmental variables are nominal variables) and it would have been unneccessary to analyse both. Non-significant environmental variables and interactions ($P>0.1$) were excluded from the analysis. The interaction between current seasonal rainfall and past seasonal rainfall were not tested as this interaction resulted in large inflation factors.

Two types of Euclidean distances were calculated using PRIMER 4.5 and these were the change in residual biomass from beginning of the trial and the change in residual biomass from year to year (**Error! Reference source not found.**, **Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**). The Euclidean distances for the rotationally grazed sites and continuously grazed sites were shown on different graphs and it should be noted that an average across the six paddocks for the rotationally grazed sites were taken to make comparisons between grazing systems, easier (**Error! Reference source not found.**, **Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**).

4.4.3. Statistical analysis for phase two (1992-1999)

There were no residual species biomass data available for phase two and only the residual biomass data for the ecological groups were analysed (**Error! Reference source not found.**). Residual biomass data from 1992 to 1999 were analysed using ordination techniques with Canoco 4.5 (Ter Braak and Smilauer 2003). A PCA was performed to identify and remove any clear outliers in the data set. Following this, a DCA was carried out to determine the lengths of gradients (e.g. species turnover or diversity in the data set). These lengths of gradients were less than 1.5 SD, which suggested that the species turnover was small. Linear models like PCA and/or RDA were thus the most appropriate techniques to use to analyse the data. A partial RDA was chosen to constrain the axes with environmental variables (e.g. stocking rate and seasonal rainfall) and to remove the spatial and temporal autocorrelation. Following this, manual forward selection of environmental variables and interactions were performed to test the significance of environmental variables and interactions between them. Non-significant environmental variables and interactions ($P>0.1$) were excluded from the analysis. It is important to note that continuously grazed treatments were discontinued at the start of phase two and the variation in the data set due to grazing system could not be analysed because of this.

4.4.4. Statistical analysis for phase three (2000 to present)

Both residual biomass data for the ecological groups and residual species biomass data were analysed with Canoco 4.5 from 2000 to 2004 (Ter Braak and Smilauer 2003).

4.4.4.1.Residual biomass for the ecological groups

A PCA was performed to identify and remove any outliers in the data set. Following this, a DCA was carried out to determine the lengths of gradient (e.g. species turnover or diversity in the data set). These lengths of gradients were less than 1.5 SD, which suggested that the species turnover was small. Linear models like PCA and/or RDA would thus be the most appropriate techniques to use to analyse the data. A partial RDA was chosen to constrain the axes with environmental variables (stocking rate and seasonal rainfall) and to remove spatial and temporal autocorrelation. Following this, manual forward selection of environmental variables and interactions were performed to test the significance of environmental variables and interactions between them. Non-significant environmental variables and interactions ($P>0.1$) were excluded from the analysis. It is important to note that continuously grazed treatments were discontinued at the start of phase two and the variation in the data set due to grazing system could not be analysed because of this.

4.4.4.2. Residual biomass for species

A PCA was performed to identify and remove any outliers in the data set. Following this, a DCA was carried out to determine the lengths of gradient (e.g. species turnover or diversity in the data set). These lengths of gradients were less than two SD, which suggested that the species turnover was small. Linear model like PCA and/or RDA would thus be the most appropriate techniques to use to analyse the data. A partial RDA was chosen to constrain the axes with environmental variables (i.e. stocking rate and seasonal rainfall) and to remove spatial and temporal autocorrelation. Following this, manual forward selection of environmental variables and interactions were performed to test the significance of environmental variables and interactions between them. Non-significant environmental variables and interactions (P>0.1) were excluded from the analysis. It is important to note that continuously grazed treatments were discontinued at the start of phase two and the variation in the data set due to grazing system could not be analysed because of this.

4.4.5. Results and discussion

4.4.5.1. Phase one (1977-1991)

There was no residual species biomass data available for phase one of the grazing trials at the Armoedsvlakte Research Station. The residual biomass data for the four ecological groups from 1977 to 1980 was only measured once during the year, while the data after this (1981 to 1991) was measured up to five times annually. Only the results of residual biomass analysis of the ecological groups from 1981 to 1991 will be discussed in this section.

The results of the Monte Carlo permutation test show that there is a statistically significant effect (P=0.002) of the environmental variables and the interactions of these variables on the first and all of the canonical axes (Table 4-17). The environmental variables that had a significant effect on the residual biomass of the ecological groups were time, seasonal past rainfall and seasonal current rainfall, while significant interactions included stocking rate by time, stocking rate by seasonal past rainfall, stocking rate by seasonal current rainfall and grazing system by seasonal past rainfall (Table 4-18). The species-environmental relationship for axes one and two explains 98.8 percent of the explainable variation in the data set, which showed that the variation in the data set were well explained by the measured environmental variables (Table 4-19). Axes one and two of the partial RDA explained 40.4 percent of the total variation in the data set (Table 4-19).

The main trend in the residual biomass of sites was that the residual biomass of sites over time has changed from being dominated by the highly desirable ecological group to a sward dominated by the desirable ecological group (**Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**). A possible reason for the above was that species in the desirable ecological group respond differently than species in highly desirable group when considering seasonal past and seasonal current rainfall. The desirable group has a positive association with both seasonal current and seasonal past rainfall, while the highly desirable ecological group has a positive association with seasonal past rainfall and a negative association with seasonal current rainfall. From **Error! Reference source not found.**, it can be concluded that between 1981 and 1986, the highly desirable ecological group residual biomass decreased dramatically and this trend was only broken by three above mean seasonal rainfall years (**Error! Reference source not found.**). The desirable ecological group residual biomass followed a completely different trend in that the residual biomass of all treatments is continuously increasing over time (**Error! Reference source not found.**).

Both continuously and rotationally grazed sites had a high residual biomass of the desirable ecological group, but the rotationally grazed sites had a higher residual biomass of the highly desirable group, compared to the continuously grazed sites (i.e. application of the distance rule). Continuously grazed sites have a much higher residual biomass of the undesirable ecological group (**Error! Reference source not found.**). This suggested that the residual biomass of rotationally grazed sites was one of higher palatability because its biomass had a relatively higher abundance of species like *Themeda triandra* (i.e. high digestibility, low cell wall component, high cell contents and high palatability), while the residual biomass of the continuously grazed had a relatively higher abundance of undesirable species like *Aristida congesta* (i.e. low digestibility, high cell wall content, low cell content and low palatability). The significant interactions of rotational grazing system by seasonal past rainfall and continuous grazing system by seasonal past rainfall indicated that the effect of grazing system is dependent of seasonal past rainfall. One of the benefits of having a rotational grazing system is that in high rainfall years, excess grazeable material is retained and this material can then be utilised in low rainfall years. Similarly, the effects of stocking rate are dependent on seasonal past rainfall, seasonal current rainfall and time.

The Euclidean distance for the rotationally grazed sites indicated no drastic change in residual biomass of ecological groups from 1980 to 1986 when compared to 1977, except for the light stocking rate treatment, which diverged from the original residual biomass. There was however a large change in the residual biomass of all treatments in the period 1987-1989 (all treatments illustrate divergence) and this might have been due to three years of above mean seasonal rainfall (**Error! Reference source not found.** and **Error! Reference source not found.**). This was followed by the convergence of all treatments because of a very low seasonal rainfall (e.g. 192mm) during 1990.

The Euclidean distance for the continuously grazed sites indicated no drastic changes in the residual biomass of ecological groups across all treatments, except for the light stocking rate treatment, which illustrated divergence from the original residual biomass (**Error! Reference source not found.**). The largest change in the residual biomass in the continuously grazed sites from year to year occurred during 1983 (**Error! Reference source not found.**). The exact reason for this was unknown (as the seasonal rainfall was relatively lower, when compared to other years during this phase). The animals mass and stocking rate for 1983 could thus not be calculated, as they were not recorded. The stocking rate for 1983 might have been lower and this is a possible explanation for this increase in residual biomass of sites.

The length of the arrows for the environmental variables and the interactions between them indicates their importance in explaining variation in the data set. Time was negatively correlated with axis one (-0.6473) and this suggested that time explained most of the variation along axis one.

These results indicated that seasonal rainfall, type of grazing system applied and stocking rate explain the variation in the residual biomass of treatments over time, indicating that the system is experiencing a continuum of non-equilibrium and equilibrium vegetation dynamics.

Table 4-17 A summary of the results of the Monte Carlo permutation test for the partial RDA for residual ecological groups biomass data during phase one (1981-1991)

Test of significance of first canonical axis

F-ratio = 129.191

P-value = 0.002

Test of significance of all canonical axes

F-ratio = 20.814

P-value = 0.002

Table 4-18 Significance of environmental variables and the interactions between on the residual ecological groups biomass of sites for the period 1981-1991

Environmental variable/interaction	P-Value	Significance
Time	0.002	Highly significant
SP	0.002	Highly significant
SC	0.034	Significant
Time*SP	0.986	Non-significant
Time*SC	0.236	Non-significant
Rot*time	0.602	Non-significant
Rot*SP	0.022	Significant
Rot*SC	0.54	Non-significant

SR*time	0.006	Highly significant
SR*SP	0.066	Significant
SR*SC	0.072	Significant

Table 4-19 Summary of the partial RDA for residual ecological group's biomass data from 1981 to 1990 with only significant environmental variables and interactions included

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.278	0.017	0.004	0.352
Species-environment correlations	0.7	0.389	0.268	
Cumulative percentage variance				
of species data	38	40.4	40.8	88.8
of species-environment relation	93	98.8	100	
Sum of all eigenvalues				0.733
Sum of all canonical eigenvalues				0.299

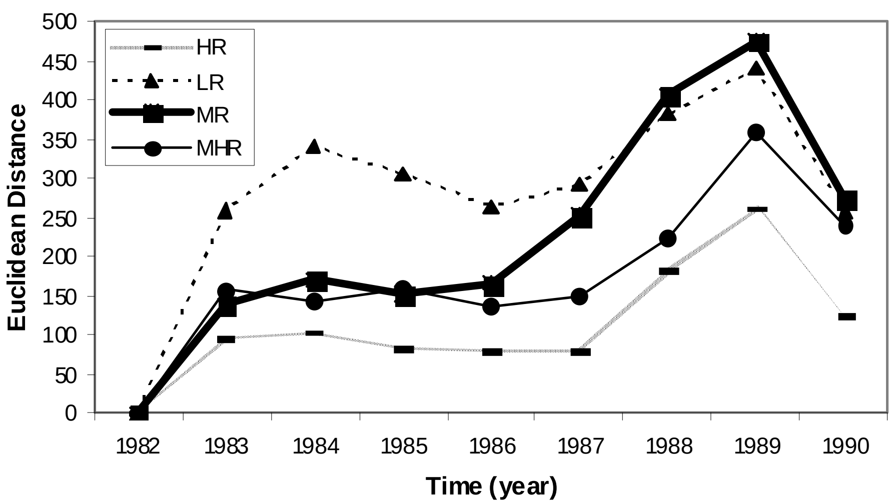


Figure 4-24: Euclidean distance for the rotationally grazed sites illustrating change in residual biomass (kg.ha^{-1}) from 1981. Treatments are: HR=Rotational grazing at a high

stocking rate, LR= Rotational grazing at a low stocking rate, MR= Rotational grazing at a medium stocking rate and MHR= Rotational grazing at a medium-heavy stocking rate.

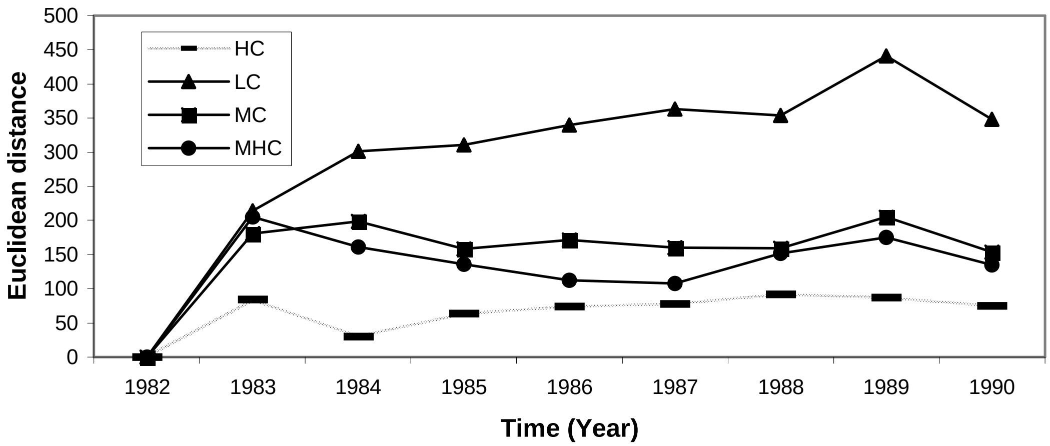


Figure 4-25: Euclidean distances for the continuously grazed sites illustrating change in residual biomass ($kg.ha^{-1}$) from 1981. Treatments are: HC=Continuous grazing at a high stocking rate, LC= Continuous grazing at a low stocking rate, MC= Continuous grazing at a medium stocking rate and MHC= Continuous grazing at a medium-heavy stocking rate.

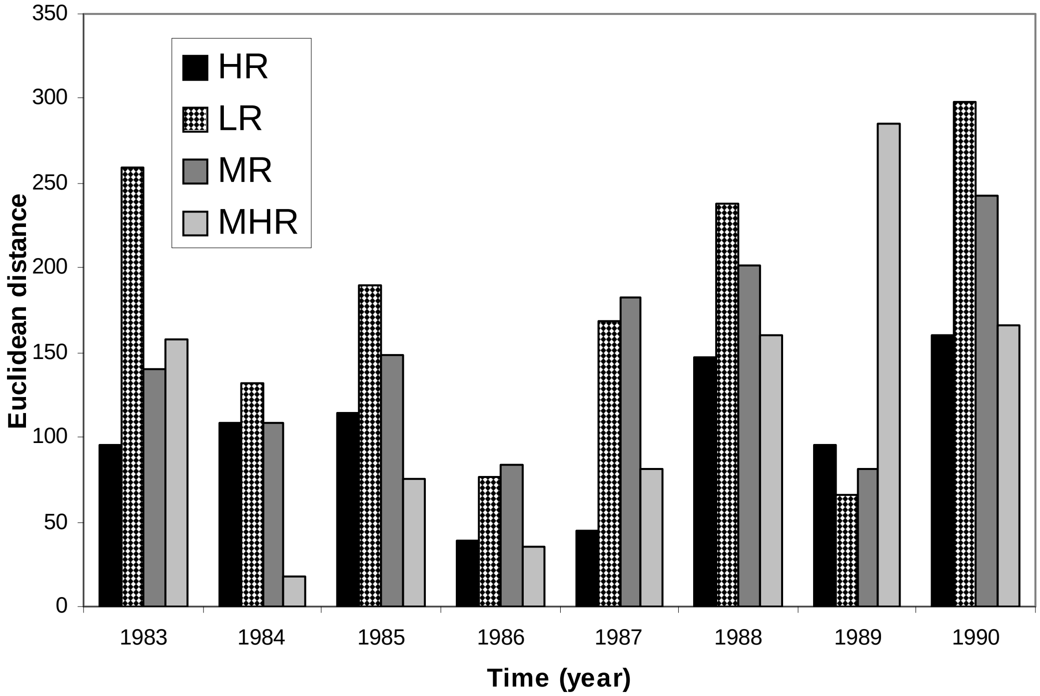


Figure 4-26: Euclidean distance for the rotationally grazed sites illustrating change in residual biomass ($kg.ha^{-1}$) from year to year. Treatments are: HR=Rotational grazing at a high stocking rate, LR= Rotational grazing at a low stocking rate, MR= Rotational grazing at a medium stocking rate and MHR= Rotational grazing at a medium-heavy stocking rate.

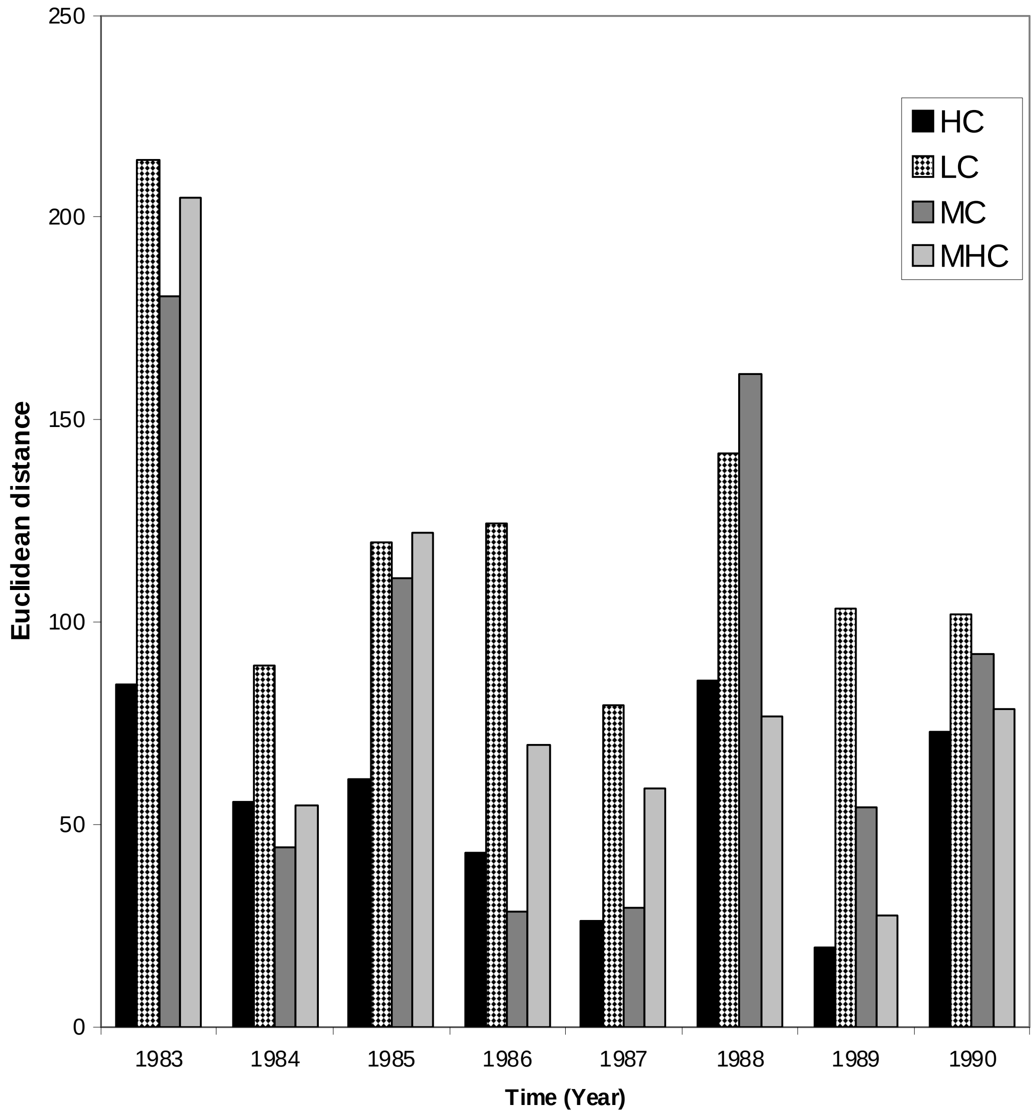


Figure 4-27: Euclidean distances for the continuously grazed sites illustrating change in residual biomass ($kg.ha^{-1}$) from year to year. Treatments are: HC=Continuous grazing at a high stocking rate, LC= Continuous grazing at a low stocking rate, MC= Continuous grazing at a medium stocking rate and MHC= Continuous grazing at a medium-heavy stocking rate.

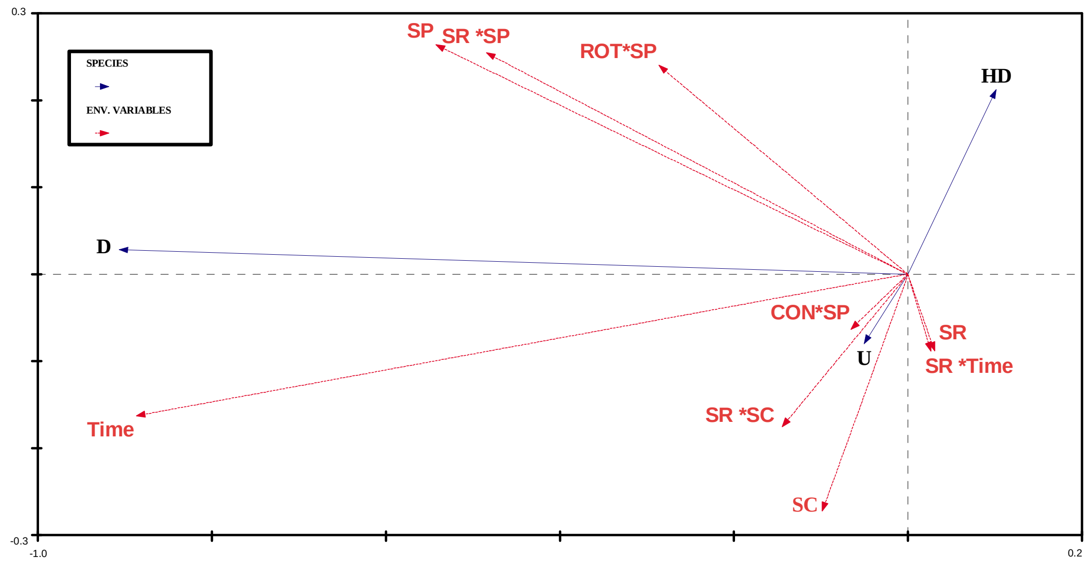


Figure 4-28: Bi-plot of the environmental variables and ecological groups along the first two axes of a partial RDA illustrating the residual biomass (kg.ha^{-1}) for different treatments. Eigenvalues are 0.278 and 0.017 for axes one and two, which represents 38 and 40.4 percent of the total variance, respectively. The environmental variables are: SP=Seasonal past rainfall (mm), SC=Seasonal current rainfall (mm), SR=Stocking rate (LSU/ha), Time=Time (Year), Rot=Rotational grazing system and Cont=Continuous grazing system. The ecological groups are D=Desirable, HD=Highly desirable and U=Undesirable.

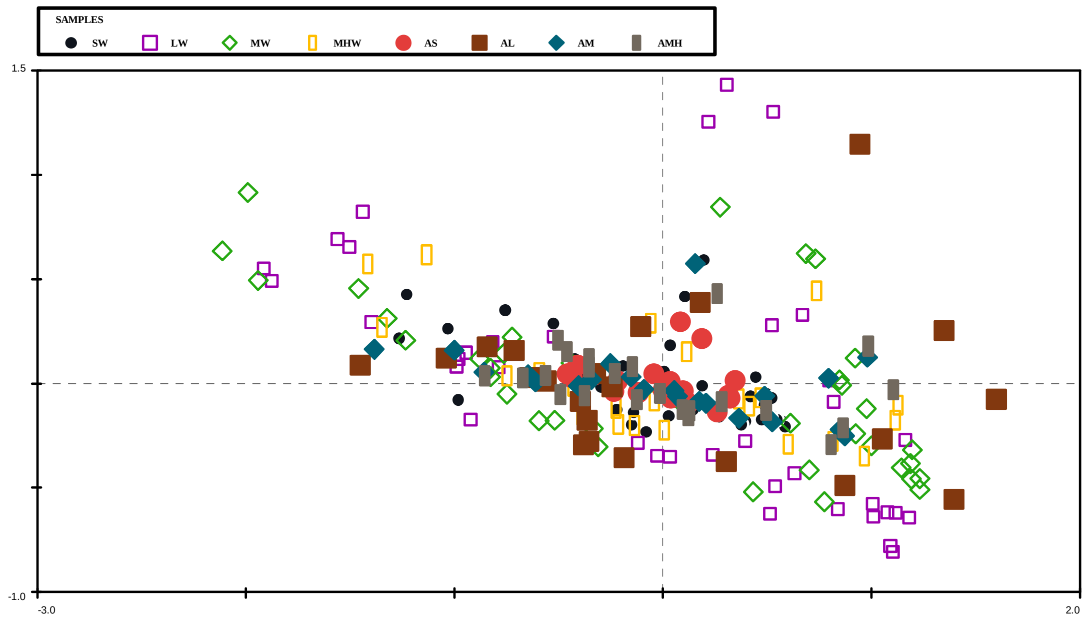


Figure 4-29: Scatter plot of residual biomass ($kg.ha^{-1}$) for sites along the first two axes of a partial RDA from the grazing trial at the Armoedsvlakte Research Station. Eigenvalues are 0.278 and 0.017 for axes one and two, which represents 38 and 40.4 percent of the total variance, respectively. Treatments are: LW= Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate, MHW= Rotational grazing at a medium-heavy stocking rate, SW= Rotational grazing at a high stocking rate, AL= Continuous grazing at a low stocking rate, AM= Continuous grazing at a medium stocking rate, AMH= Continuous grazing at a medium-heavy stocking rate and AH= Continuous grazing at a high stocking rate.

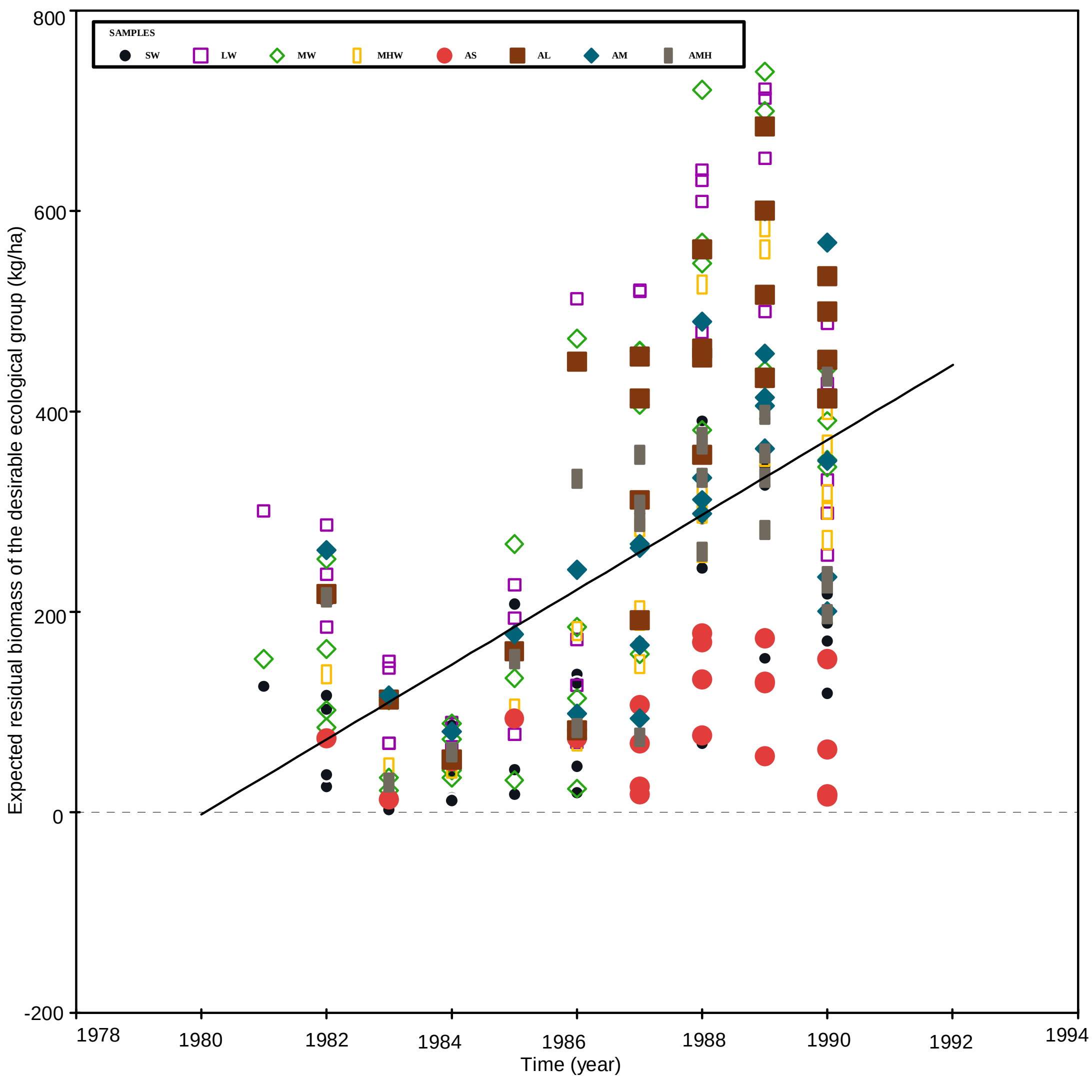


Figure 4-30: Generalized Linear Model (GLM) illustrating residual biomass ($kg.ha^{-1}$) for the desirable ecological group for all treatments over time. The linear regression was statistically significant ($F=89.25$ and $P<0.001$) and $Y=-73976.5+37.361X$, where Y=Expected residual biomass for the desirable ecological group ($kg.ha^{-1}$) and X=Time (year). LW= Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate, MHW= Rotational grazing at a medium-heavy stocking rate, SW= Rotational grazing at a high stocking rate, AL= Continuous grazing at a low stocking rate, AM= Continuous grazing at a medium stocking rate, AMH= Continuous grazing at a medium-heavy stocking rate and AH= Continuous grazing at a high stocking rate.

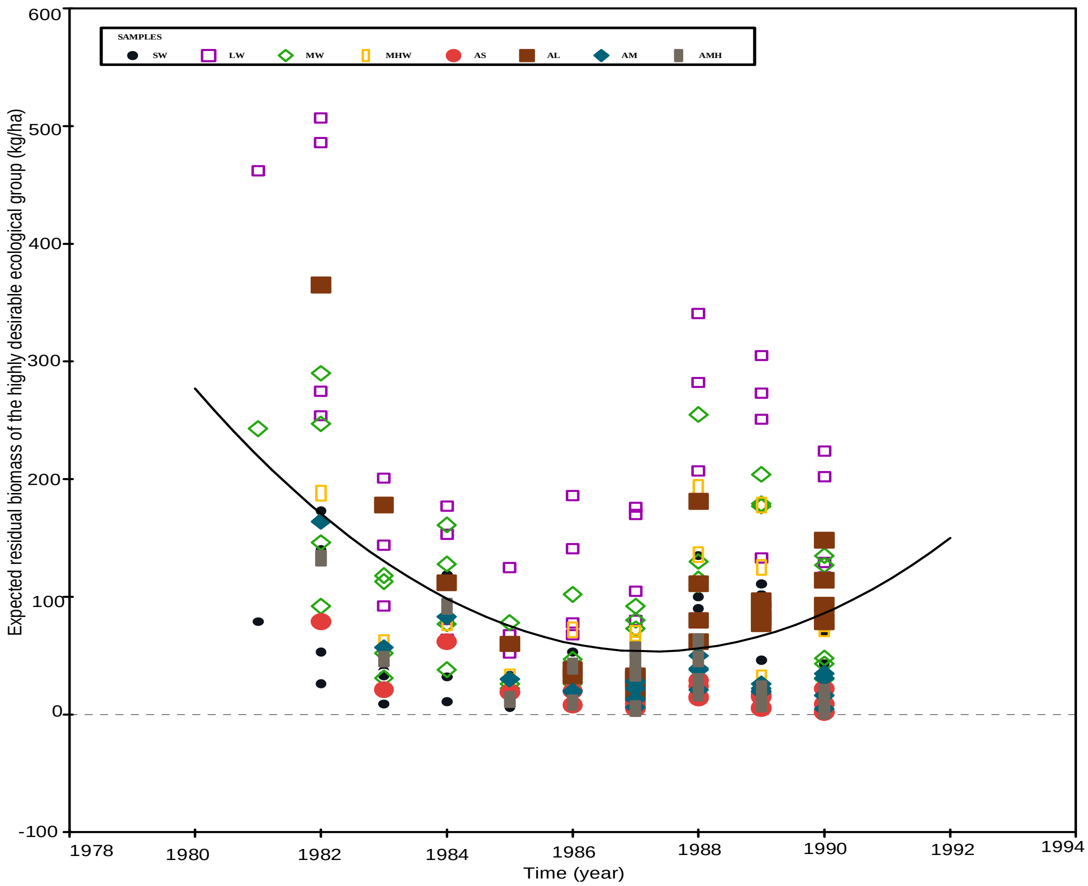


Figure 4-31: Generalized Linear Model (GLM) illustrating residual biomass (kg.ha^{-1}) for the highly desirable ecological group for all treatments over time. The logistic regression was highly statistically significant (F=24.29 and P<0.001) and $Y=16.82*10^{-9}-16.92*10^{3}X+4.258X^{2}$, where Y=Expected residual biomass for the highly desirable ecological group (kg.ha^{-1}) and X=Time (year). Treatments are: LW= Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate, MHW= Rotational grazing at a medium-heavy stocking rate, SW= Rotational grazing at a high stocking rate, AL= Continuous grazing at a low stocking rate, AM= Continuous grazing at a medium stocking rate, AMH= Continuous grazing at a medium-heavy stocking rate and AH= Continuous grazing at a high stocking rate.

4.4.5.2. Phase two (1992-1999)

The results of the Monte Carlo permutation test indicated that there was a statistically significant effect (P=0.002) of the remaining environmental variables and the interactions of these variables on the first and all of the canonical axes (Table 4-20). The environmental variables that had a significant effect on the residual biomass of the ecological groups are time, seasonal past rainfall and seasonal current rainfall, while significant interactions were the stocking rate by time and stocking rate by seasonal past rainfall interactions (Table 4-21) The species-environmental relationship for axes one and two explained 96 percent of the explainable variation in the data set, which showed that the variation in the data set are well explained by the measured environmental variables (Table 4-22). Axes one and two of the partial RDA explained 27.7 percent of the total variation in the residual biomass data set (Table 4-22).

There has been a large increase in total residual biomass of treatments (sum of residual biomass of all three ecological groups) over time (**Error! Reference source not found.**). The ecological group that changed the most in terms of its residual biomass was the highly desirable group, whose residual biomass has increased over time (**Error! Reference source not found.**). The desirable and undesirable ecological groups residual biomass also increased, but to a lesser extent.

Stocking rate had a negative association with total residual biomass and the residual biomass of all three ecological groups. For example, an increase in stocking rates resulted in a large decrease in the residual biomass of the highly desirable ecological group, a smaller but still relatively large decrease in the desirable ecological group residual biomass and a small decrease in the residual biomass of the undesirable ecological group. These results were partially against expectation, because although high stocking rates resulted in a decrease in residual biomass of highly desirable and desirable ecological groups, a concomitant increase in the residual biomass of undesirable group were expected. The significant interactions of stocking rate by time and stocking rate by seasonal past rainfall indicated that the effect of stocking rate was dependent on time and seasonal past rainfall.

An increase in seasonal current rainfall, resulted in a surprising decrease in total residual biomass (**Error! Reference source not found.**), probably due to the different reactions of the three ecological groups to seasonal current rainfall. The highly desirable ecological group indicated large increases in their residual biomass in response to higher current seasonal rainfall, while the desirable ecological group showed a relatively large decrease in residual biomass. The undesirable ecological group showed no effect of seasonal current rainfall on residual biomass (i.e. orthogonal). High seasonal past rainfall, however, resulted in different residual biomass patterns, as there was an increase in the total residual biomass and an increase in all three ecological groups with increasing seasonal past rainfall (**Error! Reference source not found.**).

The length of the arrows in **Error! Reference source not found.** for the environmental variables and the interactions between them indicated their importance in explaining variation. Axis one was weakly negatively correlated to stocking rate (-0.4631) and to the interaction between stocking rate and time (-0.4626), which suggested that stocking rate explains most of the variation in axis one. Seasonal current rainfall had a very weak negatively correlation (-0.3154) with axis two, which indicated that seasonal current rainfall explained most of the variation in axis two.

These results indicated that stocking rate is more important in explaining variation in residual biomass, although seasonal current rainfall explained an additional amount of variation in the data set. These results thus suggested that there is continuum of non-equilibrium and equilibrium vegetation dynamics in the system.

Table 4-20 A summary of the results of the Monte Carlo permutation test for the partial RDA for residual ecological groups biomass data during phase two (1992-1999)

Test of significance of first canonical axis

F-ratio = 56.927

P-value = 0.002

Test of significance of all canonical axes

F-ratio = 15.389

P-value = 0.002

Table 4-21 Significance of environmental variables and the interactions between on the residual ecological groups biomass data of sites for the phase two (1992-1999)

Environmental variables/interactions	**P-value**	**Significance**
Time	0.002	Highly significant
SP	0.002	Highly significant
SC	0.002	Highly significant
Time*SP	0.470	Non-significant
Time*SC	0.526	Non-significant
SR*Time	0.002	Highly significant
SR*SP	0.070	Significant
SR*SC	0.418	Non-significant

Table 4-22 Summary of the partial RDA for residual ecological groups biomass data from 1992-1999 with only significant environmental variables and interactions included

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.23	0.05	0.01	0.38
Species-environment correlations	0.63	0.39	0.32	
Cumulative percentage variance				
of species data	23.1	27.7	28.8	66.8
of species-environment relation	80	96	100	

Sum of all eigenvalues				1
Sum of all canonical eigenvalues				0.29

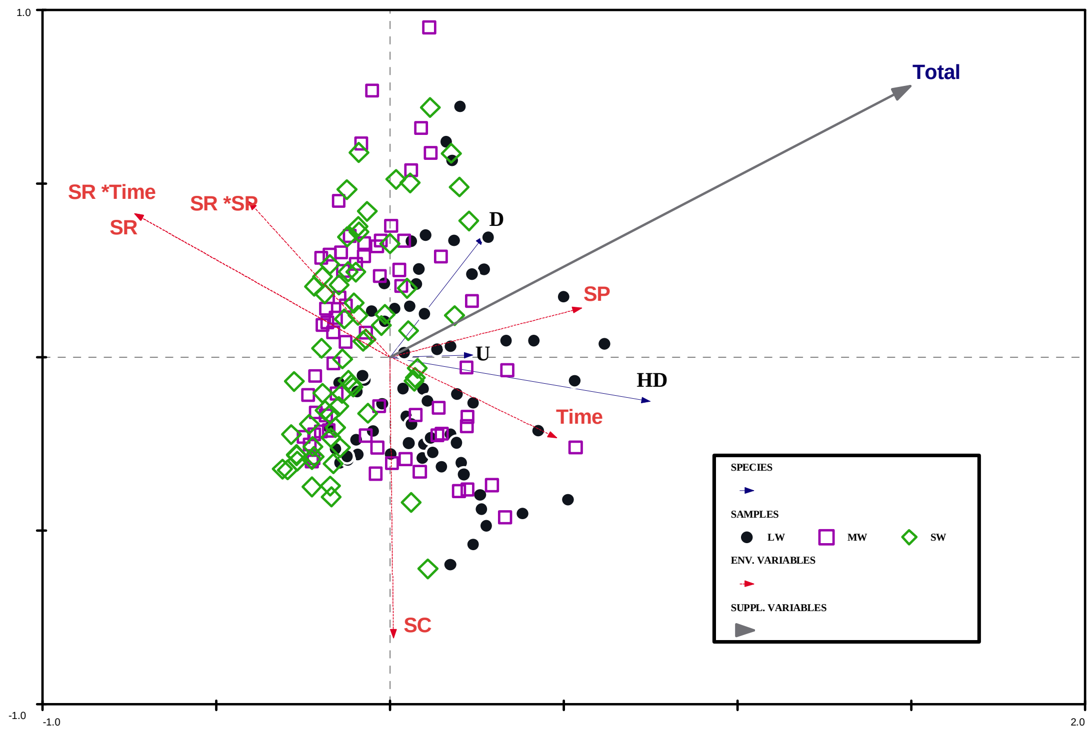


Figure 4-32: Tri-plot of residual biomass (kg.ha^{-1}) for ecological groups, environmental variables, supplementary environmental variables and sites along the first two axes of a partial RDA from the grazing trial at the Armoedsvlakte Research Station. Eigenvalues are 0.231 and 0.046 for axes one and two, which represents 23.1 and 27.7 of the total variance, respectively. Treatments are LW= Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate and SW= Rotational grazing at a high stocking rate. The environmental variables are: SP=Seasonal past rainfall (mm), SC=Seasonal current rainfall (mm) and SR=Stocking rate (LSU/ha). The ecological groups are: HD=highly desirable ecological group, D= Desirable ecological group and U=Undesirable ecological group. The only supplementary environmental variable is Total=total residual biomass (kg.ha^{-1}).

4.4.5.3. Phase three (2000 to present residual biomass for ecological groups)

The results of the Monte Carlo permutation test indicated that there is a highly statistically significant effect (P=0.002) of environmental variables and the interactions between them on residual biomass of the ecological groups for the first canonical and all of the canonical axes (Table 4-23). The only environmental variable that had a significant effect on the residual biomass of species was stocking rate, while significant interactions included the stocking rate by time and stocking rate by seasonal current rainfall (Table 4-24). The species-environmental relationship for axis one and axis two explained 99.2 percent of the explainable variation in the data set, which illustrated that the environmental variables had explained the variation in the data set (Table 4-25). Axes one and two of the partial RDA, however explained only 17 percent of the total variation in the residual biomass data set (Table 4-25).

The general trend was that over time, there had been a substantial increase in the residual biomass of the highly desirable ecological group, relatively large increase in residual biomass of the desirable ecological group and small increases in the residual biomass of the undesirable and less-desirable ecological groups (**Error! Reference source not found.**).

The data illustrated that an increase in stocking rates resulted in a large decrease in the residual biomass of the highly desirable ecological group and small decrease in the residual biomass of the less-desirable ecological group. The same trend existed for the desirable and undesirable ecological groups, as higher stocking rates resulted in a lower residual biomass of these two ecological groups, with the desirable ecological group responding the most of these two. High stocking rates resulted in a decrease in the biomass of less-desirable and desirable grass species, which is the opposite of what theory would suggest. It is important to note that the effect of stocking rate on the residual biomass of the ecological groups was dependent on time and on the seasonal current rainfall (**Error! Reference source not found.**).

Current seasonal rainfalls had a negative association with the residual biomass within all four ecological groups, as higher current seasonal rainfall resulted in a lower residual biomass of all of the groups. The highly desirable ecological group responded the most in this association (**Error! Reference source not found.**). Seasonal past rainfall had a positive association with residual biomass of the desirable and undesirable ecological groups, while seasonal past rainfall had a negative association with residual biomass of the highly desirable and less desirable ecological groups (**Error! Reference source not found.**).

The length of the arrows in **Error! Reference source not found.** for the environmental variables and the interactions between them indicated their importance in explaining variation in the data set. Axis one was very weakly negatively correlated to stocking rate (-0.2737) and the interaction between stocking rate and seasonal current rainfall (-0.3801), which suggested that stocking rate explains most of the variation in axis one. Seasonal past rainfall had a very weak negative correlation (-0.1298) with axis two, which indicates that seasonal past rainfall explained most of the variation in axis two.

These results indicated that both rainfall and stocking rate is important in explaining variation in the residual biomass of sites, which suggest that the system is experiencing a continuum of equilibrium and non-equilibrium vegetation dynamics.

Table 4-23 A summary of the results of the Monte Carlo permutation test for the partial RDA for residual ecological groups biomass data during phase three (2000 to present)

Test of significance of first canonical axis
F-ratio = 40.184
P-value = 0.002

Test of significance of all canonical axes
F-ratio = 9.172
P-value = 0.002

Table 4-24 Significance of environmental variables and the interactions between on the residual ecological groups biomass data of sites for the phase three (2000 to present)

Environmental variables/interactions	P-Value	Significance
Time	0.228	Non-significant
SP	0.332	Non-significant
SC	0.002	Highly significant
Time*SP	0.488	Non-significant
Time*SC	0.116	Non-significant
SR*Time	0.002	Highly significant
SR*SP	0.484	Non-significant
SR*SC	0.078	Significant

Table 4-25 Summary of the partial RDA for residual ecological groups biomass data from 2000 to present with only significant environmental variables and interactions included

Axes	1	2	3	4
Eigenvalues	0.13	0.01	0	0
Species-environment correlations	0.43	0.33	0.33	0.06
Cumulative percentage variance				
of species data	15.4	17	17.2	17.2
of species-environment relation	89.5	99.2	100	100
Sum of all eigenvalues				0.87
Sum of all canonical eigenvalues				0.15

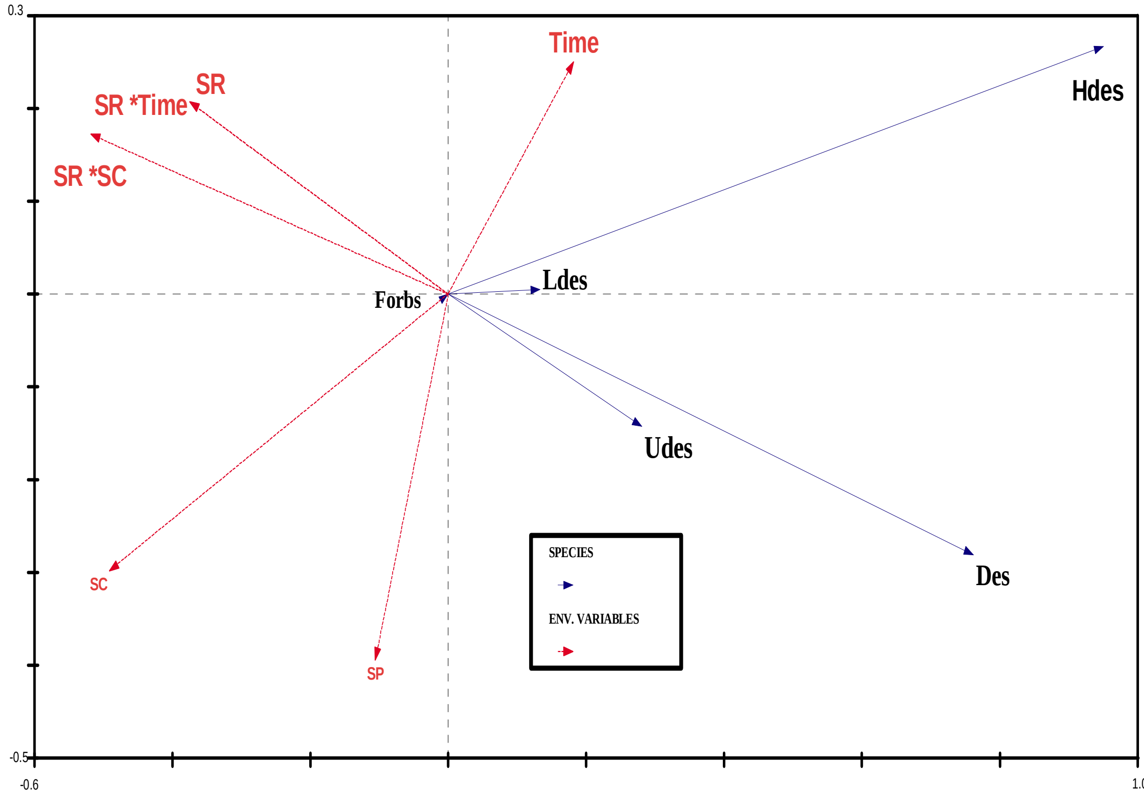


Figure 4-33: Bi-plot of residual biomass (kg.ha^{-1}) for ecological groups, environmental variables and interactions between them along the first two axes of a partial RDA from the grazing trial at the Armoedsvlakte Research Station. Eigenvalues are 0.133 and 0.014 for axes one and two, which represents 15.4 and 17 percent of total variance, respectively. The environmental variables are: SC=Seasonal current rainfall (mm), SR=Stocking rate (LSU/ha) and Time=Time (year). Ecological groups are: Hdes=Highly desirable, Des=Desirable, Ldes=Less-desirable and Udes=Undesirable.

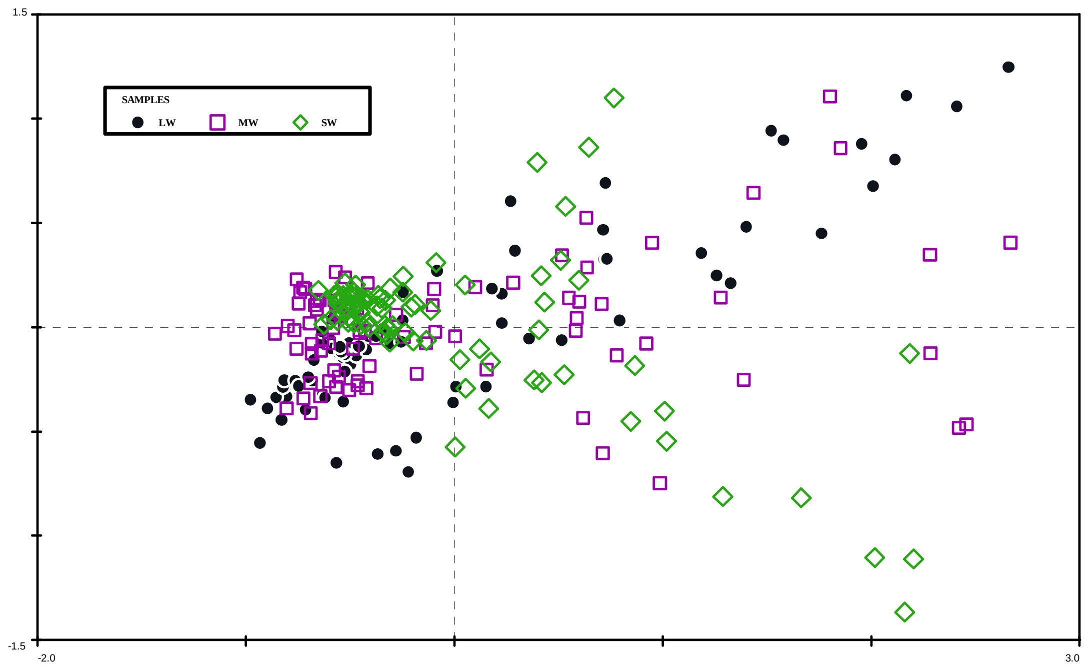


Figure 4-34: Scatter plot of samples for residual biomass data along the first two axes of a partial RDA. Eigenvalues are 0.117 and 0.027 for axes one and two, which represents 11.7 and 14.5 of the total variance, respectively. Treatments are: LW= Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate and SW= Rotational grazing at a high stocking rate.

4.4.5.3.1. Phase three (2000 to present residual biomass for species)

The results of the Monte Carlo permutation test showed that there was a highly significantly effect (P=0.002) of environmental variables and the interactions between them on residual biomass of the species for the first canonical and all of the canonical axes (Table 4-26). The environmental variables that had a significant effect on the residual biomass of species is time and seasonal current rainfall, while the only significant interaction was the stocking rate by time interaction (Table 4-27).The species-environmental relationship for axes one and two explained 93.8 percent of the explainable variation in the data set, which illustrated that the environmental variables had explained the variation in the residual biomass data set (Table 4-28). Axes one and two of the partial RDA however explain only 13.9 percent of the total variation in the data set (Table 4-28).

The general trend was that over time, there had been a substantial increase in the residual biomass of *Digitaria eriantha* and *Eragrostis lehmanniana*, relatively large increase in the residual biomass of *Aristida congesta* and a small increase in the residual biomass of *Eragrostis superba* (**Error! Reference source not found.**).

The data illustrated that an increase in stocking rates resulted in a substantial decrease in the residual biomass of *Digitaria eriantha* and *Eragrostis lehmanniana* (**Error! Reference source not found.**). A similar trend existed for *Aristida congesta* and *Eragrostis superba*, as higher stocking rates resulted in a lower residual biomass of this species. This is unexpected as undesirable species tend to increase at high stocking rates (**Error! Reference source not found.**). Current seasonal rainfalls had a negative association with *Digitaria eriantha, Eragrostis lehmanniana, Aristida congesta* and *Eragrostis superba*, as higher current seasonal rainfall resulted in a lower residual biomass of all of these species and *Digitaria eriantha* and *Eragrostis lehmanniana* responded the most in this association (**Error! Reference source not found.**). Current past rainfall had a positive association with *Eragrostis lehmanniana, Aristida congesta* and *Eragrostis superba*, as higher past seasonal rainfall resulted in a higher residual biomass of all of these species. *Eragrostis lehmanniana* responded the most in this association (**Error! Reference source not found.**) and *Digitaria eriantha* had a negative association with seasonal past rainfall, as higher seasonal past rainfall result in a lower residual biomass of this species. It is important to note that the significant interactions of stocking rate by time and stocking rate by seasonal past rainfall indicated that the effect of stocking rate was dependent on time and seasonal past rainfall (**Error! Reference source not found.** and **Error! Reference source not found.**).

The length of the arrows in **Error! Reference source not found.** for the environmental variables and the interactions between them indicated their importance in explaining variation. Axis one was very weakly negatively correlated to the interactions between stocking rate and time (-0.2928) and stocking rate and seasonal past rainfall (-0.3433), which suggested that stocking rate explained most of the variation in axis one. Seasonal past rainfall had a very weak negatively correlation (-0.1439) with axis two, which indicated that seasonal current rainfall explains most of the variation in axis two.

These results indicated that both rainfall and stocking rate are important in explaining variation in the residual biomass of sites, which suggest that the system is experiencing a continuum of equilibrium and non-equilibrium vegetation dynamics.

Table 4-26 A summary of the results of the Monte Carlo permutation test for the partial RDA for residual species biomass data during phase three (2000 to present)

Test of significance of first canonical axis

F-ratio= 23.066

P-value= 0.002

Test of significance of all canonical axes

F-ratio= 6.666

P-value = 0.002

Table 4-27 Significance of environmental variables and the interactions between on the residual species biomass data of sites for the phase three (2000 to present)

Environmental variables or interactions	**P-value**	**Significance**
Time	0.012	Significant
SP	0.490	Non-significant
SC	0.002	Highly significant
Time*SP	0.052	Significant
Time*SC	0.760	Non-significant
SR*Time	0.002	Highly significant
SR*SP	0.078	Significant
SR*SC	0.156	Non-significant

Table 4-28 Summary of the partial RDA for residual species biomass data from 2000 to present with only significant environmental variables and interactions included

Axes	**1**	**2**	**3**	**4**
Eigenvalues	0.1	0.01	0.01	0
Species-environment correlations	0.46	0.37	0.34	0.18
Cumulative percentage variance				
of species data	12.3	13.9	14.6	14.8
of species-environment relation:	82.7	93.8	98.4	99.6
Sum of all eigenvalues				0.81
Sum of all canonical eigenvalues				0.12

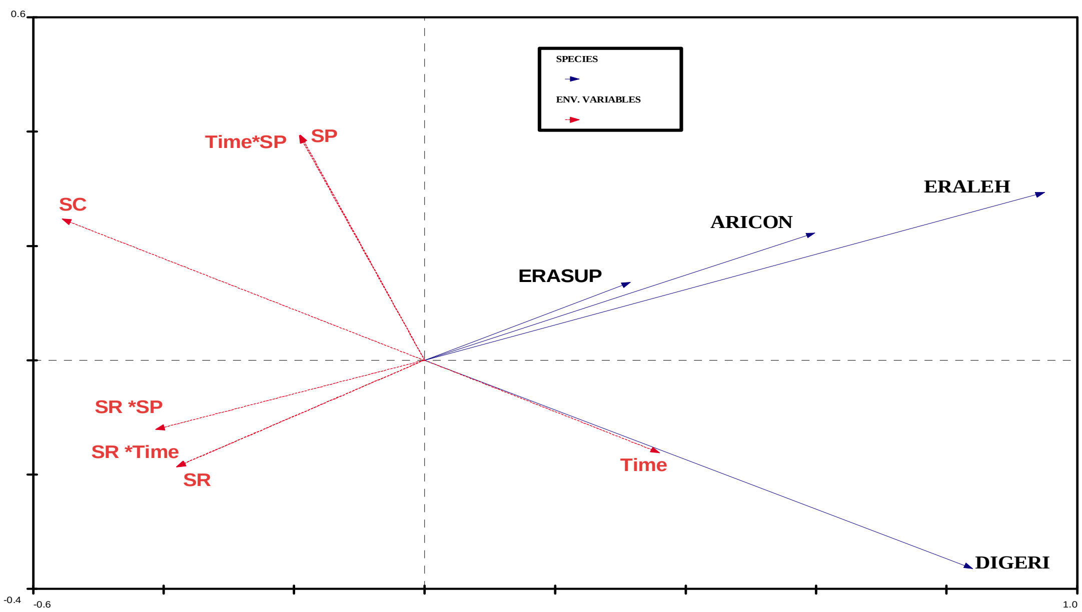


Figure 4-35: Bi-plot of residual biomass of species, environmental variables and the interactions between them along the first two axes of a partial RDA from the grazing trial at the Armoedsvlakte Research Station. Eigenvalues are 0.099 and 0.013 for axes one and two, which represents nine and 13.9 percent of the total variance, respectively. Species with less than 10 percent of their variance explained by the bi-plot are not shown. The environmental variables are: SP=Seasonal past rainfall (mm), SC=Seasonal current rainfall (mm), SR=Stocking rate (LSU/ha) and Time (year). Species are:

Digeri=*Digitaria eriantha*, Aricon=*Aristida congesta*, Erasup=*Eragrostis superba* and Eraleh=*Eragrostis lehmanniana*.

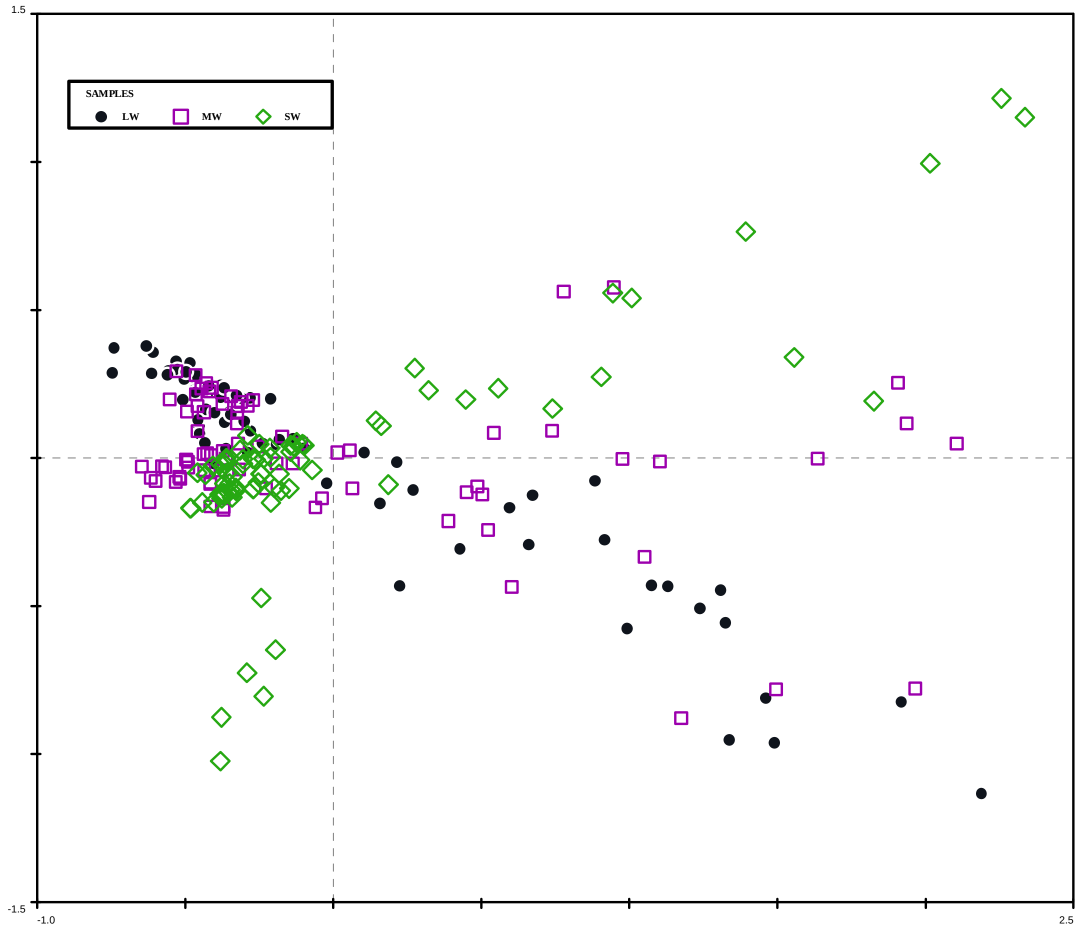


Figure 4-36: Scatter-plot of sites along the first two axes of a partial RDA from the grazing trial at the Armoedsvlakte Research Station. Eigenvalues are 0.099 and 0.013 for axes one and two, which represents 12.3 and 13.9 percent of the total variance, respectively. Treatments are: LW= Rotational grazing at a low stocking rate, MW= Rotational grazing at a medium stocking rate and SW= Rotational grazing at a high stocking rate.

4.4.6. Conclusions

4.4.6.1.Phase one (1977-1991)

Over time there were changes in the residual biomass of sites, from being dominated by the highly desirable ecological group to being dominated by the desirable ecological group. Rotationally grazed sites had a higher residual biomass of the highly desirable ecological group, compared to continuously grazed sites, while the continuously grazed sites had a higher residual biomass of the undesirable ecological group. A large change in the residual biomass of the light and rotationally grazed site occurred throughout phase one, but not in other rotationally grazed treatments, until 1987 to 1989, when all sites showed divergence due to the higher seasonal rainfall. This was followed by convergence of all of the rotationally grazed sites because of very low seasonal rainfall. The continuously grazed treatments showed no drastic changes in residual biomass, except for the light stocking rate treatment, which showed divergence from the original residual biomass. It is important to note that the effect of grazing system and stocking rate on residual biomass was dependent on seasonal past rainfall. These results indicated that seasonal rainfall, type of grazing system applied and stocking rate all explained variation in residual biomass and this indicates that there is a continuum of non-equilibrium and equilibrium vegetation dynamics.

4.4.6.2.Phase two (1992-1999)

During phase two, there were a large increase in the residual biomass over time and the ecological group that changed the most was the highly desirable ecological group, which showed large increases in residual biomass, while the residual biomass of the desirable and undesirable ecological group increased to a lesser extent. Stocking rate had a negative association with total residual biomass and the residual biomass of all three ecological groups. High stocking rates resulted in a substantial decrease in the residual biomass of the highly desirable ecological group, a large decrease in the desirable ecological group and a small decrease in the residual biomass of the undesirable group. The effect of stocking rate on residual biomass was dependent on time and seasonal past rainfall. The general trend in rainfall utilisation of the three ecological groups was that higher seasonal current rainfall, resulted in increased residual biomass of the highly desirable ecological group, a decrease of the desirable ecological group and had no effect on the undesirable ecological group. All three ecological groups residual biomass had a positive association seasonal past rainfall. These results indicated that there was a continuum of non-equilibrium and equilibrium vegetation dynamics in the system as both rainfall and stocking rate explained variation in residual biomass.

4.4.6.3.Phase three (2000 to present)

During phase three, there was a large increase in the residual biomass over time and the ecological group that changed the most was the highly desirable ecological group, which showed large increases in residual biomass. The desirable, undesirable and less-desirable ecological groups increased to a lesser extent. High stocking rates resulted in a substantial decrease in the residual biomass of the highly desirable and desirable ecological groups, while the undesirable and less-desirable group decreased to a lesser extent. The effect of stocking rate on the residual biomass of ecological groups was dependent on time and seasonal current rainfall. There was a negative association between the residual biomass of the ecological groups and seasonal current rainfall and the highly desirable ecological group responded the most in this association. The highly desirable and less desirable ecological group had negative associations with seasonal past rainfall, while the opposite trend existed for the desirable and undesirable ecological group. These results indicate that there is a continuum of non-equilibrium and equilibrium vegetation dynamics in the system, as both rainfall and stocking rate explained variation in residual biomass.

5. Cattle production

5.1. INTRODUCTION

A commonly accepted agricultural objective of a grassland system is to maximise animal production, while maintaining veld and soil resources (Edwards 1969, Aucamp and Barnard 1980, Danckwerts and Daines 1981). Changes due to the treatment applied are usually slow for veld condition variables and not easily reversed and it is essential that the veld condition evaluation is based on long term trials (>10 years) (Edwards 1969). The grazing trial at the Armoedsvlakte Research Station allowed researchers to study the long-term effects and interactions of stocking rate, type of grazing system applied and seasonal rainfall on both cattle production and veld condition. The aim of this chapter is to investigate these effects and interactions on cattle production and to see whether the mass gain data followed the widely used Jones and Sandland (1974) model. The model predicts that as stocking rate is increased, there will originally be a constant or slight increase in gain per animal, whereafter there will be a decrease in gain per animal due to more competition between animals at high stocking rates (due to reduced forage intake and increasing energy expenditure to obtain forage) (Fynn 1998). The model predicts that production per hectare will increase as stocking rates increase up to a point where gain per hectare will start declining, because at these high stocking rates, individual animal gains will be so poor that the gain per hectare will start declining (Fynn 1998).

One of other aims of this chapter is to study whether the effect of rainfall is more important than the effect of stocking rate on animal production (e.g. mass gain data and/or other animal production variables). If this is the case, the area experiences non-equilibrium vegetation dynamics and managers should then monitor rainfall patterns and use adaptive management (suggested by Stuart-Hill 1989) and opportunistic management (suggested by Westoby *et al.* 1989) to optimise animal production. An example of opportunistic management in semi-arid areas is to purchase cattle during wet years and to sell cattle during dry years (i.e. this is example of an opportunity, whereas unfavourable changes will be seen as hazards) (Fynn 1998). There are economic problems with this approach. During a wet year, most of the area will have had similar rainfall. Farmers purchase more cattle and as a result increases the demand for cattle, resulting in a high purchase price.

Furthermore, if stocking rate is more important than rainfall in explaining variation in animal production, then the area is experiencing equilibrium vegetation dynamics and stocking rate is a more important management variable and adaptive management of this variable should be used to optimise animal production.

The effect and interactions of stocking rate, type of grazing system applied, seasonal rainfall and residual biomass on other animal production variables such as conception rate, calving percentages, weaning percentages, condition scores, dressing percentage, carcass mass and grade and price of meat produced will also be investigated.

5.2. GAIN PER ANIMAL AND GAIN PER HECTARE

5.2.1. Methods and materials

The mass of cattle was recorded monthly with an Avery cattle scale (Fourie 1983) Cattle were kept in a kraal for between 15 and 18 hours before weighing and no grazing and water was available to them during this period (Fourie 1983). During phase one (1977-1991) the trials were stocked with Bonsmara steers and heifers (Chapter 1.1 for further discussions) and animals were replaced annually (Coetzee 2002). During phase two (1992-1999) the growing animal system was replaced with a weaner production system (cow-calf system) (see Chapter 1.1 for the reasons). The birth mass of calves were recorded three days after it was born) and thereafter it is weighed monthly and when it was 100 days and 205 days (weaning mass) old. Cows and heifers were weighted monthly.

5.2.2. Statistical analysis and discussion of results

5.2.2.1.Phase one (1977-1991)

The mass gain data were analyzed, using multiple regression with the statistical programming package Genstat 8.1. Two particular analyses were performed and these were the seasonal mass gain per animal per day (kg/animal/day) and seasonal mass gain per ha (kg/hectare/year).

For both the gain per animal and gain per hectare data, two types of multiple linear regression models were developed and either rainfall or residual biomass were incorportated into the model. Rainfall and residual biomass can not be incorporated into the same model as these variables were closely correlated (Fynn 1998). By comparing the results of each model (e.g. amount of variation explained in the multiple linear regressions), it could be concluded which variable (rainfall or residual biomass) was a better indicator of animal gain per animal and gain per hectare (Fynn 1998).

The rainfall model was used to investigate both the significance of gain per animal and gain per hectare on the main effects (stocking rate and seasonal rainfall) and first order interactions (stocking rate by seasonal rainfall interaction). The type of grazing system applied was used as the grouping factor. Time was left out of the analysis, as it resulted in large inflation factors between itself and stocking rate and seasonal rainfall.

The residual biomass model was used to investigate both the significance of gain per animal and gain per hectare on the main effects (stocking rate and seasonal rainfall) and first order interactions (stocking rate by seasonal rainfall interaction). The type of grazing system applied was used as the grouping factor. Time was left out of the analysis, as it resulted in large inflation factors between itself and stocking rate and seasonal rainfall.

5.2.2.1.1. Gain per animal rainfall model for phase one (1977-1991).

The results indicated that there was a highly statistically significant effect (P=0.003) of seasonal rainfall on gain per animal (**Error! Reference source not found.**). Closer investigation of the data suggested that increasing seasonal rainfall resulted in high gain per animal for phase one (**Error! Reference source not found.**). Stocking rate had no significant effect on gain per animal, but stocking rate had a significant interaction with seasonal rainfall, which suggests that the effect of stocking rate is dependent on seasonal rainfall (**Error! Reference source not found.**).

Grazing systems and its interaction with stocking rate had no statistically significant on gain per animal (**Error! Reference source not found.**). This result contradicts most of the scientific literature, were some authors concluded that rotational grazing systems produce higher animal production than continuous grazing systems and others researchers state that continuous grazing systems produce higher animal production than rotational grazing systems.

Table 5-1: Results of the multiple linear regression of the gain per animal and seasonal rainfall model for phase one (1977-1991). Abbreviations used are: SR=stocking rate (LSU/ha), Searain=seasonal rainfall (mm) and GS=grazing system applied

Parameter	**Estimate**	**Standard Error**	**T(57)**	**T pr.**
Constant	0.31	0.08	3.97	<0.001
SR	0.42	0.54	0.77	0.444
Searain	0.00	0.00	3.05	0.003
SR.Searain	0.00	0.00	-2.93	0.005
GS Rot	0.03	0.07	0.51	0.613
SR.GS ROT	-0.10	0.53	-0.19	0.85
SR.Searain.GS Rot	0.00	0.00	-0.91	0.365

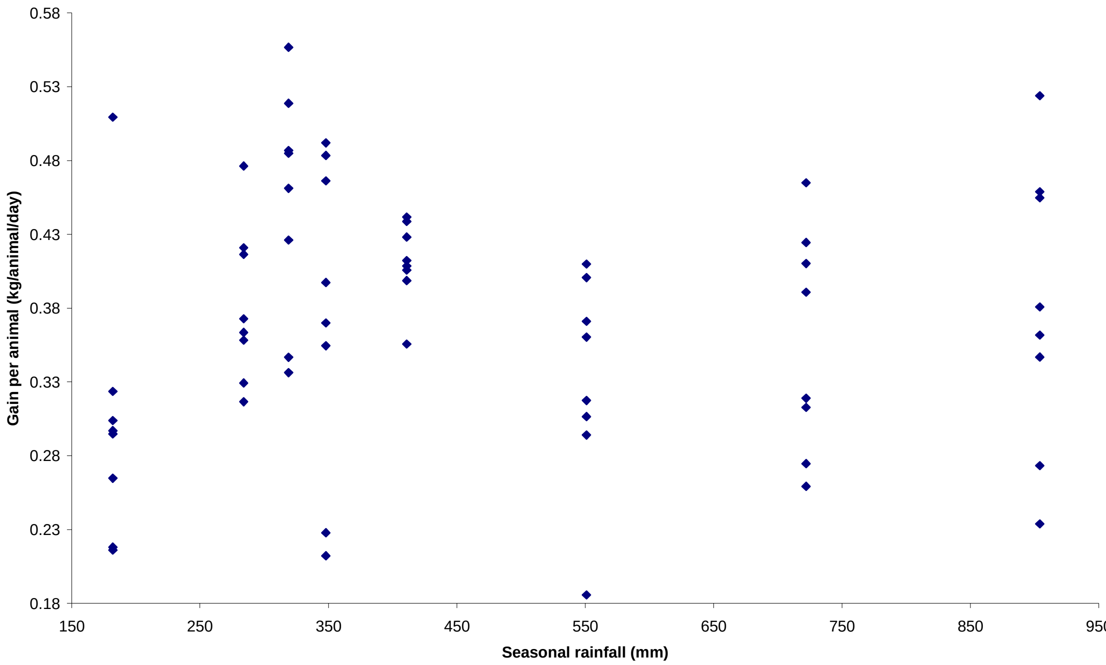


Figure 5-1: The relationship between gain per animal and seasonal rainfall for phase one (1977-1991) for the seasonal rainfall model.

5.2.2.1.2. Gain per hectare and seasonal rainfall model for phase one (1977-1991)

The results indicated that there was a statistically significant effect ($P<0.001$) of seasonal rainfall on gain per hectare and statistically significant effect ($P=0.005$) of stocking rate on gain per hectare (**Error! Reference source not found.**). Closer investigation of the data suggested that increasing seasonal rainfall, resulted in higher gains per hectare during for phase one (**Error! Reference source not found.**).

Higher stocking rates resulted in an increase in gain per hectare (**Error! Reference source not found.**). These results did not follow the widely used Jones and Sandland (1974) model, as increasing stocking rates resulted in higher gains per hectare, which suggested that the turning point of the typical Jones and Sandland (1974) model had not been reached possibly due to the lower than suggested stocking rates, applied during the duration of phase one (Appendix 4- Appendix 17 and **Error! Reference source not found.**). Stocking rate had a highly significant interaction ($P=0.005$) with seasonal rainfall, which suggests that the effect of stocking rate is dependent on seasonal rainfall (**Error! Reference source not found.**).

Grazing system and its interaction with stocking rate and seasonal rainfall had no statistically significant on gain per animal (**Error! Reference source not found.**). Two theories are disssued in the literature. One research group support the theory that animals produce higher under continuous grazing systems than under rotational grazing systems, while others support the direct opposite (O'Reagain and Turner 1992). These trial results thus contradict both theories.

Table 5-2: Results of the multiple linear regression of gain per animal and seasonal rainfall model for phase one (1977-1991). Abbreviations used are: SR=stocking rate (LSU/ha), Searain=seasonal rainfall (mm) and GS=grazing system applied

Parameter	**Estimate**	**Standard error**	**t(57)**	**t pr.**
Constant	-9.18	6.70	-1.37	0.176
SR	207.50	46.80	4.43	<.001
Searain	0.04	0.01	2.95	0.005
SR.Searain	-0.22	0.09	-2.36	0.022
GS Rot	0.57	5.65	0.1	0.92
SR.GS Rot	9.50	45.70	0.21	0.836
SR.Searain.GS Rot	-0.03	0.05	-0.64	0.528

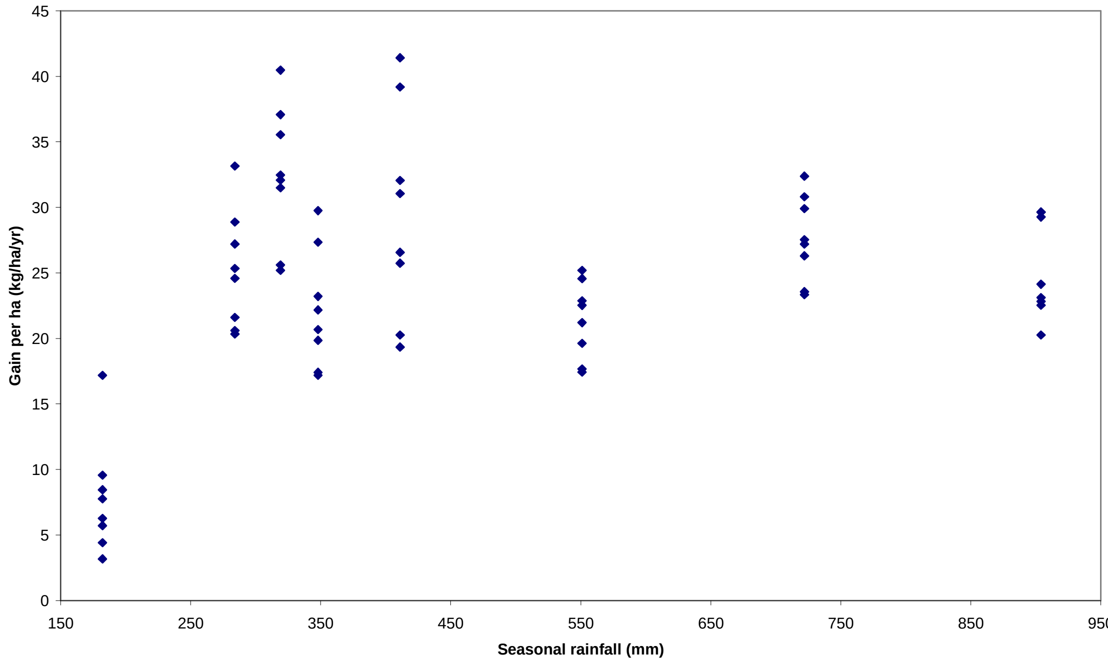


Figure 5-2: The relationship between gain per hectare and seasonal rainfall for phase one (1977-1991) for the seasonal rainfall model.

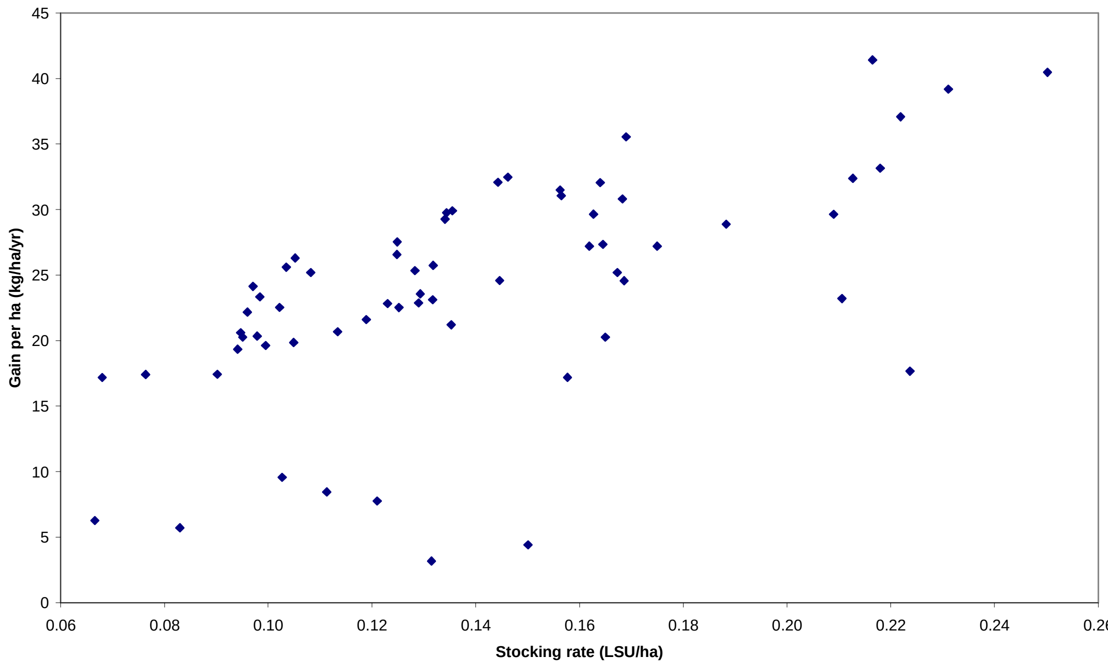


Figure 5-3: The relationship between gain per hectare and stocking rate for phase one (1977-1991) for the seasonal rainfall model.

5.2.2.1.3. Gain per animal and residual biomass model for phase one (1977-1991)

The results indicated that there was a statistically significant effect (P<0.001) of stocking rate on gain per animal (**Error! Reference source not found.**). Closer investigation of the data suggested that higher stocking rates result in a decline in gain per animal for phase one (**Error! Reference source not found.**). Residual biomass and the interaction of this variable with stocking rate had no significant impact on gain per animal.

Grazing system and its interaction with stocking rate and seasonal rainfall had no statistically significant effect on gain per animal (**Error! Reference source not found.**). Two theories are disssued in the literature. One research group support the theory that animals produce higher under continuous grazing systems than under rotational grazing systems, while others support the direct opposite (O'Reagain and Turner 1992). These trial results thus contradict both theories.

Table 5-3 Results from the multiple linear regression of the gain per animal and residual biomass model for phase one (1977-1991). Abbreviations used are: SR=stocking rate (LSU/ha), RB=residual biomass (kg.ha^{-1}) and GS=grazing system applied

Parameter	Estimate	Standard error	t(57)	t pr.
Constant	0.5377	0.0814	6.61	<.001
SR	-1.019	0.452	-2.25	0.028
RB	-0.00004	0.000184	-0.22	0.83
SR.RB	-0.00011	0.00158	-0.07	0.944
GS Rot	0.0175	0.0867	0.2	0.841
SR.GS Rot	-0.227	0.498	-0.45	0.651
SR.RB.GS Rot	0.00016	0.00101	0.16	0.872

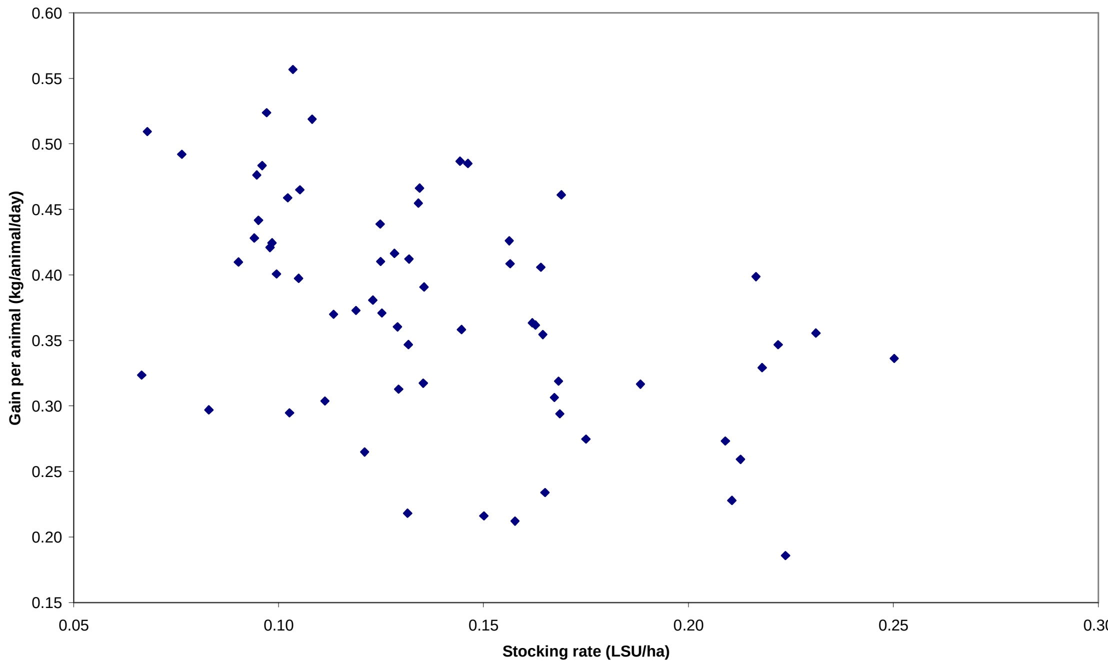


Figure 5-4: The relationship between stocking rate and gain per animal for phase one (1977-1991) for the residual biomass and stocking rate model.

5.2.2.1.4. Gain per hectare and residual biomass model for phase one (1977-1991)

There was a statistically significant effect (P=0.008) of stocking rate on gain per hectare (**Error! Reference source not found.**). Closer investigation of the data suggested that higher stocking rates resulted in a increase in gain per hectare for phase one (**Error! Reference source not found.**), and this suggested that the "turning" point of the typical Jones and Sandland model has not been reached. This might be due to the lower than suggested stocking rates applied during the duration of phase one (Appendix 4-Appendix 17). Residual biomass and the interaction of this variable with stocking rate had no significant impact on gain per animal (**Error! Reference source not found.**).

Grazing system and its interaction with stocking rate and seasonal rainfall had no statistically significant on gain per animal (**Error! Reference source not found.**). Two theories are disssued in the literature. One research group support the theory that animals produce higher under continuous grazing systems than under rotational grazing systems, while others support the direct opposite (O'Reagain and Turner 1992). These trial results thus contradict both theories.

Table 5-4: Results from the multiple linear regression of the gain per hectare and residual biomass model for phase one (1977-1991). Abbreviations used are: SR=stocking rate (LSU/ha), RB=residual biomass ($kg.ha^{-1}$) and GS=grazing system applied

Parameter	Estimate	Standard error	t(57)	t pr.
Constant	6.49	7.13	0.91	0.366
SR	109.1	39.6	2.75	0.008
RB	-0.0066	0.0161	-0.41	0.684
SR.RB	0.106	0.138	0.76	0.448
GS Rot	3.04	7.59	0.4	0.69
SR.GS Rot	-4.4	43.7	-0.1	0.92
SR.RB.GS Rot	-0.0573	0.0883	-0.65	0.519

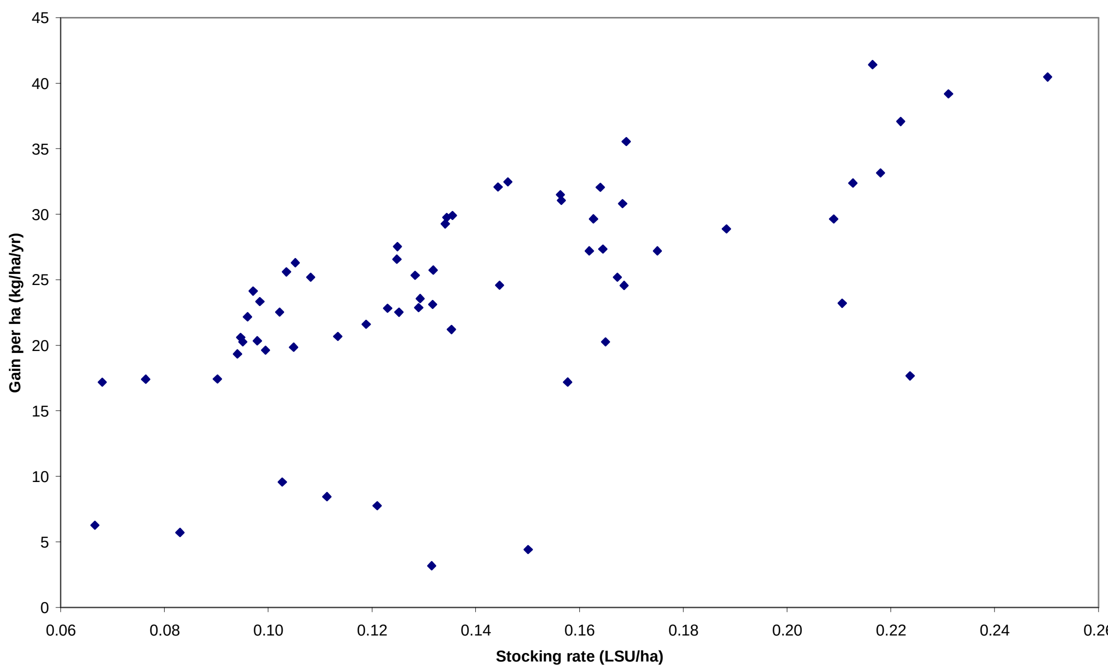


Figure 5-5: The relationship between gain per hectare and stocking rate for phase one (1977-1991) for the residual biomass model.

5.2.2.2.Phase two (1992-1999)

Multiple regression analyses were used for the statistical analysis, using Genstat 8.1. Two particular analyses were performed and these were the seasonal mass gain per animal per day (kg/animal/day) and seasonal mass gain per ha (kg/hectare/year).

For both the gain per animal and gain per hectare data, two types of multiple linear regression models were developed to incorporate both rainfall and residual biomass into the model. Rainfall and residual biomass cannot be incorporated into the same model as these variables are closely correlated (Fynn 1998). By comparing the results of both models (i.e. amount of variation explained in the multiple linear regressions), it can be concluded which variable (rainfall or residual biomass) is a better indicator of animal gain per animal and gain per hectare (Fynn 1998).

The seasonal rainfall model was used to investigate the significance of the main effects and interactions on gain per animal and gain per hectare. The model included the main effects (stocking rate and seasonal rainfall) and first order interactions (stocking rate by seasonal rainfall interaction) and there was no grouping factor, as grazing system treatments were discontinued at the end of phase one. Time was left out of the analysis as it resulted in large inflation factors between itself and stocking rate and seasonal rainfall.

The residual biomass model was used to investigate the significance of the main effects and interactions on gain per animal and gain per hectare. The model included the main effects (stocking rate and seasonal rainfall) and first order interactions (stocking rate by seasonal rainfall interaction) and there was no grouping factor, as grazing system treatments were discontinued at the end of phase one. Time was left out of the analysis as it resulted in large inflation factors between itself and stocking rate and seasonal rainfall.

5.2.2.2.1. Gain per animal and seasonal rainfall model for phase two (1992-1999)

The results indicated that there were no statistically significant effects and/or interactions of stocking rate and seasonal rainfall on gain per animal (**Error! Reference source not found.**).

Table 5-5 Results from the linear regression on the gain per animal and seasonal rainfall model for phase two (1992-1999). Abbreviations used are: SR=stocking rate (LSU/ha) and Searain=seasonal rainfall (mm)

Parameter	Estimate	Standard error	t(20)	t pr.
Constant	0.45	0.46	0.97	0.34
SR	-0.96	3.82	-0.25	0.80
Searain	0.00	0.00	-0.16	0.88
SR.Searain	0.00	0.01	0.14	0.89

5.2.2.2.2. Gain per hectare and seasonal rainfall model for phase two (1992-1999)

The results indicated that there were no statistically significant effects and/or interactions of stocking rate and seasonal rainfall on gain per hectare (**Error! Reference source not found.**).

Table 5-6 Results from the multiple linear regression on the gain per hectare and seasonal rainfall model for phase two (1992-1999). Abbreviations used are: SR=stocking rate (LSU/ha) and Searain=seasonal rainfall (mm)

Parameter	Estimate	Standard Error	t(20)	t pr.
Constant	2.3	15	0.15	0.88
SR	47	123	0.38	0.708
Searain	-0.0033	0.028	-0.12	0.906
SR.Searain	0.116	0.238	0.49	0.632

5.2.2.2.3. Gain per animal and residual biomass model for phase two (1992-1999)

The results indicated that there were no statistically significant effects and/or interactions of stocking rate and residual biomass on gain per animal (Table 5-7 **Results from the multiple linear regression of the gain per animal and residual biomass model. Abbreviations used are: SR=stocking rate (LSU/ha) and RB=residual biomass (kg.ha-1)**

Parameter	Estimate	Standard error	t(20)	t pr.
Constant	0.88	0.37	2.37	0.03
SR	-4.13	2.67	-1.54	0.14
RB	0.00	0.00	-1.45	0.16
SR.RB	0.01	0.01	1.36	0.19

).

Table 5-7 Results from the multiple linear regression of the gain per animal and residual biomass model. Abbreviations used are: SR=stocking rate (LSU/ha) and RB=residual biomass ($kg.ha^{-1}$)

Parameter	Estimate	Standard error	t(20)	t pr.
Constant	0.88	0.37	2.37	0.03
SR	-4.13	2.67	-1.54	0.14
RB	0.00	0.00	-1.45	0.16
SR.RB	0.01	0.01	1.36	0.19

5.2.2.2.4. Gain per hectare and residual biomass model for phase two (1992-1999)

The results indicated that there were no statistically significant effects or interactions of stocking rate and residual biomass on gain per hectare (**Error! Reference source not found.**).

Table 5-8: Results from the multiple linear regression for the gain per hectare and residual biomass model for phase two (1992-1999). Abbreviations used are: SR=stocking rate (LSU/ha) and RB=residual biomass ($kg.ha^{-1}$)

Parameter	Estimate	Standard error	t(20)	t pr.
Constant	8.10	12.60	0.64	0.53
SR	31.40	90.80	0.35	0.73
RB	-0.02	0.02	-0.71	0.49
SR.RB	0.17	0.19	0.92	0.37

5.2.2.3. Phase three (2000 to present)

Multiple linear regression analyzes were used for the statistical analysis, using Genstat 8.1. Two particular analyses were performed and these were the seasonal mass gain per animal per day (kg/animal/day) and seasonal mass gain per ha (kg/hectare/year).

For both the gain per animal and gain per hectare data, two types of multiple linear regression models were developed to incorporate both rainfall and residual biomass into the model. Rainfall and residual biomass could not be incorporated into the same model as these variables were closely correlated (Fynn 1998). By comparing the results of both models (e.g. amount of variation explained in the multiple linear regressions), it was concluded which variable (rainfall or residual biomass) is a better indicator of animal gain per animal and gain per hectare (Fynn 1998).

The seasonal rainfall model was used to investigate the significance of the main effects and interactions on gain per animal and gain per hectare. The model included the main effects (stocking rate and seasonal rainfall) and first order interactions stocking rate by seasonal rainfall and there was no grouping factor, as grazing system treatments were discontinued at the end of phase one Time was left out of the analysis as it resulted in large inflation factors between itself and stocking rate and seasonal rainfall.

The residual biomass model was used to investigate the significance of the main effects and interactions on gain per animal and gain per hectare. The model included the main effects (stocking rate and residual biomass) and first order interactions (stocking rate by residual biomass interaction) and there was no grouping factor, as grazing system treatments were discontinued at the end of phase one. Time was left out of the analysis as it resulted in large inflation factors between itself and stocking rate and seasonal rainfall.

5.2.2.3.1. Gain per animal and seasonal rainfall model for phase three (2000 to present)

The results indicated that there were no statistically significant effects or interactions of stocking rate and seasonal rainfall on gain per animal (**Error! Reference source not found.**).

Table 5-9: Results from the linear regression on the gain per animal and seasonal rainfall model for phase three (2000 to present). Abbreviations used are: SR=Stocking rate (LSU/ha) and Srain=seasonal rainfall (mm)

Parameter	Estimate	Standard error	t(8)	t pr.
Constant	0.40	0.66	0.61	0.56
SR	0.20	5.18	0.04	0.97
Srain	0.00	0.00	0.11	0.92
SR.Srain	0.00	0.01	-0.17	0.87

5.2.2.3.2. Gain per hectare and seasonal rainfall model for phase three (2000 to present)

The results indicated that there were no statistically significant effects or interactions of stocking rate and seasonal rainfall on gain per hectare (**Error! Reference source not found.**).

Table 5-10: Results from the multiple linear regression on the gain per hectare and seasonal rainfall model for phase three (2000 to present). Abbreviations used are: SR=stocking rate (LSU/ha) and Srain=seasonal rainfall (mm)

Parameter	Estimate	Standard error	t(8)	t pr.
Constant	-6.90	37.70	-0.18	0.86
SR	274.00	297.00	0.92	0.38
Srain	0.02	0.06	0.24	0.82
SR.Srain	-0.21	0.49	-0.43	0.68

5.2.2.3.3. Gain per animal and residual biomass model for phase three (2000 to present)

The results indicated that there were no statistically significant effects or interactions of stocking rate and residual biomass on gain per animal (**Error! Reference source not found.**).

Table 5-11: Results from the multiple linear regression of the gain per animal and residual biomass model for phase three (2000 to present). Abbreviations used are: SR=stocking rate (LSU/ha) and Srain=seasonal rainfall (mm)

Parameter	Estimate	Standard error	t(8)	t pr.
Constant	0.32	0.11	2.76	0.03
SR	0.04	0.76	0.05	0.96
RB	0.00	0.00	1.05	0.33
SR.RB	0.00	0.00	-0.34	0.75

5.2.2.3.4. Gain per hectare and residual biomass model for phase three (2000 to present)

The results indicated that there is a statistically significant (P=0.008) effect of stocking rate on gain per hectare (**Error! Reference source not found.**). At low stocking rates, gain per hectare increased at a rapid rate, but as stocking rates increased to high stocking rates, the rate of increase in gain per hectare declined, until it eventually reached a turning point, whereafter gain per hectare declined with increasing stocking rates (**Error! Reference source not found.**). This is the typical "Jones and Sandland 1974" response of gain per hectare to stocking rate. The relationship of residual biomass and gain per hectare was non-significant (**Error! Reference source not found.**).

Table 5-12 Results from the multiple linear regression for the gain per hectare and residual biomass model for phase three (2000 to present). Abbreviations used are: SR=stocking rate (LSU/ha) and RB=residual biomass ($kg.ha^{-1}$)

Parameter	Estimate	Standard error	t(8)	t pr.
Constant	-4.00	6.56	-0.61	0.56
SR	161.00	43.50	3.70	0.01
RB	0.00	0.00	0.45	0.67
SR.RB	0.01	0.03	0.38	0.71

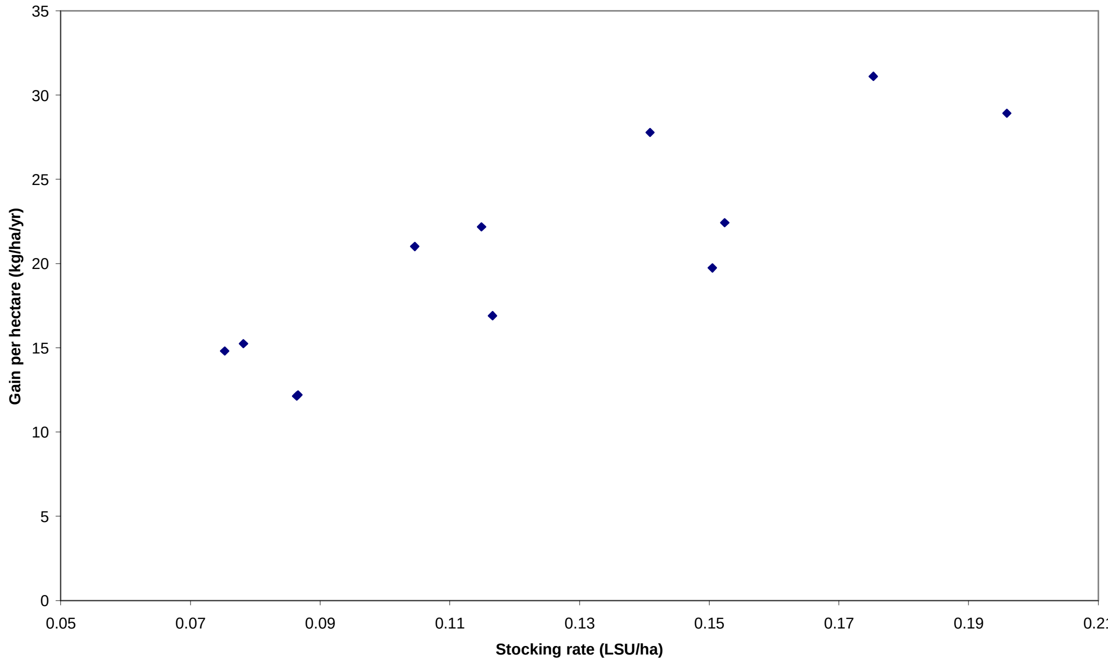


Figure 5-6: Relationship between stocking rate and gain per hectare for phase three (2000 to present).

5.2.3. Conclusions

5.2.3.1.Phase one (1977-1991)

The residual biomass and seasonal rainfall model for phase one indicated completely different results for the gain per animal data. In the seasonal rainfall model, stocking rate did not have a significant effect on gain per animal, but seasonal rainfall and the interaction of stocking rate with seasonal rainfall explained most of the variation in gain per animal. This suggested a continuum of non-equilibrium and equilibrium dynamics and that animal production is more sensitive to seasonal rainfall than to stocking rate, although the significant interaction of stocking rate with seasonal rainfall suggested that the effect of seasonal rainfall on animal production is dependant on stocking rate.

The residual biomass model however indicated that stocking rate was more important than rainfall in explaining variation in the mass gains per animal. The stocking rate effect on gain per animal was significant and indicated that as stocking rate increased, that gain per animal decreased. Seasonal rainfall and the interaction of stocking rate with seasonal rainfall had no significant effect on gain per animal.

The amount of variation explained by the seasonal rainfall model (28.4%) was larger than the residual biomass model (17.3%) and this indicated that rainfall explained more variation in gain per animal, than residual biomass did. This possibly indicated that non-equilibrium effects are stronger than the equilibrium effects, but it is important to note that stocking rate had a significant effect in some cases.

The gain per hectare models (seasonal rainfall and residual biomass) for phase one indicated that stocking rate had a significant effect on gain per hectare. Increasing stocking rates resulted in higher gains per hectare, which suggested that the turning point of the typical "Jones and Sandland 1974 model" has not been reached and this might have been due to light stocking rates applied during the duration of phase one. The seasonal rainfall model however has significant effects of seasonal rainfall and interactions of stocking rate with seasonal rainfall on gain per hectare. This suggests that the effect of stocking rate is dependent on seasonal rainfall and that seasonal rainfall explain an additional amount of variation in gain per hectare.

Grazing system and its interaction with stocking rate and seasonal rainfall had no statistically significant on gain per animal and on gain per hectare for both the residual biomass and seasonal rainfall models. Two theories are disssued in the literature. One research group support the theory that animals produce higher under continuous grazing systems than under rotational grazing systems, while others support the direct opposite (O'Reagain and Turner 1992). These trial results thus contradict both theories.

5.2.3.2.Phase two (1992-1999)

Both the residual biomass and seasonal rainfall models for phase two did not show any significant effects and interactions between and with stocking rate, seasonal rainfall and/or residual biomass on both gain per animal and gain per hectare.

5.2.3.3.Phase three (2000-2004)

Both the residual biomass and seasonal rainfall models for phase three did not show any significant effects and interactions of stocking rate, seasonal rainfall and/or residual biomass on animal gains per animal. The seasonal rainfall model did not show any any significant effects and interactions of stocking rate, seasonal rainfall and/or residual biomass on animal gains per hectare. However, the residual biomass model indicated that stocking rate had a significant effect on gain per hectare and the production closely followed the "Jones and Sandland 1974 model" as at low stocking rates, gain per hectare increased at a rapid rate, but high stocking rates rates, the rate of gain per hectare declined, until it eventually reaches a turning point, whereafter gain per hectare declined with increasing stocking rates.

5.3. ANIMAL PRODUCTION VARIABLES OTHER THAN MASS GAIN DATA

5.3.1. Animal production variables measured for cattle in different treatments

The following animal production variables were measured for each cow during phase two and three:

- Conception rates (cows pregnant/cows mated *100)
- Calving percentages (cows that calved/cows mated*100)
- Weaning percentages (Calves weaned/cows mated *100)

Condition scores are given to all cows four times during the year. The condition scores were given to each cow before servicing, after servicing, before calving and after weaning. The condition score was a value of between one and five, where a score of one was if the cow is very thin and score of five is where the cow was very fat.

If cows, calves and heifers are slaughtered, their slaughtered mass, carcass mass, dressing percentage, the grade of the meat and the price offered for different grades, are recorded. The South African grading system of meat operates on two main variables and these are the age of the animal and the fatness of the meat (Anon 2005). The age of the animal is divided into four age classes (Anon 2005). These are A-grade (animal with no permanent incisors is under the age of one), AB grade (animal that has two teeth, is one to one and half years old with two permanent incisors), B grade (animal that has four teeth, two years old with three to six permanent incisors) and C grade (animal that is called a full mouth of teeth, two and a half years to three years old with more than six permanent incisors) (Anon 2005). The fatness of the carcass is judged by how much fat can visually been seen on the carcass (Anon 2005). If an animal has very little or no fat, the meat is graded as zero to one code (Anon 2005). When an animal is not too lean nor to fat, the meat is graded the codes two, three and four (Anon 2005). An animal that is slightly over weight will be classified as code five and an excessively fat animal's meat will be classified as code six (Anon 2005).

5.3.2. Statistical analysis and discussion of results

5.3.2.1.Phase one (1977-1991)

The only animal production variable that was measured during phase one was the mass gain of steers and heifers and these results are discussed in Chapter 5.2.2.1.

5.3.2.2.Phase two (1992-1999)

Simple linear regression analysis, using Genstat 8.1, was used to study the effect of stocking rate on condition score for phase two. Multiple linear regressions (also using Genstat 8.1) were used to investigate the effect and interactions of stocking rate and rainfall on calving percentage, weaning percentage, conception rate and the percentage of desirable grade meat. The percentage desirable grade meat was calculated as follows (Section 5.3.1):

% desirable grade meat=∑ of Grade A2 and Grade A3/∑ of all grades of meat*100

5.3.2.2.1. Condition score of cows during phase two (1992-1999)

There was a statistically significant (P<0.001) effect of stocking rate on the condition scores of cows for phase two (**Error! Reference source not found.**). The relationship between stocking rate and condition score clearly indicated that high stocking rates resulted in low condition scores (**Error! Reference source not found.**).

Table 5-13 Results from the simple linear regression of stocking rate on the condition score of cows during phase two (1992-1999). The abbreviation used is: SR=stocking rate (LSU/ha)

Parameter	Estimate	Standard error	t(21)	t pr.
Constant	3.911	0.106	37	<.001
SR	-4.684	0.917	-5.11	<.001

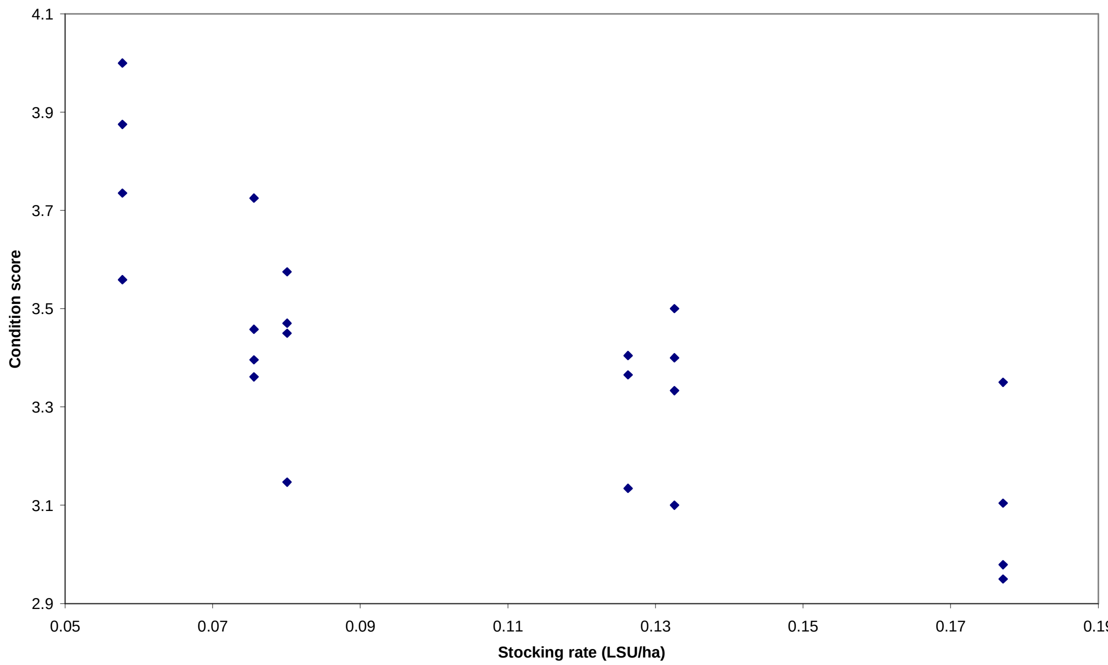


Figure 5-7: Relationship between stocking rate and the condition score of cows during phase two (1992-1999).

5.3.2.2.2. Calving percentages

There was no statistically significant effect and interaction of stocking rate and seasonal rainfall on the calving percentage of cows during phase two (**Error! Reference source not found.**).

Table 5-14: Results from the multiple linear regression of stocking rate and seasonal rainfall on the calving percentage for phase two (1992-1999). Abbreviations used are: SR=stocking rate (LSU/ha) and Searain=seasonal rainfall (mm)

Parameter	Estimate	Standard error	t(17)	t pr.
Constant	101.8	38.3	2.66	0.017
SR	-179	326	-0.55	0.591
Searain	-0.0187	0.0737	-0.25	0.802
SR.Searain	0.302	0.659	0.46	0.652

5.3.2.2.3. Weaning percentages

There was no statistically significant effect and interaction of stocking rate and seasonal rainfall on the weaning percentage of calves during phase two (**Error! Reference source not found.**).

Table 5-15: Results from the multiple linear regression of stocking rate and seasonal rainfall on the weaning percentage of calves for phase two (1992-1999). Abbreviations used are: SR=stocking rate (LSU/ha) and Searain=seasonal rainfall (mm)

Parameter	Estimate	Standard error	t(17)	t pr.
Constant	86.7	38	2.28	0.035
SR	-50	323	-0.15	0.879
Searain	-0.0008	0.073	-0.01	0.991
SR.Searain	0.098	0.653	0.15	0.882

5.3.2.2.4. Conception percentages

There was no statistically significant effect and interaction of stocking rate and seasonal rainfall on the conception percentages of cows during phase two (**Error! Reference source not found.**).

Table 5-16: Results from the multiple linear regression of stocking rate and seasonal rainfall on the conception rate of cows during phase two (1992-1999). Abbreviations used are: SR=stocking rate (LSU/ha) and Searain=seasonal rainfall (mm)

Parameter	Estimate	Standard error	t(17)	t pr.
Constant	134.7	36.4	3.7	0.002
SR	-495	310	-1.6	0.128
Searain	-0.0787	0.07	-1.12	0.276
SR.Searain	0.865	0.626	1.38	0.185

5.3.2.2.5. The percentage of desirable meat grades produced

There was no statistically significant effect and interaction of stocking rate and seasonal rainfall on the percentages of desirable meat grades produced during phase two (**Error! Reference source not found.**).

Table 5-17: Results from the multiple linear regression of stocking rate and seasonal rainfall on the percentage of desirable meat grades produced during phase two (1992-1999). Abbreviations used are: SR=stocking rate (LSU/ha) and Searain=seasonal rainfall (mm)

Parameter	Estimate	Standard error	t(17)	t pr.
Constant	1.23	0.35	3.48	0.00
SR	-3.90	3.00	-1.30	0.21
Searain	0.00	0.00	-1.16	0.26
SR.Searain	0.01	0.01	1.16	0.26

5.3.2.3.Phase three (2000 to present)

Simple linear regression analysis, using Genstat 8.1 was used to study the effect of stocking rate on condition score of cows during phase three.

5.3.2.3.1. Condition score of cows for phase three (2000 to present)

There was a statistically significant effect of stocking rate (P<0.001) on the condition scores of cows during phase three (**Error! Reference source not found.**). There is definite negative association with stocking rate and the condition score of cows, as higher stocking rates resulted in decreasing condition score of cows (**Error! Reference source not found.**).

Table 5-18: Results from the simple linear regression of stocking rate on the condition scores of cows for phase three (2000 to present). The abbreviation used is: SR=Stocking rate (LSU/ha)

Parameter	**Estimate**	**Standard error**	**t(46)**	**t pr.**
Constant	3.4442	0.0878	39.22	<.001
SR	-1.948	0.689	-2.82	0.007

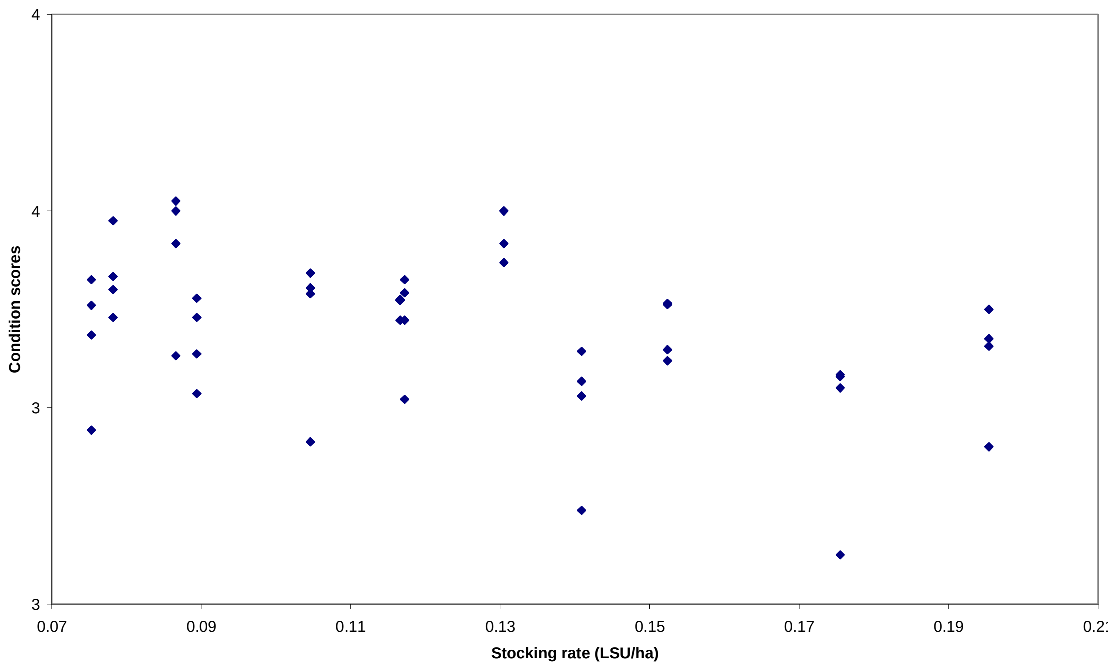


Figure 5-8: Relationship between stocking rate and the condition score of cows for phase three (2000 to present).

5.3.3. Conclusions

5.3.3.1.Phase two (1992-1999)

Stocking rate only had a significant effect on the condition score of cows during phase two. No significant effects and interactions of stocking rate and seasonal rainfall was indicated on calving percentage, weaning percentage, conception rates and percentage of desirable meat produced. This suggested that animal production are not affected by density dependent effects and/or density independent effects in this system. A possible reason for this is that no significant effects and interactions can be seen as the actual stocking rates were much lower than what they should have been, as per specifications of the trial design (refer ton Appendix 12 to Appendix 14)

5.3.3.2.Phase three (2000 to present)

The only variable that was available for phase three was the condition scores of cows. This variable had a significant effect with stocking rate, and the results indicated that high stocking rates result in poor cattle condition.

References

Acocks JPH 1966. Non-selective grazing as a means of veld reclamation. Proceedings of the Grassland Society of southern Africa 1: 33-39.

Acocks JPH 1988. Veld types of South Africa. Memoirs of the Botanical survey of South Africa no. 57, Pretoria.

Anderson MJ and Gribble NA 1998. Partitioning the variation among the spatial component of ecological variation. Australian Journal of Ecology 23: 158-167.

Anonymous 1926. The great drought problem of South Africa. Department of Agriculture, Government Printer, Pretoria, pp. 26.

Anonymous 1972. Landbou-ontwikkelingsplan vir die Vrystaat-streek. Unpublished report, Departement van Landbou, Vrystaat-streek, Glen.

Anonymous 1984. Livestock and range research in Botswana 1983-1984. Animal Production Research Unit, Ministry of Agriculture, Private Bag 0033, Gaberone, Botswana.

Anonymous 1985. Livestock and range research in Botswana 1985. Animal Production Research Unit, Ministry of Agriculture, Private Bag 0033, Gaberone, Botswana.

Anonymous 2005. Red meat marketing. Accessed on the 4 April 2005. Http://www.nda.agric.za/docs/MarketExtension/7Livestock.pdf.

Archer SR and Smeins FE 1991. Ecosystem-level processes. In: Heitschmidt RK and Stuth JW (Eds.) Grazing Management: an Ecological Perspective. Pp.109-139. Portland: Timber Press.

Archibald S and Bond W 2003. Modelling interactions between fire, rainfall and grazing. Proceedings of the VIIth International Rangeland Congress, Durban, South Africa. Pp. 308-311.

Aucamp AJ and Barnard HH 1980. The development of the animal production potential of the dry grass-bush communities of the Eastern Cape. Proceedings of the Grassland Society of southern Africa 15: 137-140.

Bailey DW, Gross JE, Laca EA, Rittenhouse LR, Coughenour MB, Swift DM and Sims PL 1996. Mechanisms that result in large herbivore grazing distribution patterns. Journal of Range Management 49 (6): 386-400.

Barnes DL 1965. A stocking rate trial in the Rhodesian high altitude sandveld. Rhodesian Journal of Agricultural Research 3: 101-107.

Barnes DL 1977. An analysis of rotational grazing on veld. Rhodesian Agricultural Journal 74 6: 147-151.

Barnes DL and McNeil L 1978. Rainfall variability and animal production in the semi-arid savanna of southern Africa. Proceedings of the Grassland Society of southern Africa 13: 59-63.

Barnes DL 1992. A critical analysis of veld management recommendations for sourveld in the south-eastern Transvaal. Journal of the Grassland Society of southern Africa 9: 126-134.

Barnes DL, Odendaal JJ and Beukes BH 1982. Use of the dry weight rank method for botanical analysis in the Eastern Transvaal Highveld. Proceedings of the Grassland Society of southern Africa 17:79-83.

Barnes DL and Denny RP 1991. A comparison of continuous and rotational grazing on veld at two stocking rates. Journal of the Grassland Society of southern Africa 8 (4): 168-173.

Barnes DL 1992. A critical analysis of veld management recommendations for sourveld in south-eastern Transvaal. Journal of the Grassland Society of southern Africa 9 (3): 126-134.

Bartholomew PE 1985. Beef production from kikuyu and Italian ryegrass. PhD thesis. University of Natal, Pietermaritzburg.

Bartholomew PE 1991. A stocking rate model. Natal Pastures Extension Pamphlet. Dept. Agric. Development, Natal Region, Pietermaritzburg.

Behnke R and Scoones I 1993. Rethinking range ecology: Implications for Rangeland Management in Africa. In: Behnke R, Scoones I and Kerven C (Eds.). Range ecology at dis-equilibrium. Chapter one. Overseas Development Institute. London. United Kingdom. Pp. 1-30.

Behnke R, Scoones I and Kerven C 2003. Range ecology at dis-equilibrium. Overseas Development Institute. London. United Kingdom.

Bestelmeyer BT, Brown JR, Havstad KM, Alexander R, Chavez G and Herrick JE 2003. Development and use of state and transition models for rangelands. Journal of Range Management 56 (2): 114-126.

Beukes PC and Cowling RM 1999. Impacts of non-selective grazing on cover, composition and productivity of Nama-karoo grassy shrubland. African Journal of Range and Forage Science 17 (1): 27-35.

Booysen P de V 1956. In grassland management it is principles that count and not systems. Fmq. S. Afr. 32: 34-40.

Booysen P De V, Tainton NM and Scott JD 1963. Shoot-apex development in grasses and its importance in grassland management. Herb. Abstr. 33: 209-213.

Booysen P de V 1964. A grassveld management system for every farm. Fmq. S. Afr. 40:64-66.

Booysen P de V 1966. A physiological approach to research in pasture utilization. Proceedings of the Grassland Society of southern Africa 1: 77-85.

Booysen P de V 1967. Grazing and grazing management terminology in southern Africa. Proceedings of the Grassland Society of southern Africa 2: 45-57.

Booysen P De V 1969. An analysis of the fundamentals of grazing management systems. Proceedings of the Grassland Society of southern Africa 4: 84-91.

Booysen P De V, Klug JR and York BS 1974. Number of camps for rotational grazing of veld. Proceedings of the Grassland Society of southern Africa 9: 145-148.

Booysen P De V 1975. Economic optimisation of stocking rate and grazing management. Proceedings of the European Grassland Federation, 6th meeting, Madrid: 243-245.

Booysen P De V, Tainton NM and Foran BD 1975. An economic solution to the grazing management dilemma. Proceedings of the Grassland Society of southern Africa 10: 77-83.

Booysen P De V and Tainton NM 1978. Grassland Management: principles and practice in South Africa. Proceedings of the First International Rangeland Congress, Denver, Colorado, pp. 551-554.

Borchard D, Legendere P and Drapeau P 1992. Partialling out the spatial component of ecological variation. Ecology 73 (3): 1045-1055.

Botha JP and Malherbe CE 1945. Sound systems of veld management give good results on sourveld. Farming in South Africa November 1945.

Boultwood JN and Rodel MGW 1981. Effects of stocking rate and burning frequency of *Brachysegia/Julbernardia* veld in Zimbabwe. Proceedings of the Grassland Society of southern Africa 16: 111-116.

Bransby DI and Maclaurin AR 2000. Designing animal production studies. In: t'Mannetjie, L. and Jones, R.M. (Eds.) Field and laboratory methods for grassland and animal production research. CABI publishing, Wallingford, Oxon.

Briske DD, Fuhlendorf SD and Smeins FE 2003. Vegetation dynamics on rangelands: a critique of the current paradigms. Journal of Applied Ecology 40: 601-614.

Brockett GM, Tainton NM and Edwards PJ 1980. Results of grazing trials on landino clover. Proceedings of the Grassland Society of southern Africa 15: 89-94.

Brockett BH 2001. Sampling efficiency for species composition assessments using the Wheelpoint method in a semi-arid savanna. African Journal of Range and Forage Science 18: 93-101.

Bryan WW and Evans TR 1973. Effects of soils, fertilizers and stocking rates on pastures and beef production on the Wallum of South-eastern Queensland. 1. Botanical composition and chemical effects on plants and soils. Aust. J. Exp. Aqr. and Anim. Husb. 13: 516-529.

Bunting C 2003. A strategy for optimal beef production off sourveld. MSc thesis, University of Natal, Pietermaritzburg.

Burger SJ, Grunow JO and Rabie JW 1975. The response of *Anthephora pubescens* to different intensities and frequencies of defoliation. Proceedings of the Grassland Society of southern Africa 10: 29-34.

Carew GW 1980. Veld management: some economic and practical considerations. Rhodesia Agricultural Journal 77: 37-39.

Caughley G 1987. Ecological relationships. In: Caughley G, Shepherd N and Short J (Eds.). Kangaroos: their ecology and management in the sheep rangelands of Australia. Cambridge University Press, Cambridge, UK, Pp. 159-186.

Chapman DF and Lemaire G 1993. Morphogenetic and structural determinants of plant growth after defoliation. Proceedings of the XVII International Grassland Congress, New Zealand: 95-104.

Chesson PL and Case TJ 1986. Overview: Non-equilibrium community theories: Chance, variability, history and coexistence. In: Diamond J and Case TJ (Eds.) Community Ecology. Harper and Row Publisher, New York. Pp. 229-239.

Coetzee PJS 1948. Principles of grassveld utilization. Fmq. S. Afr. 23:486-496.

Coetzee M 2002. Determining grazing capacity norms of Vryburg Shrub Bushveld at Armoedsvlakte Research Station with a weaner-calf production system. Unpublished progress report No. 5, V5411/36/01/01.

Connolly J 1976. Some comments on the shape of the gain-stocking rate curve. J. Agric. Camb. 86: 103-109.

Conway A 1963. Effects of grazing management on beef production. II. Comparison of three stocking rates under two systems of grazing. Journal of Agricultural Research 2: 243-257.

Daines T 1980. The use of grazing patterns in the management of Dohne Sourveld. Proceedings of the Grassland Society southern Africa 15: 185-188.

Danckwerts JE 1984. Towards improved livestock production of Sweet Grassveld. Volume one. Ph.D. thesis, University of Natal, Pietermaritzburg.

Danckwerts JE 1989a. Management of veld types: Sweet Grassveld. In: Danckwerts, JE and Teague WR (Eds.). Veld management in the Eastern Cape. Pasture Research Section, Eastern Cape Region.

Danckwerts JE 1989b. Animal performance. In: Danckwerts JE and Teague WR. (Eds.). Veld management in the Eastern Cape. Pasture Research Section, Eastern Cape Region.

Danckwerts JE 1989c. The quality of herbage ingested by cattle in a grazed semi-arid grassveld of the Eastern Cape. Journal of the Grassland Society of southern Africa 6 (2): 65-70.

Danckwerts JE and Daines T 1981. Animal production off grassveld. Proceedings of the Grassland Society of southern Africa 16: 19-22.

Danckwerts JE and King PG 1984. Conservative stocking or maximum profit: A grazing management dilemma? Journal of the Grassland Society of southern Africa 1 (4): 25-28.

Danckwerts JE and Stuart-Hill GC 1988. The effect of severe drought and management after drought on the mortality and recovery of semi-arid grassveld. Journal of the Grassland Society of southern Africa 5 (4): 218-222.

Danckwerts JE and Drewes RH 1989. Stocking rate and carrying capacity. Grazing management: A strategy for the future. Department of Agriculture and Water Supply, Pretoria.

Demarchi DA 1973. Relationship of range quality and range condition in the Chilcotin Region British Columbia. Journal of Range Management 26: 345-353.

Denny RP and Barnes DL 1977. Trials of multi-paddock grazing systems on veld. 3. A comparison of six grazing procedures at two stocking rates. Rhodesian Journal of Agricultural Research 15: 129-142.

Denny RP and Steyn JSH 1977. Trials of multi-paddock grazing systems on veld. 2. A comparison of a 16-paddocks to one herd system with a four paddock to one herd system using breeding cows. Rhodesian Journal of Agricultural Research 15: 119-127.

Deshmukh IK 1984. A common relationship between precipitation and grassland peak biomass for East and Southern Africa. African Journal of Ecology 22: 181-186.

Donaldson CH 1967. The immediate effects of the 1964/1966 drought on the vegetation of specific study areas in the Vryburg District. Proceedings of the Grassland Society of Southern Africa 2: 137-141.

Donaldson CH and Rootman GT 1983. Continuous grazing and fixed seasonal rotational grazing systems. Unpublished Report: Facet T5411/41/1/1/. Department of Agriculture, Transvaal Region.

Donaldson CH 1986. The camp No. 6 veld grazing trial: an important milestone in the development of pasture research at the Grootfontein College of Agriculture. Karoo Agric 3: 1-6.

Dowhover SL, Teague WR, Ansley RJ and Pinchak WE 2001. Dry-weight-rank method assessment in heterogeneous communities. Journal of Range Management 54: 71-76.

Drewes RH 1991. The Potch System: An approach to the management of semi-arid grasslands in southern Africa. Journal of the Grassland Society of southern Africa 8 (4): 174-178.

Du Toit PF 1972. The goat in a grass-bush community. Proceedings of the Grassland Society of southern Africa. 7: 44-50.

Du Toit JCO 2003. Patch grazing at Kroomie. MSc Agriculture, University of Natal, Pietermaritzburg.

Dyksterhuis EJ 1949. Condition and management of range land based on quantitative ecology. Journal of Range Management 2: 104-115.

Edwards PJ 1969. The evaluation of veld by animal production. Proceedings of the Grassland Society of southern Africa 4: 99-103.

Edwards PJ and Nel SP 1973. Short term effects of fertilizer and stocking rates on the Bakenveld. 1. Vegetational changes 2. Animal production. Proceedings of the Grassland Society of southern Africa 8: 81-96.

Edwards PJ 1975. The effect of selective defoliation and fertilization on *Cymbopogon – Themeda* veld. Proceedings of the Grassland of southern Africa 15: 73-78.

Edwards PJ 1980. The use of stocking rate animal performance models in research and extension. Proceedings of the Grassland Society of southern Africa 15: 73-77.

Edwards PJ 1981. Grazing management. In: Tainton NM (Ed.). Veld and Pasture management in South Africa. University of Natal Press, Pietermaritzburg.

Egerton FN 1973. Changing concepts of the balance of nature. Quarterly Review of Biology 483: 22-350.

Ellis JE and Swift DM 1988. Stability of African pastoral ecosystems: Alternate paradigms and implications for development. Journal of Range Management 41: 450-459.

Eng PK, Kerridge PC and t'Mannetjie L 1978. Effects of phosphorus and stocking rate on pasture and animal production from a quinea grass-legume pasture in Johora, Malaysia. 1. Dry matter yields, botanical and chemical composition. Tropical Grasslands 12: 188-197.

Everson CS and Clarke GPY 1987. A comparison of six methods of botanical analysis in the montane grasslands of Natal. Vegetatio 73: 47-51.

Everson TM, Clarke GPY and Everson CS 1990. Precision in monitoring plant species composition in montane grasslands. Vegetatio 88: 135-141.

Fernandez-Gimenez ME and Allen-Diaz B 1999. Testing a non-equilibrium model of rangeland vegetation dynamics in Mongolia. Journal of Applied Ecology 36: 871-885.

Foran BD and Stafford Smith DM 1991. Risk, biology and drought management strategies for cattle stations in Central Australia. Journal of Environmental Management 33: 17-33.

Fourie JH 1974. *'n Vergelykende studie van drie veldtipes in Noord-Kaapland*. MSc dissertation. University of the Orange Free State, Bloemfontein.

Fourie JH 1983. *Karakterisering van die weidingkapasiteit van natuurlike weiding in Noord-Kaapland.* PhD. thesis. University of the Orange Free State, Bloemfontein.

Fourie JH, Opperman DPJ and Roberts BR 1985a. Influence of stocking rate and grazing systems on available grazing in the Northern Cape. Journal of the Grassland Society of southern Africa 2 (3): 24-26.

Fourie JH, Opperman DPJ and Roberts BR 1985b. Evaluation of the grazing potential of grass species in *Tarchonanthus* veld of the Northern Cape. Journal of the Grassland Society of southern Africa 2 (4): 13-17.

Fourie JH, Engels EAN and De Bruyn HL 1986a. The influence of stocking rate and grazing systems on crude protein content and digestibility of *Tarchonanthus* veld in the Northern Cape. Journal of the Grassland Society of southern Africa 3 (2): 62-69.

Fourie JH, Engels EAN and Roberts BR 1986b. Herbage intake by cattle on *Tarchonanthus* veld in the Northern Cape as affected by stocking rate and grazing system. Journal of the Grassland Society of southern Africa 3 (3): 85-89.

Friedel MH and Shaw K 1987. Evaluation of methods for monitoring sparse patterned vegetation in arid rangelands. I. Herbage. Journal of Environmental Management 25: 297-308.

Friedel MH, Chewings VH and Bastin GN 1988. The use of comparative yield and dry weight rank techniques for monitoring arid rangeland. Journal of Range Management 41 (5): 430-435.

Friedel MH 1991. Range condition assessment and the concept of thresholds: A viewpoint. Journal of Range Management 44 (5): 422-426.

Frischknecht MC, Harris LE and Woodward HK 1953. Cattle gains and vegetal changes by grazing treatment on crested wheatgrass. Journal of Range Management. 6: 151-158.

Fritz H and Duncan P 1994. On the carrying capacity for large ungulates of African savanna ecosystems. Proceedings of the Royal Society of London 256: 77-82.

Frost P, Medina JC, Solbrig O, Swift M and Walker B 1986. Responses of savannas to stress and disturbance: a proposal for a collaborative programme of research. Report of IUBS working group on Decade of Tropics/Tropical Savanna Ecosystems. Biology International. Special Issue 10.

Fuhlendorf SD and Smeins FE 1999. Scaling effects of grazing in a semi-arid savanna. Applied Vegetation Science 4: 177-188.

Fuhlendorf SD, Briske DD and Smeins FE 2001. Herbaceous vegetation change in variable environments: The relative contribution of grazing and climatic variability. Applied Vegetation Science 4: 177-188.

Fuls ER 1992. Semi-arid rangeland: A resource under siege due to patch selective grazing. Journal of Arid Environments 22: 191-193.

Fynn RWS 1998. Effect of stocking rate and rainfall on rangeland dynamics and cattle performance in a semi-arid savanna, KwaZulu-Natal. MSc dissertation, University of Natal, Pietermaritzburg.

Fynn RWS and O'Connor TG 2000. Effect of stocking rate and rainfall on rangeland dynamics and cattle performance in a semi-arid savanna, South Africa. Journal of Applied Ecology 37: 491-507.

Gammon DM 1978. A review of experiments comparing systems of grazing management on natural systems. Proceedings of the Grassland Society of southern Africa 13: 75-82.

Gammon DM and Roberts BR 1978a. Patterns of defoliation during continuous and rotational grazing of the Matopos Sandveld of Rhodesia, 1. Selectivity of grazing. Rhodesian Journal of Agricultural Research 16: 117-131.

Gammon DM and Roberts BR 1978b. Patterns of defoliation during continuous and rotational grazing of the Matopos Sandveld of Rhodesia, 2. Severity of defoliation. Rhodesian Journal of Agricultural Research 16: 133-145.

Gammon DM and Roberts BR 1978c. Patterns of defoliation during continuous and rotational grazing of the Matopos Sandveld of Rhodesia, 3. Frequency of defoliation. Rhodesian Journal of Agricultural Research 16: 147-164.

Gammon DM 1983a. Veld management: stocking rate and drought consideration. Zimbabwe Journal of Agricultural Research 80: 183-185.

Gammon DM 1983b. Effects of bush clearing, stocking rates and grazing systems on vegetation and cattle gains in the south-western Lowveld of Zimbabwe. Zimbabwe Journal of Agricultural Research 80: 219-228.

Gammon DM 1984. An appraisal of short-duration grazing as a method of veld management. Zimbabwe Journal of Agricultural Research 84: 59-74.

George MR, Brown JR and Clawson J 1992. Application of non-equilibrium ecology to management of Mediterranean grasslands. Journal of Range Management 45: 436-440.

Germishuizen G and Meyer WL 2003. Plants of southern Africa: an annotated checklist. Strelitzia 14. National Botanical Institute, Pretoria.

Gibbs Russell GE, Watson L, Koekemoer M, Smook L, Barker NP, Anderson HM and Dallwitz MJ 1991. Grasses of southern Africa. Memoirs of the Botanical survey of South Africa No 58, National Botanic Gardens/Botanical Research Institute, Pretoria.
Gifford GF and Hawkins RH 1978. Hydrologic impact of grazing on infiltration: a critical review. Water Resources Research 14: 305-313.

Gillen RL and Smith EL 1986. Evaluation of the Dry weight rank method for determining species composition in Tallgrass Prairie. Journal of Range Management 39 (3): 283-285.

Grof B and Harding WAT 1970. Dry matter yields and animal productions of quinea grass *Panicum maximum* on the humid coast of north Queensland. Tropical Grasslands 4: 85-95.

Grunow JO 1959. Rapid rotational grazing for sourveld. Fmq. S. Afr. 35: 40-41.

Grunow JO 1973. Research relating to the management of South African ecosystems. South African Journal of Science. 69: 54-56.

Grunow JO 1980. Principles and practise of controlled selective grazing. Multicamp symposium, Mazelspoort. Department of Plant Production, University of Pretoria.

Hardy MB and Mentis MT 1986. Grazing dynamics in sour grassveld. South African Journal of Science 82: 566-572.

Hardy MB and Hurt CR 1989. An evaluation of veld condition techniques in Highland Sourveld. Journal of the Grassland Society of southern Africa 6 (2): 51-58.

Hardy, MB and Tainton NM 1982. Towards a technique for determining the basal cover in tufted grasslands. African Journal of Range and Forage Science 10 (2): 77-81.

Hardy MB, Hurt CR and Bosch OJH 1999. Veld condition. In: Tainton NM (Ed.) Veld management in South Africa. Chapter eight. University of Natal Press, Pietermaritzburg.

Hart RH 1978. Stocking rate theory and its application to grazing on rangeland. In: Proceedings of the 1st Int. Rangeland Congress, DN Hyder (Ed), Society of Rangeland Management, Denver, Colorado: 547-550.

Hary I, Schwartz H, Pielert V and Mosler C 1996. Land degradation in African pastoral systems and the destocking controversy. Ecological Modelling 86: 227-233.

Hatch GP 1994. The bio-economic implications of various stocking strategies in the semi-arid savanna of Natal. PhD thesis. University of Natal. Pp. 89-102.

Hatch GP 1995. Does conservative stocking in a variable environment pay? Proceedings of the Fifth International Rangeland Congress, Volume one. Salt Lake City, Utah. Pp. 217.

Hatch GP and Tainton NM 1995. The influence of stocking rate, range condition and rainfall on the residual herbage mass in the semi-arid savanna of KwaZulu-Natal. African Journal of Range and Forage Science 12 (2): 76-80.

Hatch GP, Tainton NM and Ortmann GF 1996. Towards the development of a bioeconomic stocking model for the semi-arid savanna of KwaZulu-Natal. African Journal of Range and Forage Science 13 (2): 67-71.

Haydock KP and Shaw NH 1975. The comparative yield method for estimating dry matter yield of pasture. Australian Journal of Experimental Agriculture 15: 663-670.

Hazell DB 1967. Effects of grazing intensity on plant composition, vigour and production. Journal of Range Management 20: 249-251.

Heitschmidt RK and Taylor CA 1991. Livestock production. In: Heitschmidt RK and Stuth JW (Eds.) Grazing management: An ecological perspective. Timber Press, Portland, Oregon.

Higgins PAT, Mastrandrea MD and Schneider SH 2002. Dynamics of climate and ecosystem coupling: abrupt changes and multiple equilibria. Philosophical Transactions of the Royal Society of London 357:647-655.

Hildyard P 1960. Even utilization of sourveld. Fmq. S. Afr. 36: 33-34.

Hoffman MT and Cowling RM 1990. Vegetation change in the semi-arid eastern Karoo over the last two hundred years: an expanding Karoo-fact or fiction? South African Journal of Science 86:286-294.

Holling CS 1973. Resilience and stability of ecosystems. Annual Review of Ecology and Systematics 4:1-23.

Houston WR and Woodward RR 1966. Effects of stocking rates on range vegetation and beef cattle production in the Northern Great Plains. United States Department of Agriculture Bulletin. 1257: 58.

Howell LN 1976. The development of multicamp systems on a farm in the southern Orange Free State. Proceedings of the Grassland Society of southern Africa 11: 53-57.

Huisman J, Grover JP, van der Waal R and Andel J 1999. Competition for light, plant-species replacement and herbivore abundance along productivity gradients. In: Olff H, Brown VK and Drent RH (Eds.). Between Plants and predators. Oxford, Blackwell Science: 239-269.

Hull JL, Meyer JH and Kromann R 1961. Influence of stocking rate on animal and forage production from irrigated pasture. Journal of Animal Science 20: 45-52.

Hurt LE and Wolf LL 1974. Stability in relation to nutrient enrichment in arthropod consumers of old-field successional ecosystems. Ecological Monographs 44: 465-482.

Huston M 1979. A general hypothesis of species diversity. American Naturalist 113: 81-101.

Illius AW and O’Connor TG 1999. On the relevance of non-equilibrium concepts to arid and semi-arid grazing systems. Ecological Applications 9 (3): 798-813.

Illius AW and O’Connor TG 2000. Resource heterogeneity and ungulate population dynamics. Oikos 89: 283-294.

Jones RM and Hargreaves JNG 1979. Improvements to the dry weight rank method for measuring botanical composition. Grass and Forage Science 34: 181-189.

Jones RJ and Sandland RI 1974. The relation between animal gain and stocking rate in grazing trials. J. Agric. Sci. Camb. 83: 335-342.

Jones RI, Theron EP and Venter AD 1967. Comparison of 3- and 4-camp systems of rotational grazing and resting on mowable Ngongoni Sourveld. Pasture management and soil conservation progress report for 1966/67. Department of Agriculture, Natal Region.

Kelly RD 1973. A comparative study of primary productivity in different kinds of land use in South East Rhodesia. PhD thesis, University of London, London.

Kelly RD and McNeil L 1980. Tests of two methods for determining herbaceous yield and botanical composition. Proceedings of the Grassland Society of southern Africa 15: 167-171.

Kennan TCD 1969. A review of research into the cattle-grass relationship in Rhodesia. Proceedings of the Veld Management conference, Bulawayo, May 1969, pp 5-26.

Kincaid DR and Williams G 1966. Rainfall effects on soil surface characteristics following range improvement treatments. Journal of Range Management 19: 346-350.

Kirkman KP, Engelbrecht A and Cockcroft VA 1994. The Dry-Weight-Rank method of botanical analysis. Bulletin of the Grassland Society Southern Africa 52: 36-38.

Kirkman KP and Moore A 1995. Perspective: Towards improved grazing recommendations for sourveld. African Journal of Range and Forage Science 12 (3): 135-144.

Kirkman KP 1999. Impact of stocking rate, livestock type and livestock movement on sustainable utilisation of sourveld. PhD thesis, University of Natal, Pietermaritzburg.

Kirkman KP unpublished. Dry weight rank data processing: Spreadsheet instructions. University of KwaZulu Natal, Pietermaritzburg.

Koch FG 1979. Agrometereologiese analise vir Armoedsvlakte 1920-1978. Unpublished report, Navorsing instituut vir grond en besproeing, Department van Landbou and Tegniese Dienste.

Kreuter UP, Brockett GM, Lyle AD, Tainton NM and Bransby DI 1984. Evaluation of veld potential in East Griqualand using beef cattle under two grazing management systems. Journal of the Grassland Society of southern Africa 1 (4): 5-10.

Langlands JP and Bennett IL 1973. Stocking intensity and pastoral production. II. Herbage intake of Merino sheep grazed at different stocking rates. Journal of Agricultural Science 81: 205-209.

Laycock WA 1989. Secondary succession and range condition criteria: introduction to the problem. In: Secondary succession and the evaluation of range condition. Lauenroth, WK and Laycock WA (Eds.) Pp. 1-15, Westview, Boulder, CO.

Laycock WA 1991. Stable states and thresholds of range condition on North American rangelands: A viewpoint. Journal of Range Management 44 (5): 427-433.

Le Houerou 1989. The grazing land ecosystems of the African Sahel. Springer-Verlag, New York.

Leps J and Smilauer P 1999. Multivariate analysis of ecological data. University of South Bohemia, Ceske Budejocie.

Leps J and Smilauer P 2003. Multivariate analysis of ecological data using Canoco. Cambridge University Press, United Kingdom.

Livingstone I 1991. Livestock management and "overgrazing" among pastoralists. Ambio 20 2: 80-85.

Macvicar CN 1991. Soil classification: A taxonomic system for South Africa. Department of Agricultural Development, Pretoria, pp. 180.

May RM 1977. Thresholds and breakpoints in ecosystems with a multiplicity of stable states. Nature 269: 471-477.

McCarthy N 2001. Rainfall variability, traditional and commercial rangelands management and the drought cycle: Some theoretical considerations and empirical evidence from Ethiopia. Fourth Toulouse Conference.

Mckay AD 1968. Rangeland and productivity in Botswana. East African Agricultural & Forage Journal 34: 178-192.

McMeekan CP and Walshe MJ 1963. The interrelationship of grazing method and stocking rate in the efficiency of pasture utilization by cattle. J. Agric. Sci. Camb. 61: 147-163.

McNaughton SJ 1983. Compensatory plant growth as a response to herbivory. Oikos 40: 329-336.

Mentis MT, Collinson RFH and Wright MG 1980. The precision of assessing components of the condition of Moist Tall Grassveld. Proceedings of the Grassland Society of southern Africa 15: 43-46.

Mentis MT 1982. A simulation of the grazing of sour grassveld. PhD Thesis, University of Natal, Pietermaritzburg.

Mentis MT, Grossman D, Hardy MB, O'Connor TG and O'Reagain PJ 1989. Paradigm shifts in South African range science, management and administration. South African Journal of Science 85: 684-687.

Meyer TC, Venter IS and Van Zijl A 1996. The influence of grazing system and stocking rate of vegetation change in the *Tarchonanthus* veld of the Ghaap Plateau. Progress report no 1, Projek no V5411/36/010/01.

Milchunas DG and Laurenroth WK 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. Ecological Monographs 63: 327-366.

Milton SJ and Hoffman MT 1994. The application of state and transition models to rangeland research and management in arid succulent and semi-arid grassy Karoo, South Africa. African Journal of Range and Forage Science 11 (1): 18-26.

Moore RM and Biddescombe EF 1964. The effects of grazing on Grasslands. In: Barnard, Macmillan & Co (Ed.) Grasses and Grasslands, Melbourne, pp 221-235.

Morris JJ 1944. A sheep grazing experiment on natural veld at Glen. Farming in South Africa September 1944, pp.591-597.

Morris CD, Tainton NM and Hardy MB 1992. Plant species dynamics in Southern Tall Grassveld under grazing, resting and fire. Journal of the Grassland Society of southern Africa 9 (2): 90-95.

Morris CD and Tainton NM 1996. Long-term effects of different rotational grazing schedules on the production and floristic composition of Tall Grassveld in KwaZulu-Natal. African Journal of Range and Forage Science 13 (1): 24-28.

Morris CD, Hardy MB and Bartholomew PE 1999. Stocking rate. In: Tainton, N.M. (Ed.) Veld management in South Africa. University of Natal Press, Pietermaritzburg.

Morris CD and Fynn RWS 2001. The Ukulinga Grassland trials: Reaping the fruits of meticulous, patient research. Bulletin of the Grassland Society of southern Africa 111: 1-17.

Mostert JWC, Roberts BR, Heslinga CF and Coetzee PGF 1971. Veld management in the Orange Free State region. Bulletin No. 399, Government Printer, Pretoria.

Norton BE 1998. The application of grazing management to increase sustainable livestock production. Animal production in Australia 22:15-26.

Noy-Meir I 1975. Stability of grazing systems: an application of predator prey graphs. Journal of Ecology 63: 459-481.

O'Connor TG 1991. Influence of rainfall and grazing on the compositional change of the herbaceous layer of a sandveld savanna. Journal of the Grassland Society of southern Africa 8 (3): 103-109.

O'Connor TG and Pickett GA 1992. The influence of grazing on seed production and seed banks of some African savanna grasslands. Journal of Applied Ecology 29: 247-260.

O'Connor TG 1994. Composition and population responses of an African savanna grassland to rainfall and grazing. Journal of Applied Ecology 31: 155-171.

O'Connor TG 1995. Transformation of a savanna grassland by drought and grazing. African Journal of Range and Forage Science 12 (2): 53-60.

O'Connor TG and Roux PW 1995. Vegetation changes 1949-71 in a semi-arid, grassy dwarf shrubland in the Karoo, South Africa: Influence of rainfall variability and grazing by sheep. Journal of Applied Ecology 32: 612-626.

O'Neill RV, DeAngelis DL, Waide JB and Allen TFH 1986. A hierarchical concept of ecosystems. Princeton University Press, Princeton, New Jersey.

O'Reagain PJ and Turner JR 1992. An evaluation of the empirical basis for grazing management recommendations for rangeland in southern Africa. Journal of the Grassland Society of southern Africa 9 (1): 38-50.

O'Reagain PJ 1996. Predicting animal production on sourveld: a species-based approach. African Journal of Range and Forage Science 13 (3): 113-123.

Pearson HA and Whitaker LB 1974. Yearlong grazing of slash pine ranges: Effects of herbage on browse. Journal of Range Management. 27: 195-199.

Peel MJS, Biggs H and Zacharias PJK 2000. The evolving use of stocking rates indices currently based on animal number and type in semi-arid heterogeneous landscapes and complex land-use systems. African Journal of Range and Forage Science 15 (3): 117-127.

Peterson RG, Lucas HL and Mott GO 1965. Relationship between rate of stocking and per animal and per acre performance on pasture. Agron Journal 57:27-30.

Pickett STA, Parker VT and Friedler PL 1992. The new paradigm is ecology: implications for conservation biology above the species level. In: Friedler PL and Jain SK (Eds.). Conservation biology: the theory and practice of nature conservation, preservation and management. Chapman and Hall, New York. Pp. 65-88.

Pickett STA. and Ostfeld RS 1995. The shifting paradigm in ecology. In: Knight RL and Bates SF (Eds.). A new century for natural resource management. Island Press Washington DC. Pp. 261-278.

Pienaar AJ 1968a. Veld control in the mixed and sourveld regions of South Africa. In: Hugo WJ (Ed.). The small stock industry in South Africa. Government Printer, Pretoria, pp. 341-368.

Pienaar AJ 1968b. Weiveldbestuur op Soutpan: Toepassings in die suur tot suuragtige gemengde Bosveld. Farmers' Day at Soutpan. Lecture Series No.1, Department of Agriculture Technical Services, Republic of South Africa.

Piper R, Cook CW and Harris LE 1959. Effects of intensity of grazing upon nutritive content of the diet. Journal of Animal Science. 18: 1031-1037.

Pluhar JJ, Knight RW and Heidtschmidt RK 1987. Infiltration rates and sediment production as influenced by grazing systems in the Texas rolling plains. Journal of Range Management 40 (3): 240-242.

Preller JH 1947. *Weiveld en weidingsgewasse proefresultate met beweidingstelsel vir natuurlike en aangeplante weidings*. Government Printer, Pretoria.

Preller JH 1948. Pasture control. Fmq. S. Afr. 24: 191-199.

Pretorius MW, Grunow JO and Rabie JW 1974. Influence of frequency and intensity of defoliation on production and morphological development of *Panicum maximum* Jacq. cv. Sabi. Proceedings of the Grassland Society of southern Africa. 9: 111-115.

Rauzi F and Hanson CL 1966. Water intake and runoff as affected by intensity of grazing. Journal of Range Management. 19: 351-356.

Rauzi F and Smith FM 1973. Infiltration rates: Three soils with three grazing levels in North-eastern Colorado. Journal of Range Management. 26: 126-129.

Reich RM, Bonham CD and Remington KK 1993. Technical notes: Double sampling revised. Journal of Range Management 46: 88-90.

Rethman NFC. 1971. Elevation of shoot apices of two ecotypes of *Themeda triandra* on the Transvaal highveld. Proceedings of the Grassland Society of southern Africa 6: 86-92.

Rhoades ED, Locke LF, Taylor HM and McIlvain EH 1964. Water intake on a sandy range as affected by 20 years of differential cattle stocking rates. Journal of Range Management 17: 185-190.

Richter CGF, Snyman HA and Smit GN 2001. The influence of tree density on the grass layer of three semi-arid savanna types of southern Africa. African Journal of Range and Forage Science 18: 103-109.

Riechers RK, Conner JR and Heitschmidt RK 1989. Economic consequences of alternative stocking rate adjustment tactics: a simulation approach. Journal of Range Management 42: 165-171.

Roberts BR 1967a. Non-selective grazing-an evaluation: 2. A survey of farmers' experiences. Farmer's Weekly 26 July 1967, pp. 34-39.
Roberts BR 1967b. Non-selective grazing-an evaluation: 3. Recommendations and conclusions. Farmer's Weekly 3 August 1967, pp. 34-37.

Roberts BR 1970. Why multicamp layouts? Proceedings of the Grassland Society of southern Africa. 5: 17-22.

Robinson GC and Simpson IH 1975. The effects of stocking rate on animal production from continuous and rotational grazing systems. J. Brit. Grassld. Soc. 30: 315-325.

Roux PW 1964a. *Veld beweidingsproef: Seligman Ou Blok Vlakteveld*. Progress Report, Facet K-Gf2. Dept. Agric. Dev., P/Bag X529, Middelburg Cape 5900.

Roux PW 1964b. *Veld beweidingsproef: Bergkamp Ranteveld*. Progress Report, Facet K-Gf3. Department of Agriculture, P/Bag X529, Middelburg Cape 5900.

Roux PW 1966. *Die uitwerking van seisoensreenval en beweiding op gemengde Karooveld*. Proceedings of the Grassland Society of southern Africa 1: 103-110.

Roux PW 1968. Principles of veld management in the Karoo and the adjacent dry sweet-grass veld. In: Hugo WJ (Ed.). The small stock industry in South Africa. Government Printer, Pretoria, pp. 318-325.

Rowland JW 1937. Grazing management. Department of Agriculture, Bulletin No. 168, Government Printer, Pretoria.

Sandland RL, Alexander JC and Haydock KP 1982. A statistical assessment of the Dry Weight Rank method of pasture sampling. Grass and Forage Science 37: 263-272.

Savory CAR. 1969. Principles of range deterioration, reclamation and management. Proceedings of the Veld Management Conference, Bulawayo. Government Printer, Salisbury, Rhodesia, pp. 83-87.

Savory A 1978. A holistic approach to ranch management using short duration grazing. Proceedings of the First International Rangeland Congress Denver, Colorado, pp. 555-557.

Scoones I 1992. Land degradation and livestock production in Zimbabwe's communal areas. Land Degradation and Rehabilitation 3: 99-113.

Scoones I 1994. New directions in pastoral development, Africa. In: Scoones, I. (Ed.). Living with certainty. Intermediate Technology publications, London, United Kingdom.

Scott JD 1947. Veld management in South Africa. Department Agriculture, Bulletin No. 278, Government Printer, Pretoria.

Senft RL, Rittenhouse LR and Woodmansee RG 1985. Factors influencing patterns of cattle grazing behaviour on Shortgrass Steppe. Journal of Range Management 38 (1): 82-87.

Simpson J 1968. Non-selective grazing symposium at Grootfontein. Farmers Weekly 3 April 1968, pp. 85.

Snyman HA and Fouche HJ 1991. Production and water use efficiency of semi-arid grasslands of South Africa as affected by veld condition and rainfall. Water South Africa 17: 263-267.

Snyman HA and Fouche HJ 1993. Estimating seasonal herbage production of a semi-arid grassland based on veld condition, rainfall and evapotranspiration. African Journal of Range and Forage Science 10 (1): 21-24.

Stobbs TH 1970. The use of liveweight gain trials for pasture evaluation in the tropics: 6. A fixed stocking rate design. J. Br. Grassld Soc. 25: 73-77.

Stringham TZ, Krueger WC and Shaver PL 2003. State and transition modelling: An ecological process approach. Journal of Range Management 56 (2): 106-113.

Stuart-Hill GC 1989. Adaptive management: The only practicable method of veld management. In: Danckwerts JE and Teague WR (Eds.). Veld management in the Eastern Cape. Chapter two. Department of Agric and Water Supply, Pretoria. Pp. 4-7.

Stuth JW 1991. Foraging behaviour. In: Heitschmidt RK and Stuth JW (Eds.), Grazing Management: an Ecological Perspective, pp. 65-83. Portland Timber Press.

Sutherland JP 1974. Multiple stable points in natural communities. American Naturalist 108: 859-873.

Swemmer A 1998. The distribution and ecology of grazing lawns in a South African savanna ecosystem. Honours, Botany, Cape Town. University of Cape Town.

Tainton NM 1958. Studies on the growth and development of certain veld grasses with special references to defoliation. MSc thesis, University of Natal, Pietermaritzburg.

Tainton NM 1972. The relative contribution of overstocking and selective grazing to the degeneration of Tall Grassveld in Natal. Proceedings of the Grassland Society of southern Africa 7:39-43.

Tainton NM, Booysen P de V and Nash RC 1977. The grazing rotation: Effects of different combinations of periods of presence and absence. Proceedings of the Grassland Society of southern Africa 12: 103-104.

Tainton NM 1982. Veld evaluation and sweetveld observation. Proceedings of the Grassland Society of southern Africa 6: 50-54.

Tainton NM 1984. A guide to the literature on research in the grassland biome of South Africa. South African Natural Science Programme Report No. 96, Dec. 1984, pp. 77.

Tainton NM 1985. Recent trends in grazing management philosophy in South Africa. Journal of the Grassland Society of southern Africa 2 (4): 4-6.

Tainton NM 1986. A system for assessing range condition in South Africa. In: Joss PJ and Williams OB (Eds.). Rangelands: a resource under siege. Proceedings of the 2nd International Rangeland Congress, Australian Academy of Sciences, Canberra, pp. 254.

Tainton NM, Morris CD and Hardy MB 1996. Complexity and stability in grazing systems. In: Hodgson J and Illius AW (Eds.). The ecology and management of grazing systems. Chapter 10. CAB International, Wallingford, Oxon. Pp. 275-299.

Tainton NM, Aucamp AJ and Danckwerts JE 1999. Principles of managing veld. In: Tainton NM (Ed.) Veld Management in South Africa. University of Natal Press, Pietermaritzburg.

Teague WR 1989. Management of Veld Types: Grass/Bush communities. In: Danckwerts JE and Teague WR (Eds.). Veld management in the Eastern Cape. Pasture Research Section, Eastern Cape Region.

Teague WR and Dowhover SL 2002. Patch grazing under rotational and continuous grazing management in large, heterogeneous paddocks. Journal of Arid Environments In Press.

Teague WR and Dowhover SL 2003. Drought and grazing patch dynamics under different grazing management treatments in Southern USA Prairie. Proceedings of the International Rangeland Congress, Durban, South Africa, Pp. 405-407.

ter Braak CJF 1987. Ordination. In: Jongman RHG, ter Braak CJF and van Tongeren OFR. (Eds.). Data analysis in community and landscape ecology. Chapter five. Pudoc Wageningen, Netherlands, Pp: 91-173.

ter Braak CJF and Smilauer P 1998. Canoco 4: Reference manual and user’s guide to Canoco for Windows: Software for Canonical Community ordination. Version four. Microcomputer Power, Ithaca, New York.

ter Braak CJF and Smilauer P 2003. Canoco 4.5 for Windows. Biometris Plant and Research International Wageningen, Netherlands.

Thurow TL, Blackburn WH and Taylor CA 1986. Hydrologic characteristics of vegetation types as affected by livestock grazing systems, Edwards Plateau, Texas. Journal of Range Management 39 6: 505-509.

Tidmarsh CEM 1951. Veld management studies at the Grootfontein College of Agriculture: 1934-1950. Pasture Research in South Africa. Progress Report No. III, Part 1. Department of Agriculture, Karoo Region.

Tidmarsh CEM and Havenga CM 1955. The Wheel-Point method of survey and measurement of semi-open Grasslands and Karoo vegetation in South Africa. Botanical Survey of South Africa, Memoir No. 29, Pretoria.

t’Mannetjie L and Haydock KP 1963. The Dry-Weight-Rank method for the botanical analysis of pasture. Journal of the British Grassland Society 18 (4): 268-275.

Turner JR and Tainton NM 1990. A comparison of four different standards of reference for the animal unit for determining stocking rate. Journal of the Grassland Society of southern Africa 7 (3): 204-207.

Turner MD 1999. Spatial and temporal scaling of grazing impact on the species composition and productivity of Sahelian annual grasslands. Journal of Arid Environments 41: 277-297.

Van den Berg JA, Roberts BR and Vorster LF 1975. Die uitwerking van seisonbeweiding op die bedekking en samestelling van *Cymbopogon-Themeda* veld. Proceedings of the Grassland Society of southern Africa 10: 111-117.

Van den Berg JA, Roberts BR and Vorster LF 1976. Die uitwerking van seisonbeweiding op die infiltrasie vermoe van gronde in n *Cymbopogon-Themeda* veld. Proceedings of the Grassland Society of southern Africa 11: 91-96.

Van der Merwe CR 1941. Soil groups and sub-groups of South Africa. Science Bulletin 231, the Government Printer, Pretoria.

Van Niekerk A, Hardy MB, Mappledoram BD and Lesch SF 1984. The effect of stocking rate and lick supplementation on the performance or lactating beef cows and its impact on Highland Sourveld. Journal of the Grassland Society of southern Africa 1 (2): 18-21.

Van Oudtshoorn F 1999. Guide to the Grasses of southern Africa. Briza Publications, Pretoria.

Van Poolen HW and Lacy JR 1979. Herbage response to grazing systems and stocking intensities. Journal of Range Management 32: 250-253.

Vaughan-Evans RH 1978. Short duration grazing for reclamation and conservation of veld. Bembezaan Natural Resources Sub-committee, Zimbabwe, pp. 45.

Venter AD and Drewes RH 1969. A flexible system of veld management. Proceedings of the Grassland Society of southern Africa 4: 104-107.

Venter IS 1991. *Weidingkapasiteitstudies op veld in die Noord-Kaap*. MSc. Agric dissertation. University of the Orange Free State, Bloemfontein.

Venter IS 1991b. *Die vasstelling van norme om dragkrag van veld te Armoedsvlakte te ondersoek*. Facet V5411/36/1/1: Progress report 1991/92. Unpublished report. Glen: Department of Agriculture, Free State Region.

Vorster LF 1975. The influence of prolonged seasonal defoliation of veld yields. Proceedings of the Grassland Society of southern Africa 10: 119-122.

Vorster LF and Visagie AFJ 1980. *Die invloed van aantal kampe en veegetalle op diereproduksie en veldtoestand*. Proceedings of the Grassland Society of southern Africa 15: 131-135.

Vorster M, Botha P and Hobson FO 1983. The utilization of Karoo veld by livestock. Proceedings of the Grassland Society of southern Africa 18: 35-39.

Wallis De Vries MF and Schippers P 1994. Foraging in a landscape mosaic: Selection for energy and minerals in free-ranging cattle. Oecologia 100: 107-117.

Walker B and Scott GD 1968. Grazing experiments at Ukiriguru, Tanzania. 3. A comparison of three stocking rates on the productivity and botanical composition of hardpan soils. East African Agricultural and Forage Journal 34: 245-255.

Walker BH, Emslie RH, Owen-Smith RN and Scholes RJ 1987. To cull or not to cull: Lessons from a southern African drought. Journal of Applied Ecology 24: 381-401.

Walker BH 1993a. Rangeland Ecology: understanding and managing change. Ambio 22: 80-87.

Walker BH 1993. Stability in rangelands: ecology and economics. Proceedings of the XVII International Grassland Congress 1885-1890.

Warren SD, Thurow TL, Blackburn WH and Garza NE 1986. The influence of livestock trampling under intensive rotation grazing on soil hydrologic characteristics. Journal of Range Management 44 (5): 266-273.

Watson IW, Westoby M and Holm A McR 1996. Event-driven or continuous, which is the better model for managers? Rangelands Journal 18: 351-369.

Westoby M 1979/80. Elements of a theory of vegetation dynamics in arid rangelands. Israel Journal of Botany 28: 169-194.

Westoby M, Walker BH and Noy-Meir I 1989. Opportunistic management for rangelands not at equilibrium. Journal of Range Management 42: 266-274.

Wiens JA 1984. On understanding a non-equilibrium world: myth and reality in community patterns and processes. In: Strong DR, Simberloff D, Abele L and Thistle AB (Eds.). Ecological Communities: Conceptual issues and the Evidence. Princeton University Press, New Jersey.

Wu J and Loucks OC 1995. From balance of nature to hierarchical patch dynamics: A paradigm shift in Ecology. The Quarterly Review of Biology 70 4: 439-466.

List of appendixes

Appendix 1: Description of the abbreviations used to describe the paddocks in **Error! Reference source not found.**

Name of Paddock	Description of treatments
LW1	Rotational grazing system at a light stocking rate replication one
LW2	Rotational grazing system at a light stocking rate replication two
LW3	Rotational grazing system at a light stocking rate replication three
LW4	Rotational grazing system at a light stocking rate replication four
LW5	Rotational grazing system at a light stocking rate replication five
LW6	Rotational grazing system at a light stocking rate replication six
MW1	Rotational grazing system at a medium stocking rate replication one
MW2	Rotational grazing system at a medium stocking rate replication two
MW3	Rotational grazing system at a medium stocking rate replication three
MW4	Rotational grazing system at a medium stocking rate replication four
MW5	Rotational grazing system at a medium stocking rate replication five
MW6	Rotational grazing system at a medium stocking rate replication six
SW1	Rotational grazing system at a high stocking rate replication one
SW2	Rotational grazing system at a high stocking rate replication two
SW3	Rotational grazing system at a high stocking rate replication three
SW4	Rotational grazing system at a high stocking rate replication four
SW5	Rotational grazing system at a high stocking rate replication five
SW6	Rotational grazing system at a high stocking rate replication six

Appendix 2: Description of the abbreviations used to describe the paddocks in **Error! Reference source not found.**

Name of Paddock	Description of treatments
LW1	Rotational grazing system at a light stocking rate replication one
LW2	Rotational grazing system at a light stocking rate replication two
LW3	Rotational grazing system at a light stocking rate replication three
LW4	Rotational grazing system at a light stocking rate replication four
LW5	Rotational grazing system at a light stocking rate replication five
LW6	Rotational grazing system at a light stocking rate replication six
MW1	Rotational grazing system at a medium stocking rate replication one
MW2	Rotational grazing system at a medium stocking rate replication two
MW3	Rotational grazing system at a medium stocking rate replication three
MW4	Rotational grazing system at a medium stocking rate replication four
MW5	Rotational grazing system at a medium stocking rate replication five
MW6	Rotational grazing system at a medium stocking rate replication six
VW1	Rotational grazing system at a medium-heavy stocking rate replication one
VW2	Rotational grazing system at a medium-heavy stocking rate replication two
VW3	Rotational grazing system at a medium-heavy stocking rate replication three
VW4	Rotational grazing system at a medium-heavy stocking rate replication four
VW5	Rotational grazing system at a medium-heavy stocking rate replication five
VW6	Rotational grazing system at a medium-heavy stocking rate replication six
SW1	Rotational grazing system at a heavy stocking rate replication one
SW2	Rotational grazing system at a heavy stocking rate replication two
SW3	Rotational grazing system at a heavy stocking rate replication three
SW4	Rotational grazing system at a heavy stocking rate replication four
SW5	Rotational grazing system at a heavy stocking rate replication five
SW6	Rotational grazing system at a heavy stocking rate replication six
LA	Continuous grazing system at a light stocking rate
MA	Continuous grazing system at a medium stocking rate
VA	Continuous grazing system at a medium-heavy stocking rate
SA	Continuous grazing system at a heavy stocking rate

Appendix 3: The division of grass species into different ecological groups as required by the ecological index method Hardy *et al.* (1999)). Other 1 refers to forb species that were grouped into the highly desirable group, Other 2 refers to forb species that were grouped into the desirable group, Other 3 refers to forb species that were grouped into the less desirable group and Other 4 to forb species that were grouped into the undesirable group.

Highly desirable group	**Desirable group**	**Less-desirable group**	**Undesirable group**
Anthephora pubescens	*Cymbopogon plurinodis*	*Cynodon dactylon*	*Aristida congesta*
Brachiaria nigropedata	*Eragrostis lehmanniana*	*Elionurus muticus*	*Tragus racemosus*
Chrysopogon serrulatus	*Eragrostis superba*	*Eragrostis nindensis*	*Enneapogon desvauxii*
Digitaria eriantha	*Fingerhuthia africana*	*Eragrostis pseudo-obtusa*	*Oropetium capense*
Eustachys paspaloides	*Heteropogon contortus*	*Aristida meridionalis*	*Pogonarthria squarrosa*
Panicum stapfianum	*Stipagrostis uniplumis*	*Enneapogon scoparius*	*Microchloa caffra*
Schmidtia pappophoroides	*Eragrostis echinochloidea*	*Brachiaria marlothii*	*Aristida stipitata*
Sporobolus fimbriatus	*Melinis repens*	*Eragrostis trichophora*	*Triraphis andropogonoides*
Themeda triandra	*Eragrostis rigidior*	*Eragrostis obtusa*	*Eragrostis pallens*
Other 1	*Diheteropogon amplectens*	Other 3	*Trichoneura grandiglumis*
	Other 2		*Tragus koelerioides*
			Aristida diffusa
			Other 4

The classification was taken from Fourie (1983). Fourie (1983) describes the four ecological groups as follows:

Highly desirable species are grass species with a high biomass production, high feeding value, good soil stabilizers and they are perennial species. These species have Decreaser characteristics because these species are dominant in veld in a very good condition and they decrease in abundance with under- and overgrazing.

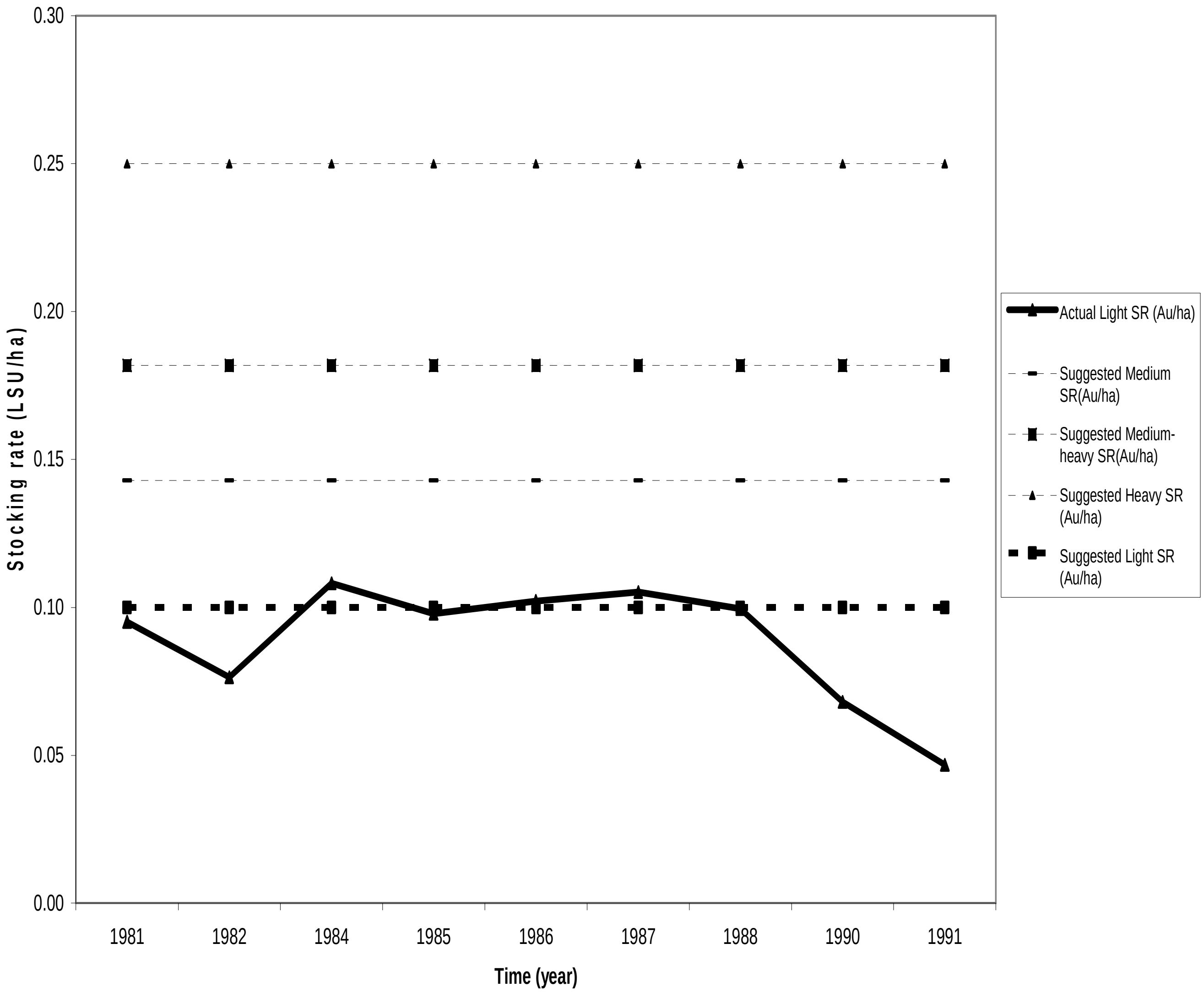
Desirable species are grass species with an average biomass production and they are good soil stabilizers. These species have Increaser 1a characteristics e.g. scarce in veld that is in good condition and they increase in abundance in veld which has slight under or selective grazing) and Increaser 2a characteristics scarce in veld that is in good condition and they increase in abundance in veld which has slightly overgrazed).

Less desirable species are grass species with poor biomass production, poor feeding value and they are weak perennials. These species are still good soil stabilizers. These species have Increaser 1b characteristics e.g. scarce in veld that is in good condition and they increase in abundance in veld which has been highly under or selective grazed) and Increaser 2b characteristics e.g. scarce in veld that is in good condition and they increase in abundance in veld which has highly overgrazed) characteristics.

Undesirable species are grass species, which have a very low biomass production, they are very weakly perennial, but mostly annual species and they are poor soil stabilizers. These species have Increaser 2c characteristics, which are species that are very scarce in veld in good condition and increase in abundance with very heavy overgrazing.

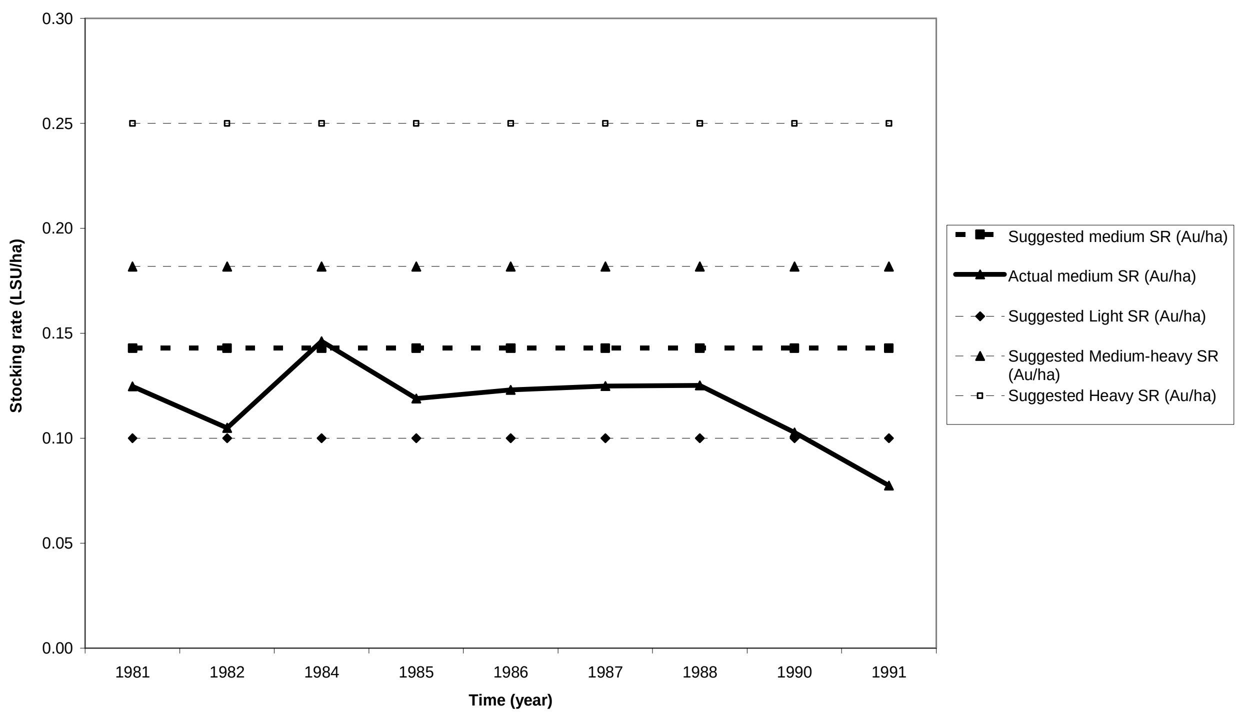
Appendix 4: Actual stocking rates applied during phase one of the grazing trial at the Armoedsvlakte Research Station for the light stocking rate and rotational grazing system treatment. The abbreviation SR refers to the stocking rate (AU/ha) applied.

Year	1981	1982	1984	1985	1986	1987	1988	1990	1991
Suggested Light SR (Au/ha)	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
Actual Light SR (Au/ha)	0.0951	0.0764	0.1082	0.0979	0.1022	0.1052	0.0995	0.0680	0.0467
Suggested Medium SR(Au/ha)	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429
Suggested Medium-heavy SR(Au/ha)	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818
Suggested Heavy SR (Au/ha)	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500



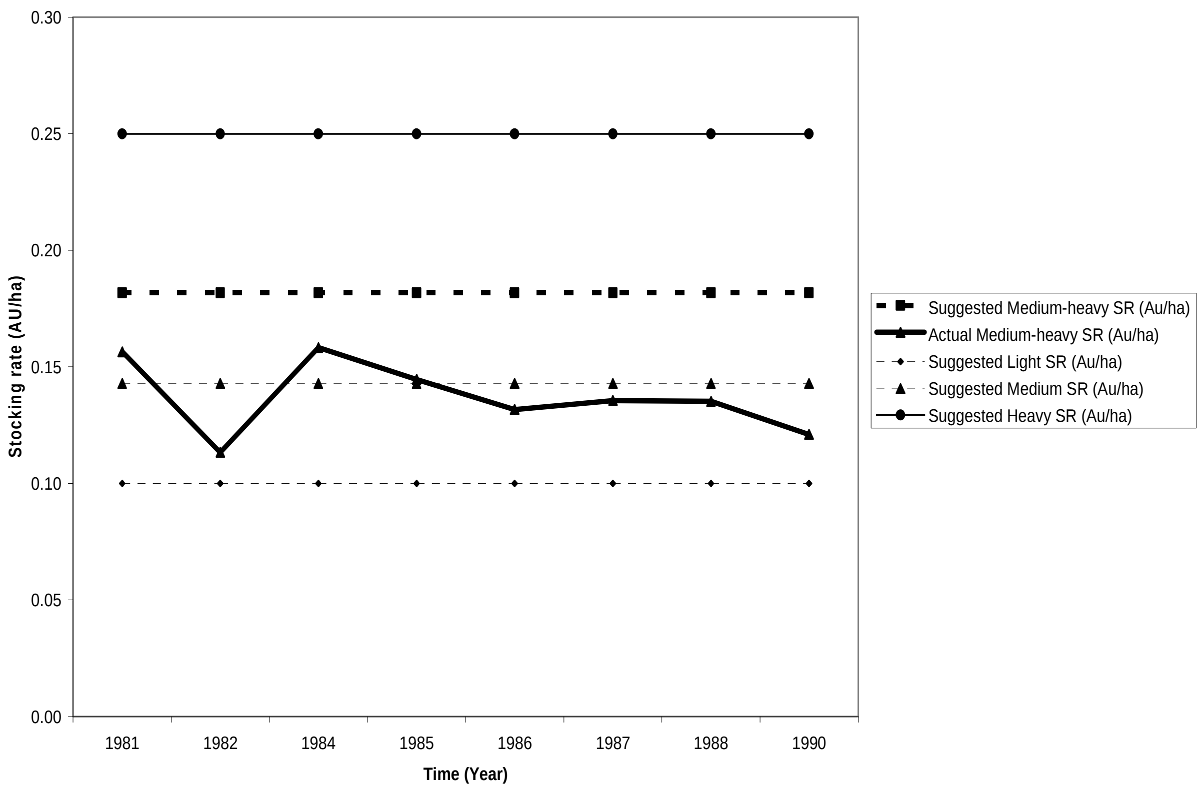
Appendix 5: Actual stocking rates applied during phase one of the grazing trial at the Armoedsvlakte Research Station for the medium stocking rate and rotational grazing system treatment. The abbreviation SR refers to the stocking rate (AU/ha) applied.

Time (year)	1981	1982	1984	1985	1986	1987	1988	1990	1991
Suggested medium SR (Au/ha)	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429
Actual medium SR (Au/ha)	0.1248	0.1049	0.1462	0.1189	0.1230	0.1249	0.1252	0.1027	0.0774
Suggested Light SR (Au/ha)	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
Suggested Medium-heavy SR (Au/ha)	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818
Suggested Heavy SR (Au/ha)	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500



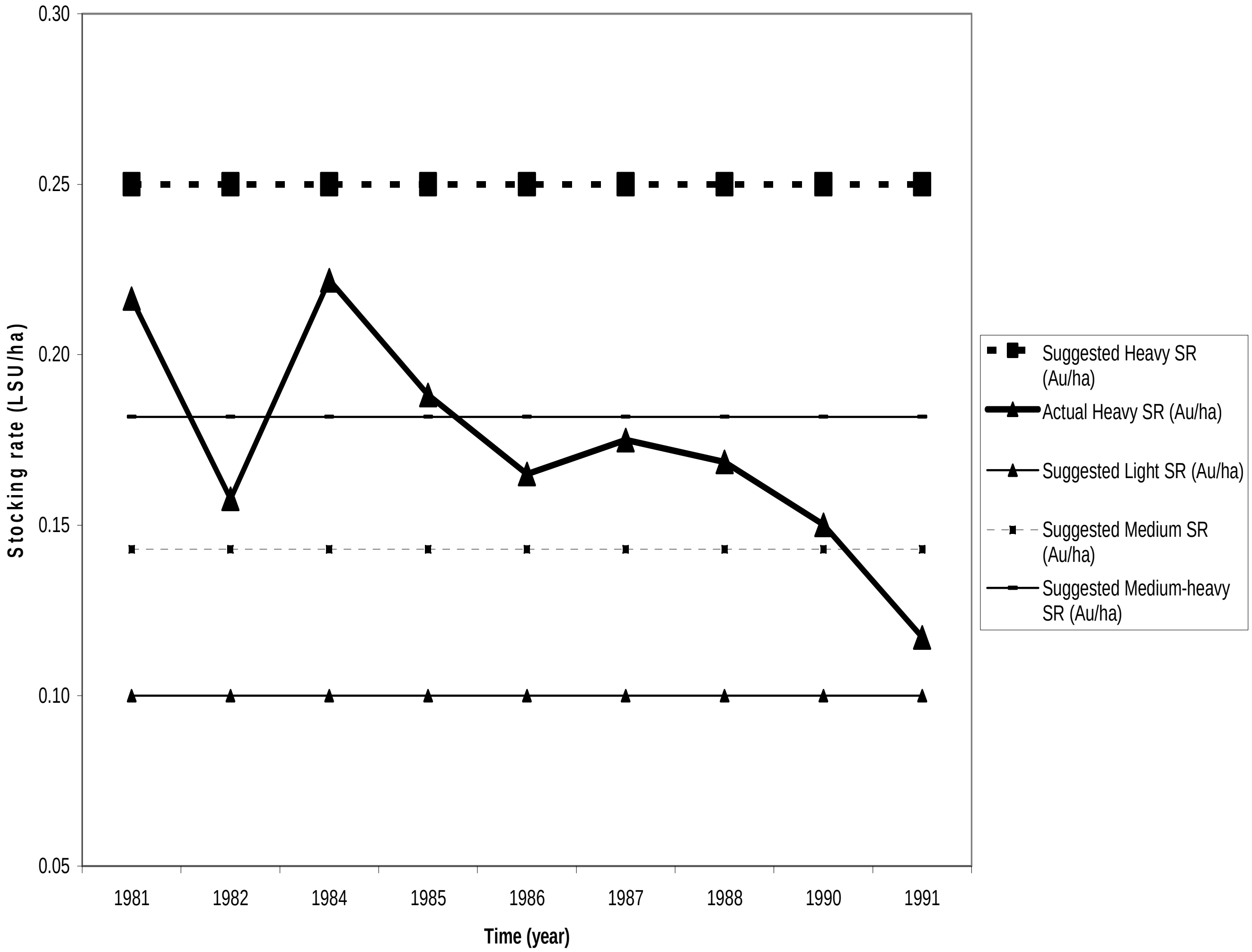
Appendix 6: Actual stocking rates applied during phase one of the grazing trial at the Armoedsvlakte Research Station for the Medium-heavy stocking rate and rotational grazing system treatment. The abbreviation SR refers to the stocking rate (AU/ha) applied.

Time (year)	**1981**	**1982**	**1984**	**1985**	**1986**	**1987**	**1988**	**1990**
Suggested Medium-heavy SR (Au/ha)	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818
Actual Medium-heavy SR (Au/ha)	0.1565	0.1134	0.1583	0.1446	0.1317	0.1355	0.1353	0.1210
Suggested Light SR (Au/ha)	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
Suggested Medium SR (Au/ha)	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429
Suggested Heavy SR (Au/ha)	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500



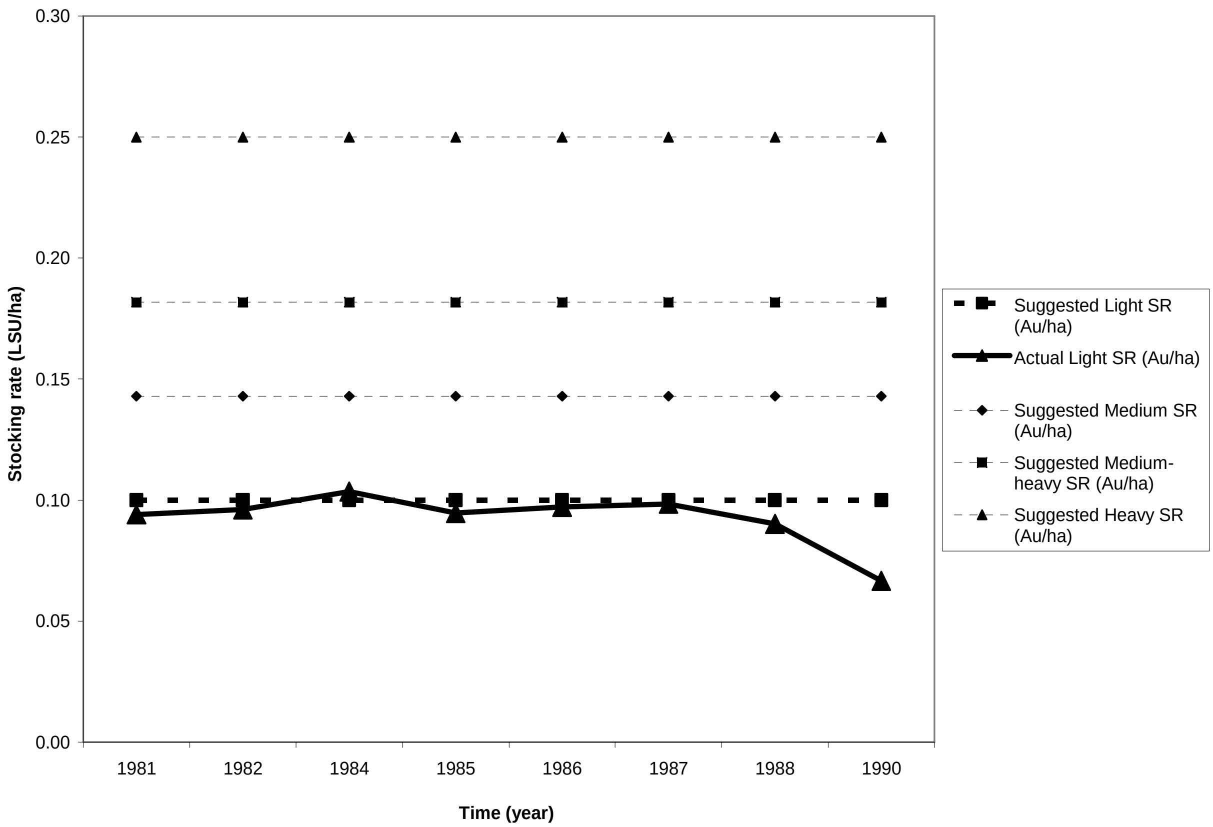
Appendix 7: Actual stocking rates applied during phase one of the grazing trial at the Armoedsvlakte Research Station for the heavy stocking rate and rotational grazing system treatment. The abbreviation SR refers to the stocking rate (AU/ha) applied.

Time (Year)	**1981**	**1982**	**1984**	**1985**	**1986**	**1987**	**1988**	**1990**	**1991**
Suggested Heavy SR (Au/ha)	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500
Actual Heavy SR (Au/ha)	0.2165	0.1577	0.2219	0.1883	0.1650	0.1750	0.1686	0.1501	0.1172
Suggested Light SR (Au/ha)	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
Suggested Medium SR (Au/ha)	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429
Suggested Medium-heavy SR (Au/ha)	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818



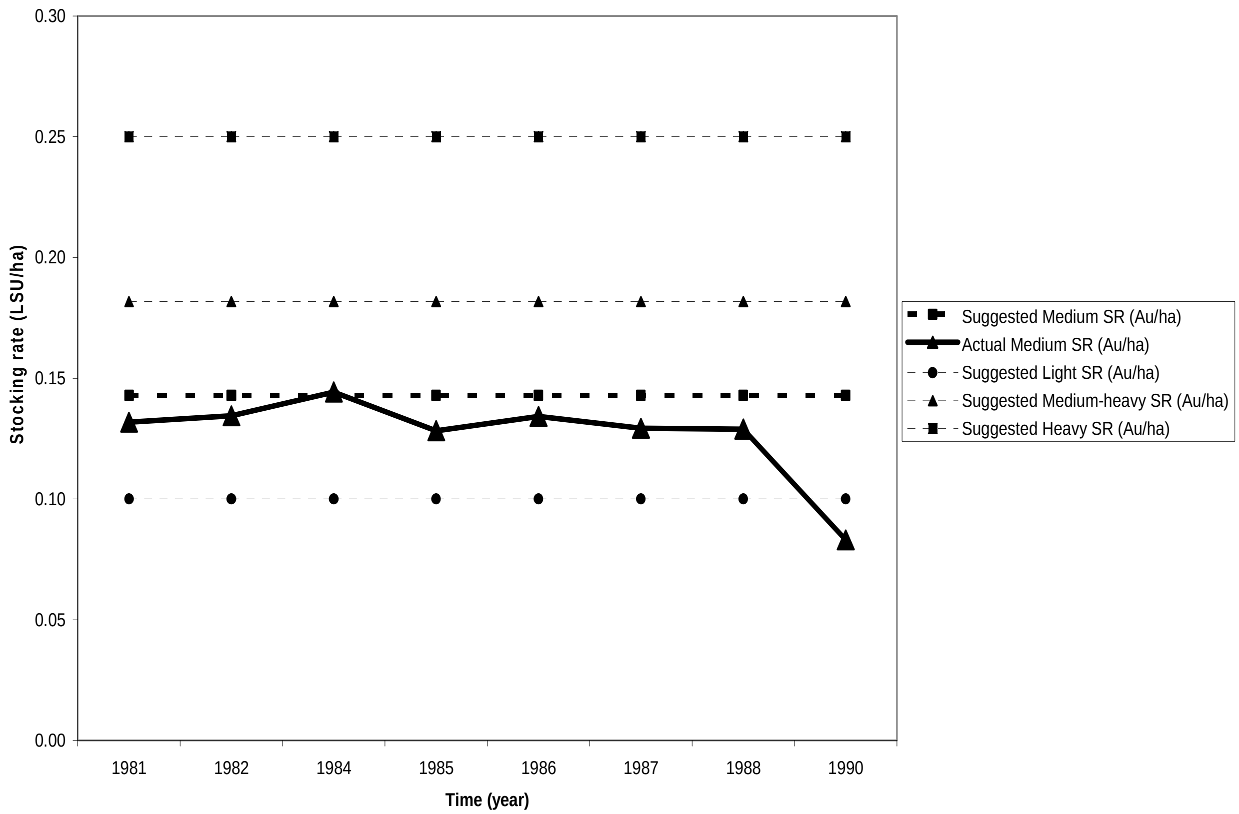
Appendix 8: Actual stocking rates applied during phase one of the grazing trial at the Armoedsvlakte Research Station for the light stocking rate and continuous grazing system. The abbreviation SR refers to the stocking rate (AU/ha) applied.

Time (Year)	1981	1982	1984	1985	1986	1987	1988	1990
Suggested Light SR (Au/ha)	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
Actual Light SR (Au/ha)	0.0941	0.0960	0.1035	0.0947	0.0971	0.0984	0.0902	0.0666
Suggested Medium SR (Au/ha)	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429
Suggested Medium-heavy SR (Au/ha)	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818
Suggested Heavy SR (Au/ha)	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500



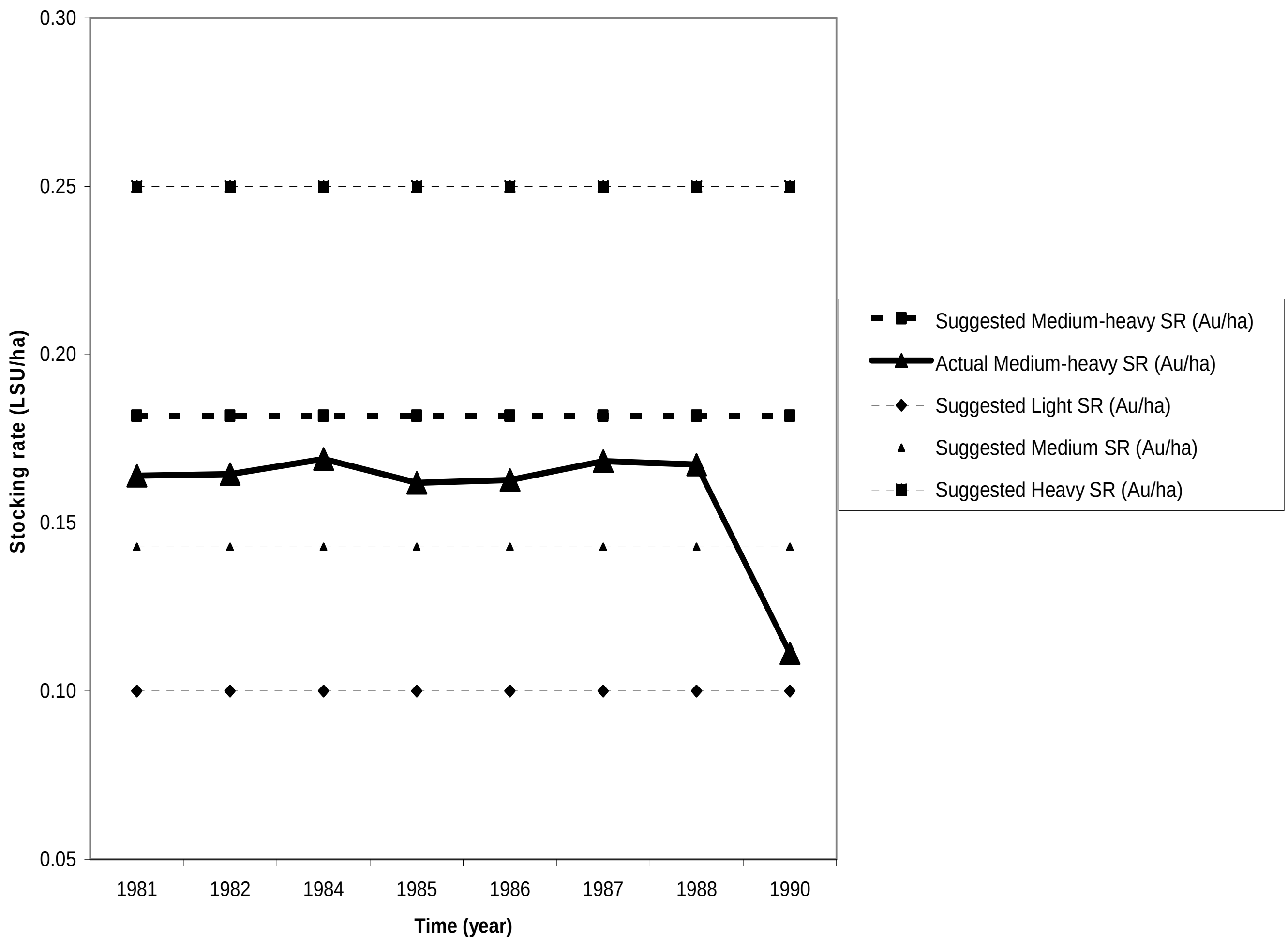
Appendix 9: Actual stocking rates applied during phase one of the grazing trial at the Armoedsvlakte Research Station for the medium stocking rate and continuous grazing system. The abbreviation SR refers to the stocking rate (AU/ha) applied.

Time (Year)	**1981**	**1982**	**1984**	**1985**	**1986**	**1987**	**1988**	**1990**
Suggested Medium SR (Au/ha)	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429
Actual Medium SR (Au/ha)	0.1318	0.1344	0.1443	0.1283	0.1341	0.1293	0.1290	0.0830
Suggested Light SR (Au/ha)	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
Suggested Medium-heavy SR (Au/ha)	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818
Suggested Heavy SR (Au/ha)	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500



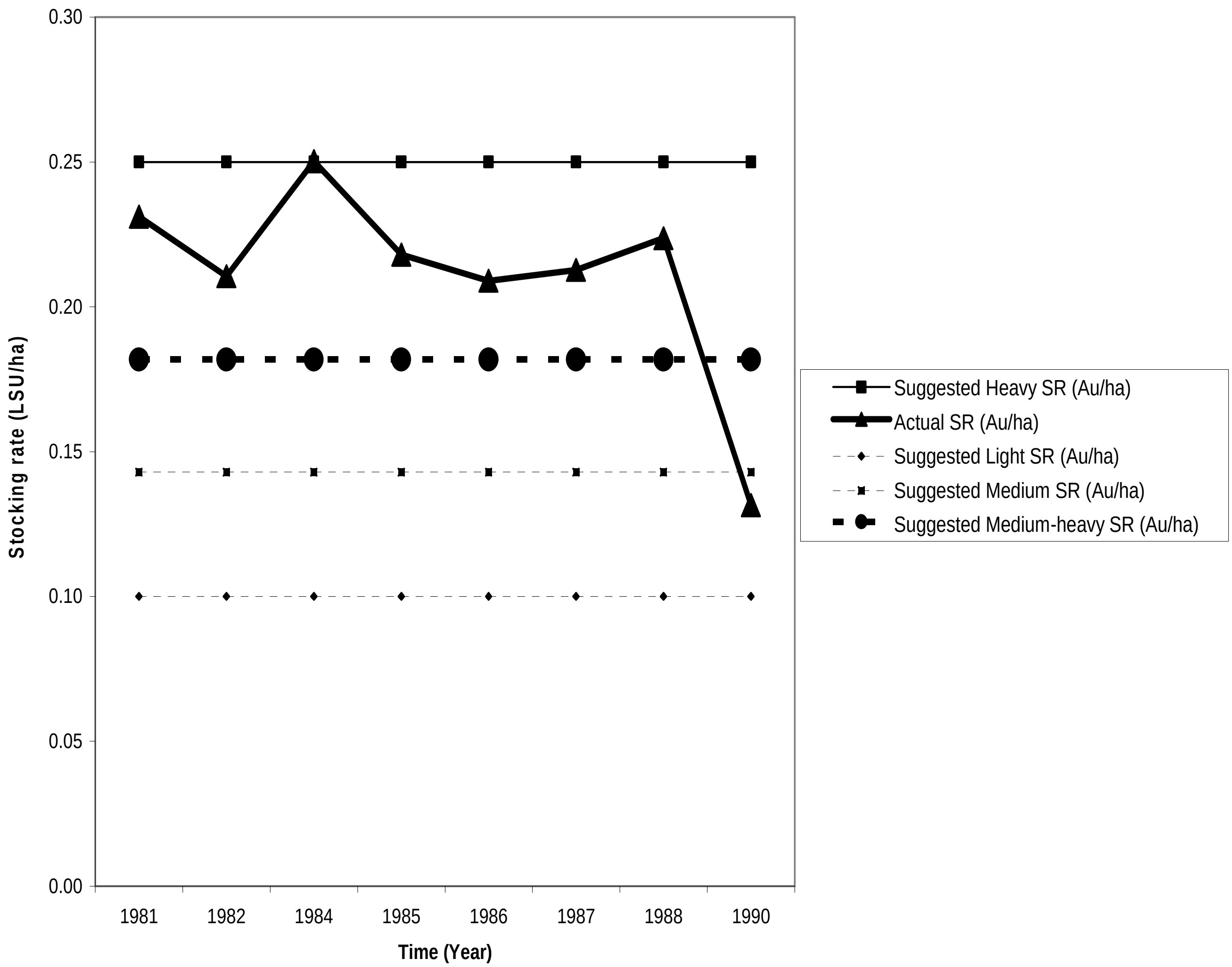
Appendix 10: Actual stocking rates applied during phase one of the grazing trial at the Armoedsvlakte Research Station for the medium-heavy stocking rate and continuous grazing system. The abbreviation SR refers to the stocking rate (AU/ha) applied.

Time (Year)	**1981**	**1982**	**1984**	**1985**	**1986**	**1987**	**1988**	**1990**
Suggested Medium-heavy SR (Au/ha)	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818
Actual Medium-heavy SR (Au/ha)	0.1640	0.1645	0.1690	0.1619	0.1627	0.1683	0.1673	0.1113
Suggested Light SR (Au/ha)	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
Suggested Medium SR (Au/ha)	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429
Suggested Heavy SR (Au/ha)	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500



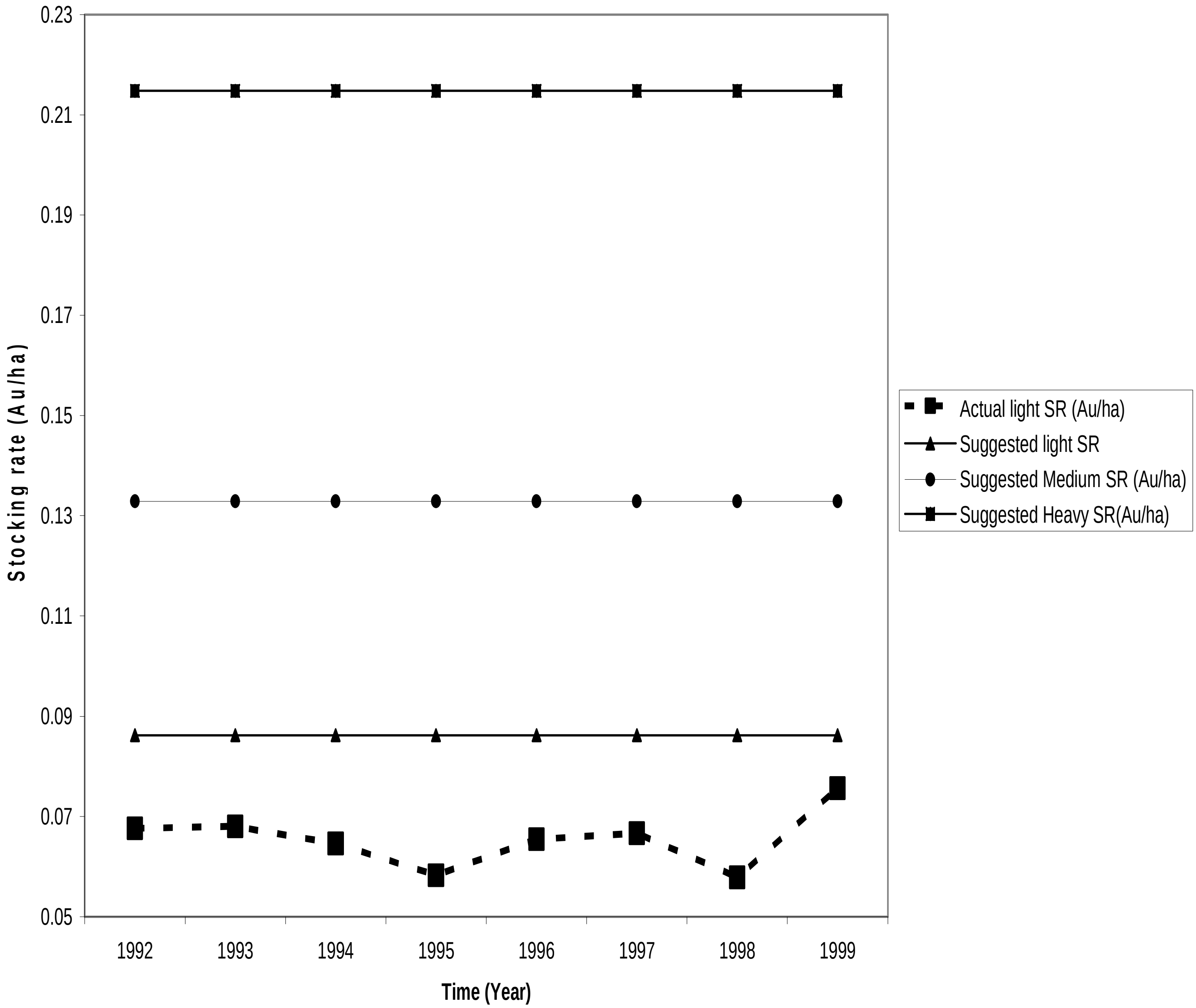
Appendix 11: Actual stocking rates applied during phase one of the grazing trial at the Armoedsvlakte Research Station for the heavy stocking rate and continuous grazing system. The abbreviation SR refers to the stocking rate (AU/ha) applied.

Time (Year)	**1981**	**1982**	**1984**	**1985**	**1986**	**1987**	**1988**	**1990**
Suggested Heavy SR (Au/ha)	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500	0.2500
Actual SR (Au/ha)	0.2311	0.2106	0.2502	0.2180	0.2090	0.2127	0.2237	0.1315
Suggested Light SR (Au/ha)	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000	0.1000
Suggested Medium SR (Au/ha)	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429	0.1429
Suggested Medium-heavy SR (Au/ha)	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818	0.1818



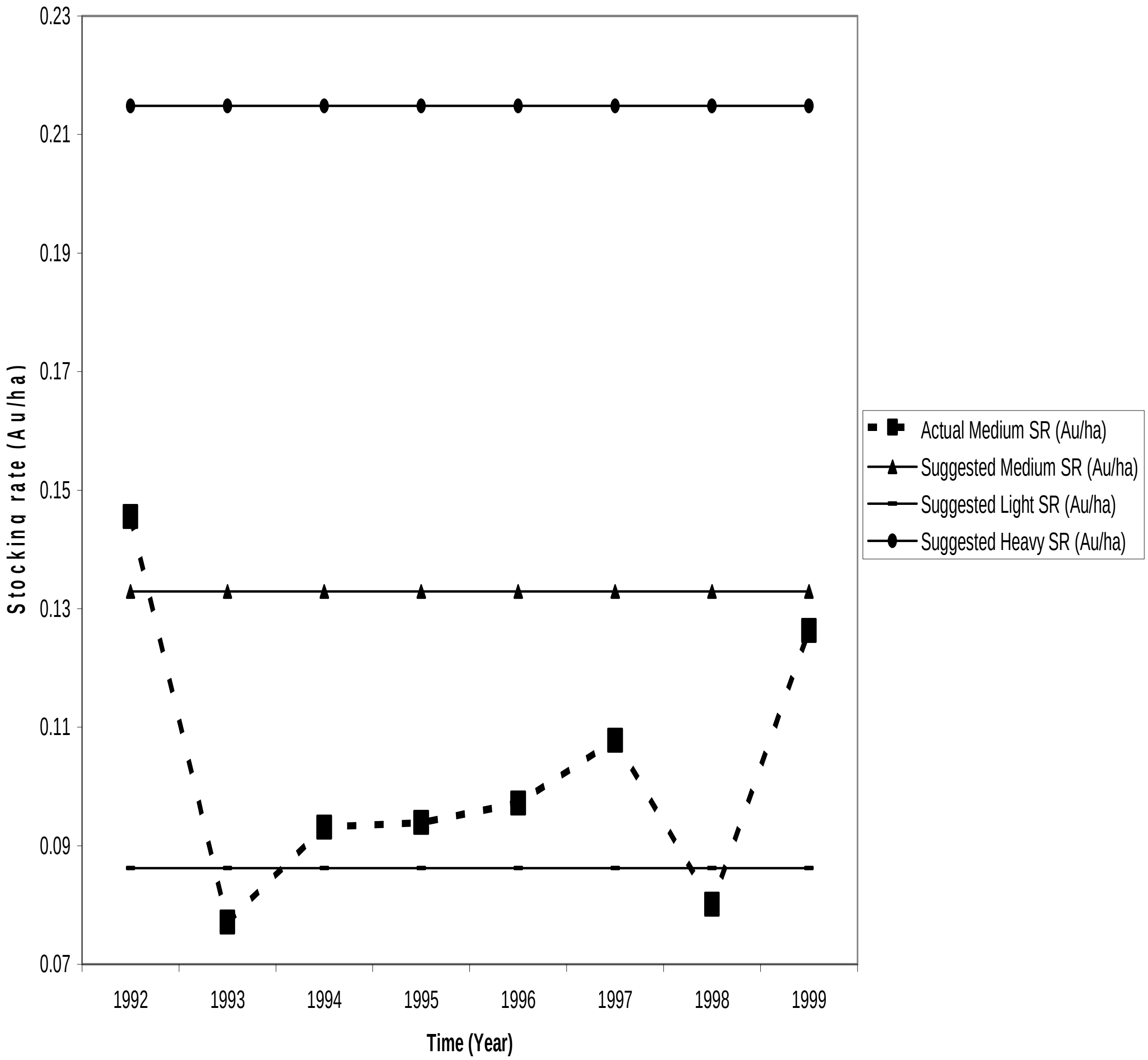
Appendix 12: Actual stocking rates applied during phase two of the grazing trial at the Armoedsvlakte Research Station for the light stocking rate and rotational grazing system treatment. The abbreviation SR refers to the stocking rate (AU/ha) applied.

Time (Year)	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Actual light SR (Au/ha)	0.0676	0.0680	0.0646	0.0582	0.0654	0.0667	0.0578	0.0756
Suggested light SR	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862
Suggested Medium SR (Au/ha)	0.1329	0.1329	0.1329	0.1329	0.1329	0.1329	0.1329	0.1329
Suggested Heavy SR(Au/ha)	0.2148	0.2148	0.2148	0.2148	0.2148	0.2148	0.2148	0.2148



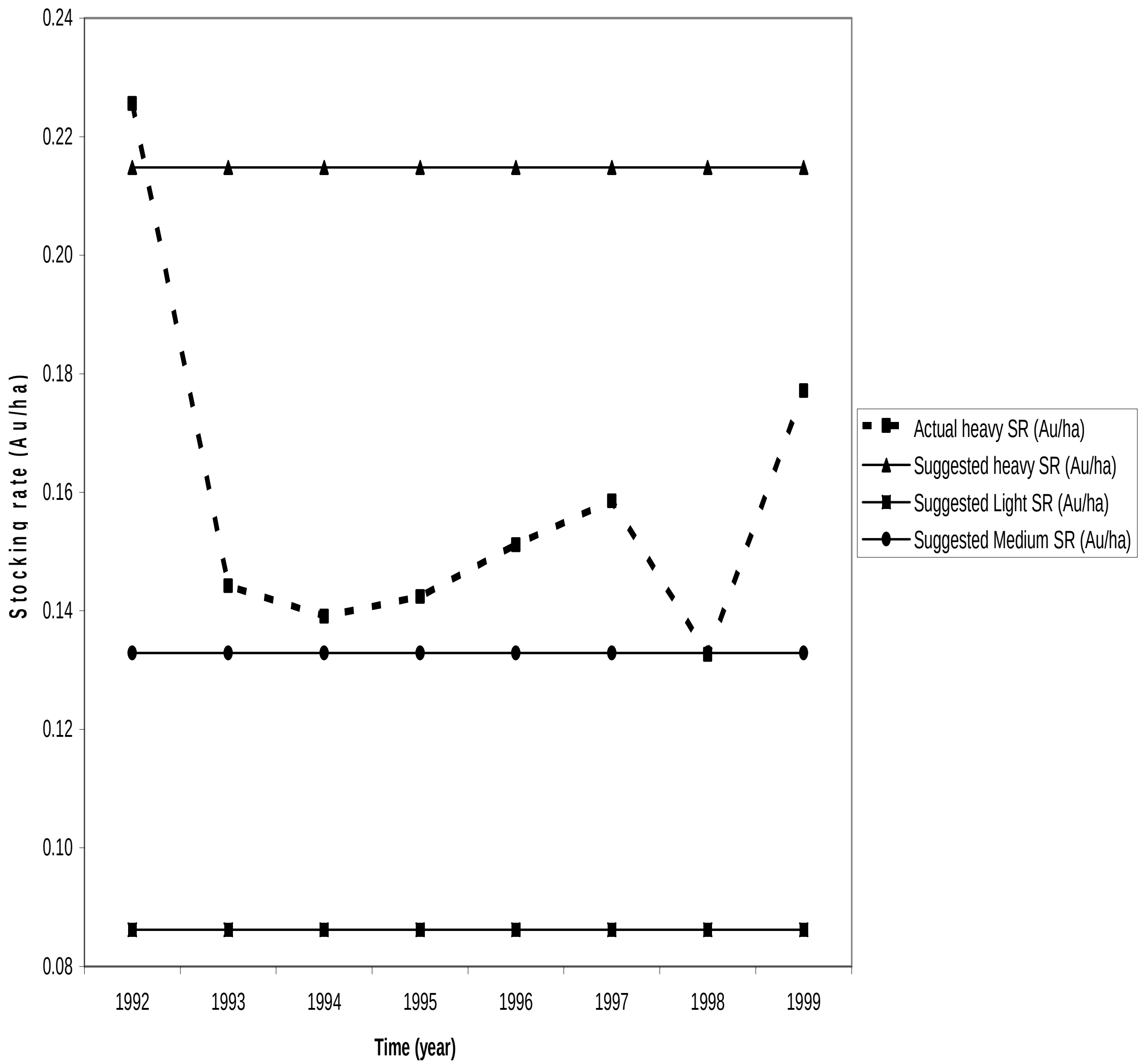
Appendix 13: Actual stocking rate applied during phase two of the grazing trial at the Armoedsvlakte Research Station for the medium stocking rate and rotational grazing treatment. The abbreviation SR refers to the stocking rate (AU/ha) applied.

Time (Year)	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Actual Medium SR (Au/ha)	0.1455	0.0771	0.0932	0.0939	0.0972	0.1078	0.0801	0.1263
Suggested Medium SR (Au/ha)	0.1329	0.1329	0.1329	0.1329	0.1329	0.1329	0.1329	0.1329
Suggested Light SR (Au/ha)	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862
Suggested Heavy SR (Au/ha)	0.2148	0.2148	0.2148	0.2148	0.2148	0.2148	0.2148	0.2148



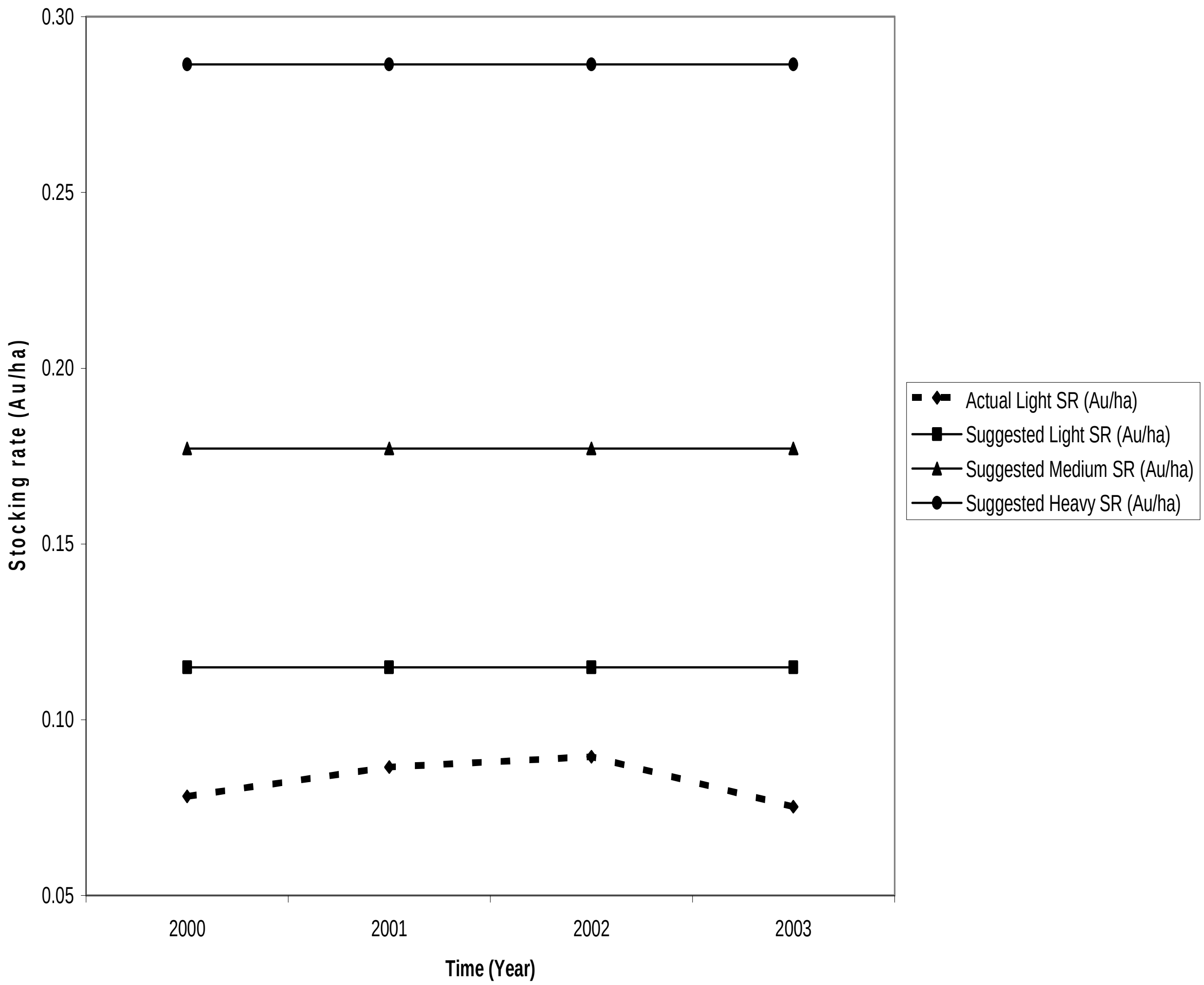
Appendix 14: Actual stocking rate applied during phase two of the grazing trial at Armoedsvlakte Research Station for the heavy stocking rate and rotational grazing treatment. The abbreviation SR refers to the stocking rate (AU/ha) applied.

Time (Year)	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
Actual heavy SR (Au/ha)	0.2256	0.1442	0.1391	0.1424	0.1511	0.1586	0.1326	0.1771
Suggested heavy SR (Au/ha)	0.2148	0.2148	0.2148	0.2148	0.2148	0.2148	0.2148	0.2148
Suggested Light SR (Au/ha)	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862	0.0862
Suggested Medium SR (Au/ha)	0.1329	0.1329	0.1329	0.1329	0.1329	0.1329	0.1329	0.1329



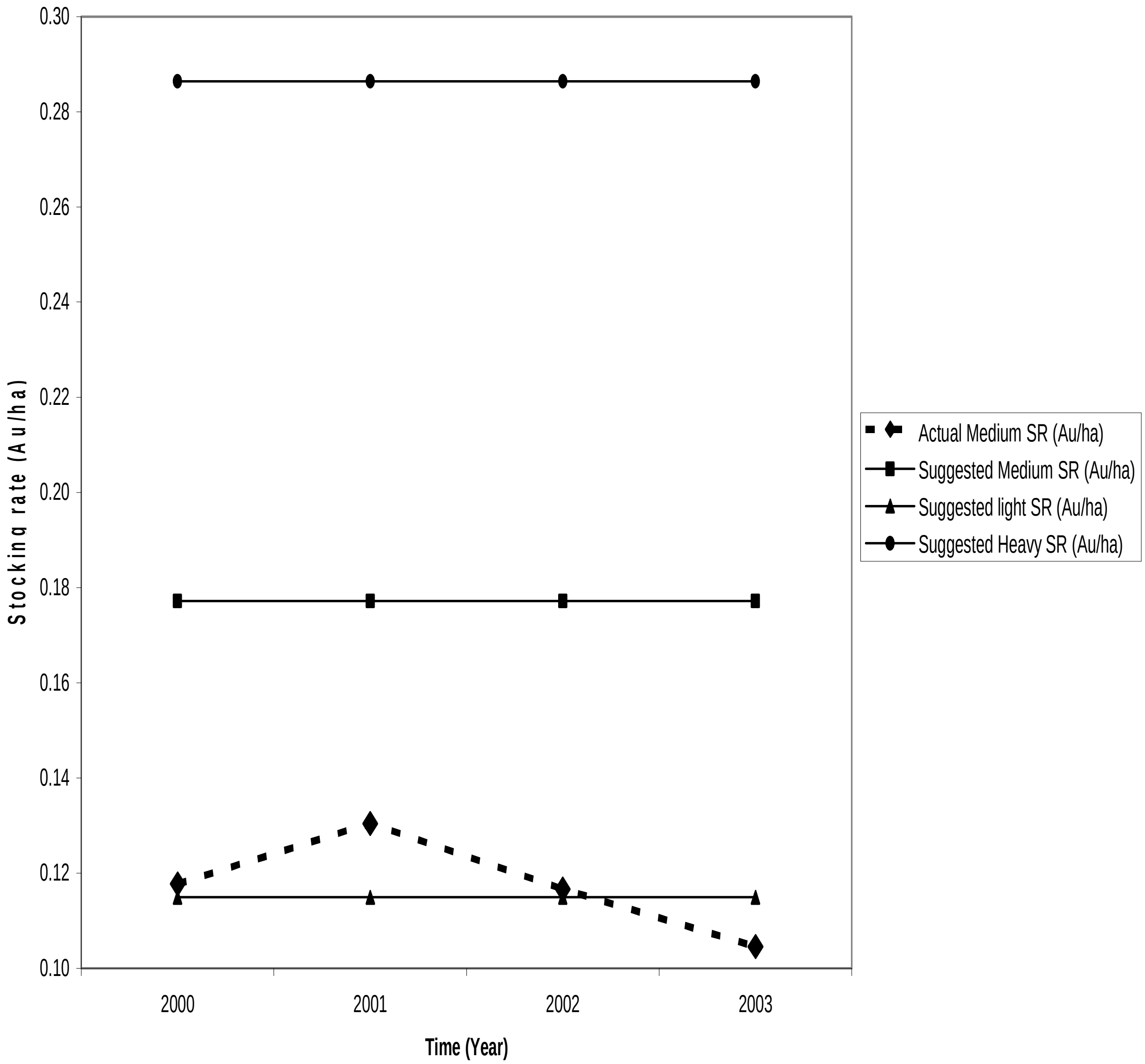
Appendix 15: Actual stocking rate applied during phase three of the grazing trial at the Armoedsvlakte Research Station for the light stocking rate and rotational grazing treatment. The abbreviation SR refers to the stocking rate (AU/ha) applied.

Time (Year)	**2000**	**2001**	**2002**	**2003**
Actual Light SR (Au/ha)	0.0782	0.0866	0.0894	0.0753
Suggested Light SR (Au/ha)	0.1149	0.1149	0.1149	0.1149
Suggested Medium SR (Au/ha)	0.1772	0.1772	0.1772	0.1772
Suggested Heavy SR (Au/ha)	0.2864	0.2864	0.2864	0.2864



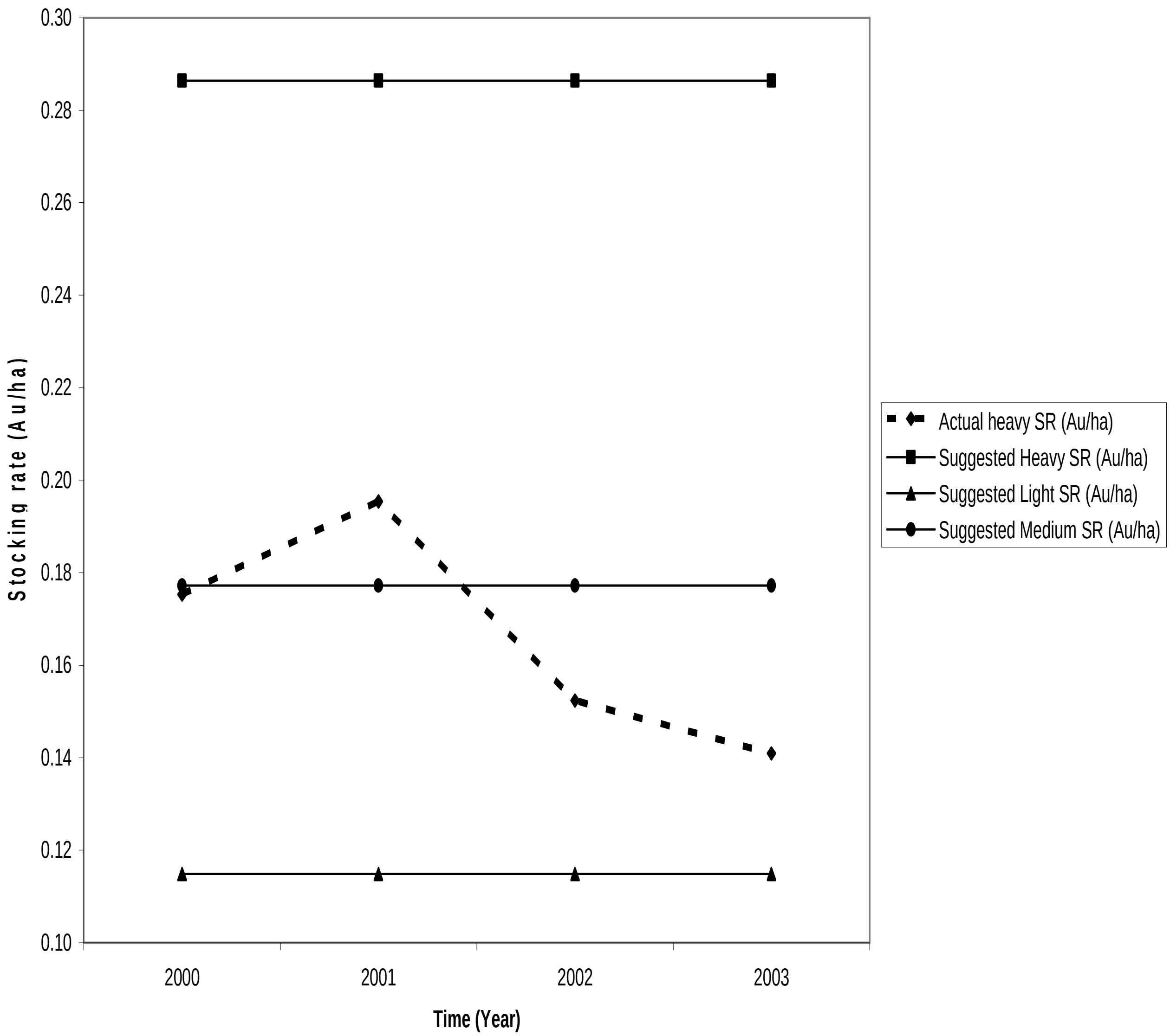
Appendix 16: Actual stocking rate applied during phase three of the grazing trial at the Armoedsvlakte Research Station for the medium stocking rate and rotational grazing treatment. The abbreviation SR refers to the stocking rate (AU/ha) applied.

Time (Year)	2000	2001	2002	2003
Actual Medium SR (Au/ha)	0.1177	0.1305	0.1166	0.1046
Suggested Medium SR (Au/ha)	0.1772	0.1772	0.1772	0.1772
Suggested light SR (Au/ha)	0.1149	0.1149	0.1149	0.1149
Suggested Heavy SR (Au/ha)	0.2864	0.2864	0.2864	0.2864



Appendix 17: Actual stocking rate applied during phase three of the grazing trial at the Armoedsvlakte Research Station for the heavy stocking rate and rotational grazing treatment. The abbreviation SR refers to the stocking rate (AU/ha) applied.

Time (Year)	**2000**	**2001**	**2002**	**2003**
Actual heavy SR (Au/ha)	0.1753	0.1954	0.1524	0.1409
Suggested Heavy SR (Au/ha)	0.2864	0.2864	0.2864	0.2864
Suggested Light SR (Au/ha)	0.1149	0.1149	0.1149	0.1149
Suggested Medium SR (Au/ha)	0.1772	0.1772	0.1772	0.1772



List of figures

List of tables