SOIL, HERBACEOUS AND WOODY RESPONSES TO DIFFERENT METHODS OF BUSH CONTROL IN A MESIC EASTERN CAPE SAVANNA

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DECLARATION

The experiment was established and laid out by Leander Jarvel in 1992. Following my appointment as a researcher at the Döhne Agricultural Development Institute in 1995 I became responsible for the project.

I, Mathembekaya Mapuma, declare that the work contained in this thesis is entirely my own work with the exception of quotations or references which I have attributed to their authors or sources. Furthermore it has not been submitted for any degree or examination in any other university.

M. MAPUMA

ABSTRACT

Bush encroachment is a major problem for the savannas supporting livestock in the Eastern Cape. Farmers employ chemical poisoning and mechanical clearing of woody vegetation to improve grass production. This thesis addressed the following questions.

1. Does soil fertility and hence, herbaceous production and/or quality increase beneath or between former bushclumps following woody clearing or poisoning?
2. Are chemical or mechanical control methods effective for all woody species?
3. Does bush density and height decline with increasing competition from the herbaceous layer?
4. Can fire and goats retard or revert woody re-establishment, thereby keeping these savannas open?

A trial for assessing different methods of controlling bush was conducted near Kei Road. Initial treatments included chemical poisoning, mechanical clearing and a control, each replicated eight times in 0.36 hectare plots. Follow-up treatments were control, fire, goats, and the combination of fire and goats each replicated twice per primary treatment. Two additional mechanically cleared plots were oversown with *Chloris gayana* seeds. Herbaceous production, species composition, foliage quality and soil fertility, and mortality, recruitment, height increase and density of woody individuals were monitored for five seasons.

Mechanical clearing of the woody vegetation increased soil fertility, except total nitrogen, and that explained the dramatic response in grass production that endured for the first four seasons since clearing. The periphery and ex-bushclump zones were characterised by increased colonization of *Panicum maximum* while there were no changes in frequencies of other key herbaceous species in all vegetation zones.

Acacia karroo and woody "weeds" (*Solanum incanum*, *Berkheya bipinnatifida*) established from seed while all other woody species recruited mainly from coppicing. Seedling recruitment and resprouting resulted in high densities of woody stems and individuals by the second season after clearing when compared with the pre-clearing levels. Oversowing cleared areas with pasture grasses did not only increase grass production but also reduced the density of coppicing woody plants and "weeds".

Chemical treatments mirrored the controls in terms of grass production, except during a very wet season, and species composition. Although encroaching woody species (e.g. *Scutia myrtina*, *Maytenus heterophylla* and *Trimeria trinervis*) were susceptible to poisoning, woody plant density was not reduced. Multi-stemmed woody individuals were resistant to poisoning. Fire and goats kept most coppicing woody plants short, less than half a metre, after three seasons of browsing and also improved grass production in the dense bushclumps suggesting that these clumps were being opened up. However, high browsing pressure forced goats to graze more hence this effect was masked.

This study indicates that chemical and mechanical control of bush are economically unsustainable for beef and mutton production, atleast in the medium term. Fire and goats are appropriate as a follow-up strategy for retarding woody regrowth, keeping bushclumps open, improving grass production and economic viability of mechanical clearing.

LIST OF CONTENTS

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CHAPTER ONE

INTRODUCTION

The mesic savannas of the eastern Cape consist of a diverse mosaic of grasslands, scattered to dense *Acacia karroo*, and mixed multi-species bushclumps within a matrix of grassland and woodland. Acocks (1953) classified these savannas as Eastern Province Thornveld. Beef and mutton production are the main farming enterprises practised in these savannas with very little use of goats although great potential exists. It has been shown that the woody component in these savannas has increased rapidly in recent times (Commins 1962; O'Connor & Crow 1999). The reasons for bush encroachment in these savannas are believed to be like those of the other savanna regions and include lack of fire, incorrect grazing practices, absence of browsing animals, and lack of damage by large wild animals. A portion of the increase in the woody component is attributed to the natural process of the vegetation, thus tending to develop towards the climax stage that happens to be thick bushclumps or forest in these savannas.

Bush encroachment in these savannas takes the form of expansion of the existing bushclumps into the adjacent grasslands. This process begins with *Acacia karroo* individuals that establish in grasslands and modifies the soils and microclimate in their vicinity (du Toit 1967; Aucamp *et al.* 1983; Jarvel & O'Connor 1999). It is hypothesised that tree species that are believed to be mostly dispersed by birds establish around and beneath *Acacia* canopies forming clusters or bushclumps that exclude grasses. As new bushclumps are initiated and the existing bushclumps enlarge, coalescence eventually occurs. The formation of bushclump savannas reduces herbaceous production by up to 90% (Jarvel 1996; Mapuma 1998), thus resulting in low grazing capacity and hence animal production. This could have serious implications if beef and mutton production are still to be practised in these savannas.

The increase in the area of grazing land covered by bush provides a strong motivation for controlling bush. The decision to partially or completely control bush depends on whether the increased herbaceous production and hence livestock production offsets the costs of bush control. Radical methods of controlling bush, either mechanically or chemically, are often used by local farmers to improve grass production, hence grazing capacity, as quickly as possible. Farmers justify the economic viability of their clearing operations by increased herbaceous production. However, these methods are not always completely successful for all bush species because bush has a potential for re-establishment from rootstock and seedbanks. Mechanical and chemical clearing have been shown to result in an immediate increase in grass production in other savanna regions as well (Barnes 1979; Dye & Spear 1982; Harrington & Johns 1990). Barnes (1979) also reported poor quality of forage on offer following mechanical clearing of the woody plants in Zimbabwe Thornveld, and attributed this to replacement of good quality species by poor quality species.

Scholes (1990) echoed that there is a dearth of published data detailing the regrowth or response of savanna trees and shrubs to clearing. This may be partly due to the over-emphasised economic significance of the grass sward for animal production. However, the limited literature does provide useful information as to what can be expected. Barnes (1972), Strang (1974) and Jarvel (1996) claimed that up to 80% recovery of bush from coppicing would occur within twenty years after clearing. Therefore, bush clearing may be an expensive and uneconomic exercise.

The use of fire (Trollope 1974) and incorporation of browsers (Aucamp 1976) have been recommended for controlling bush encroachment for many years. However, the use of such biological methods has not been warmly received by cattle and sheep farmers. These methods are also recommended to control regrowth of bush following clearing with the aim of improving financial soundness of the clearing methods.

There are a number of shortcomings regarding the studies that involve bush clearing. Most studies on bush clearing have been focused exclusively on single-species tree savannas. It is also of note that most of these studies reported only on their initial successes in increasing grass production and very few reported on grass production several years after clearing. Most bush control experiments have also failed to include other community processes or variables other than grass production when looking the responses to clearing. Inclusion of such variables (soil fertility, grass quality, and changes in species composition) would provide a valid assessment of the financial soundness of bush control operations (Moore & Odendaal 1987). There is also a dearth of published literature detailing the response of bush to clearing, particularly time taken by bush to reach the pre-cleared levels. The potential of goats and fire in controlling the regrowth of bush after clearing in mesic savanna regions, thereby improving financial soundness of clearing methods, has not been fully explored.

The above shortcomings formed the basis of the study that was established with the aim of addressing the question of controlling of bush encroachment in the mesic savanna regions of the Eastern Cape. The specific objectives are detailed after the relevant literature has been reviewed in the following chapter.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Bush encroachment has been identified as a serious constraint for animal production, particularly beef and mutton. It appears to be a problem in savanna regions worldwide as reported in Africa (Donaldson & Kelk 1970; Kelly 1977; O'Connor & Crow 1999), America (Fischer 1977; Tausch & Teuller 1977; Jacoby 1985; Beeskow *et al.* 1995) and Australia (Beale 1973; Walker *et al.* 1981; Harrington & Johns 1990). Bush encroachment, particularly in southern Africa, is mostly as a result of an invasion of grasslands by a single species, hence mono-species savannas are common. In mesic regions a potential exists for the development of multi-species bushclump savannas that can expand and eventually form closed woodland (Commins 1962; Archer *et al.* 1988). The relatively high rainfall in these savannas encourages rapid growth of woody plants.

2.2 Consequences of bush encroachment

The relationships between bush density and herbaceous production can be summed up in two categories depending on whether encroachment is occurring in grassland or savanna communities. In this regard Scanlan (1992) produced a model of woody-herbaceous production relationships with stimulatory and competitive factors as influential factors on the outcome.

In cases where encroachment is in the form of an invasion of open grassland by bush, it appears that herbaceous production does not decrease linearly with increasing densities of bush. Bush is believed to have a stimulatory effect on herbaceous production when present in low densities, and hence increase herbaceous production because of increased soil fertility in the vicinity of the individual trees, particularly in semi-arid regions. Studies conducted in southern Africa (Bosch & van Wyk 1970; Kennard & Walker 1973; Walker 1974; Kelly 1977; Stuart-Hill *et al.* 1987; Smith & Goodman 1987) confirmed this idea. An increase of up to 300% in herbaceous production was reported at low densities of bush compared to grass communities with no bush at all (Weltzin & Coughenour 1990; Belsky *et al.* 1993). Similar results were reported in the savanna regions of America where bush encroachment on grasslands resulted initially in an increase in herbaceous production at low densities and followed by a decrease as bush density increased further (Scrifes *et al.* 1982). Contrary to these findings, Donaldson & Kelk (1970) and Mentis (1977) reported a linear decline in herbaceous production with increasing bush density. Beale (1973) and Walker *et al.* (1972) working in the Queensland mulga (*Acacia aneura*) and *Eucalyptus* savannas of Australia respectively, also reported similar results. In south-east Africa it was found that maximum grass production is attained at 300 tree equivalents per hectare, and beyond this level the negative effect of bush on grass manifests itself (Aucamp *et al.*1983; Stuart-Hill 1987). Above 300 tree equivalents per hectare bush can reduce annual grass production by up to 90%

(du Toit 1972; Trollope 1977; Trollope *et al.* 1989), and hence reduce grazing capacity.

If encroachment is the aggregation or thickening up of the existing bush, bush negatively affects herbaceous production, thus showing a competitive effect through the interception of light and usage of water and nutrients. This is a characteristic of thick broad-leafed savannas (Walker & Noy-Meir 1982; Mordelet & Menaut 1995). Substantial reduction of herbaceous production through shading had been reported in several studies throughout the world (Hobbs & Mooney 1986; Scanlan 1992; Scanlan & Archer 1991; Mordelet & Menaut 1995; Jarvel & O'Connor1999). This was despite fertile soil under these bush canopies (Mordelet *et al.* 1993; Jarvel 1996) compared with open grasslands. Bush changes herbaceous composition under its canopies. *Panicum maximum*, a highly productive grass species, was found to be associated with closed bush canopies (Kennard & Walker 1973; Grossman *et al.* 1980), even though this association reduced its biomass production in most cases. Jarvel (1996) found that growth of *Helictotricon capense* was also limited to under thick bushclump canopies.

In turn a dense herbaceous layer has been reported to reduce the establishment of tree seedlings and to retard the growth of mature trees (Stuart-Hill & Tainton 1989; Donaldson 1969). High efficiency in using water by the herbaceous layer in the upper layers of the soil, thereby reducing water infiltrating to the subsoil layers (Walker & Noy-Meir 1982; Stuart-Hill & Tainton 1989) was advanced as one of the reasons for this effect. Direct competition for moisture, light, carbon dioxide and soil nutrients was also considered as important factors limiting successful establishment of tree seedlings in a dense herbaceous layer (O'Connor 1995). With heavy grazing, the herbaceous layer becomes less competitive due to reduced vigour and root mass, hence shallow root system (Reuss 1988; Skarpe 1990), which leads to less use of water by the herbaceous layer in the topsoil. More water therefore infiltrates to subsoil layers (Reuss 1988), thus encouraging tree dominance.

2.3 Herbaceous and woody responses to bush clearing

Radical methods of controlling bush encroachment, namely mechanical and chemical clearing, are often used with the aim of improving grass production as quickly as possible (Trollope *et al.* 1989). The effect of tree removal on herbaceous production has received considerable attention, particularly in the mono-species savanna regions, owing to the economic significance of the grass layer in livestock production. Increases of herbaceous production of up 700% following mechanical clearing of bush were reported in South Africa (Donaldson 1969), Botswana (Pratchett 1978), Zimbabwe (Kennan 1969; Barnes 1979; Dye & Spear 1982) and Australia (Walker *et al.* 1986; Harrington & Johns 1990). A similar study conducted in the bushclump savannas of the Eastern Cape reported an initial increase of two- to sixfold in grass production over a two year period (Jarvel 1996).

Application of chemical poison resulted in increased herbaceous production in the Zimbabwe savannas (Barnes 1979; Dye & Spear 1982), Australian *Eucalyptus* savanna (Walker *et al.* 1972) and Thorn Woodlands of Texas (Jacoby *et al.* 1982; Scrifes & Welch 1982), although this increase was not as high as that of mechanical clearing. An increase of 220-740% in herbaceous production following chemical poisoning was recorded in the Northern Cape (Moore *et al.* 1985). Herbaceous production following chemical poisoning of bush did not show significant increase in a mesic savanna in the Eastern Cape (Jarvel 1996). This poor effect of chemical poisoning was attributed to dense bushclumps that made application of poison very difficult. In many studies the level of herbaceous response to bush clearing in terms of production, has been reported to be dependent on rainfall.

Studies conducted in Zimbabwe thornveld and sandveld (Barnes 1972; Dye & Spear 1982) reported replacement of *Panicum maximum* by *Urochloa mosambicensis*. Increases of 20% in basal cover and desirable species were recorded in Botswana thornveld (Anon 1979). Recent studies in a mesic savanna in the Eastern Cape showed replacement of *Helictotricon capense*, a species normally associated with bushclumps, by creeping grass species, e.g. *Cynodon dactylon* and *Digitaria eriantha*, following bush clearing (Jarvel 1996). It appears as if not all changes in composition following bush clearing are desirable.

Bush clearing was associated with a decline in forage quality even though the immediate season following clearing had increased forage quality, particularly plant nitrogen (Barnes 1979; Jarvel 1996). Replacement of palatable species (e.g. *Panicum maximum*) by less palatable species was advanced as the reason for the decline in forage quality in Zimbabwean savannas (Barnes 1979).

There is dearth of published literature detailing responses of bush to clearing. The limited literature does provide information as to what can be expected. Mechanical clearing alone does not result in mortality of bush. Barnes (1972) measured 80% recovery of bush, mainly from coppicing, within the first twenty years after clearing in Zimbabwe highveld. Faster rates of bush recovery, within nine years, following bush clearing were reported in the *Eucalyptus* savanna of Australia (Walker *et al.* 1986; Harrington and Johns 1990). In fact, prolific resprouting and coppicing has the potential of increasing bush density by up to five times that of pre-clearing levels (Jarvel 1996). Mechanical clearing can also result in germination of seeds in the seedbank, particularly those of *Acacia karroo* (Jarvel 1996). Application of chemical poisoning resulted in less coppicing than mechanical clearing as a significant amount of bush re-encroachment came from germination of seeds (Scholes 1990). Rainfall has been reported to play a significant role in the rate of bush re-encroachment (Scholes 1990; Beale 1973).

It is important to note that most studies reported on their initial successes in increasing herbaceous production except the studies conducted in the eastern Transvaal (Scholes 1990) and in Zimbabwe (Dye & Spear 1982), that ran for fourteen and fifteen years respectively. Most studies on control of bush encroachment focused exclusively on savannas dominated by a single woody species (e.g. Donaldson 1969; du Toit 1972a; Trollope 1974; Sweet 1982; Scholes 1990). Less work has been done on multi-species savannas (Mordelet *et al.* 1993; Jarvel 1996). This is a primary shortcoming in the study of controlling bush encroachment considering that each savanna community is functionally unique (Teague & Smith 1992) resulting in a variety of responses. Other community processes such as changes in soil nutrient status, forage quality and woody responses after clearing have also not been reported upon in many studies which limits the understanding of responses to bush clearing and the economics of the operations. Very little work has been done on the effect of bush clearing on soil fertility. Jarvel (1996) reported increase in soil fertility, particularly soil nitrogen, in the first season following bush clearing.

2.4 Economics of bush clearing

The economics of bush clearing are unique in every case and this makes the exercise of choosing a cost-effective method very difficult. Bush clearing methods have been reported to be very expensive (Barnes 1972, 1979; Sousa dė Almedia 1974; Trollope *et al.* 1989; Scholes 1990), particularly when cleared land is to be utilised for livestock production with the exception of dairy production. The cost of clearing operations is a function of bush density, equipment used and size and species of bush. Jarvel (1996) reported direct costs of R1500/ha and R1750/ha for mechanical clearing and chemical poisoning, respectively, for clearing of bush in a mesic savanna in the Eastern Cape. These high costs of bush clearing may justify the use of cheap biological methods (fire and goats) of controlling bush or retarding bush recovery after clearing, thus improving the financial soundness of clearing methods.

2.5 Herbaceous and woody responses to fire

Head fires (fires burning with the wind) result in increased grass production in savanna regions in the medium to long term, particularly when fire is applied to control bush encroachment (Dillon 1980; Trollope 1983b; McNaughton 1985; Walker 1985; Wu *et al.* 1985). Such results are only achieved when burning is applied during the dormant season of the grass sward (West 1965; Dillon 1980; Trollope 1983b). Conversely, back fires (fires burning against the wind) reduce grass production and basal cover as back fires adversely affect growing points of the grass sward that are situated at ground level where back fires are hottest (Trollope 1983b). Fire improved herbage quality in Zimbabwe savannas (West 1965) and in the Tall Grassveld of Natal (Tainton *et al.* 1977). Species diversity, density and composition were reported to have improved following application of fire in Australia (Cary & Morrison 1995) and America (Callaway & Davis 1993). This is provided that fire is not applied too frequently. Fire was also reported to increase soil fertility in the Botswana Thornveld (Sweet 1982).

Fire completely kills non-sprouters (bush with no ability to coppice) because the cambium layer of such trees/bushes is easily damaged by fire (Ryan & Rainhardt 1988; Bond & van Wilgen 1996). Thus both the structure and composition of savannas or forests can be completely altered or eliminated by fire. The recovery of such savannas is very slow and depends on seeds from patches that escaped burning (Bond & van Wilgen 1996). The majority of savanna regions of the world have trees/bushes that fall into the category of sprouters (bush with ability to coppice). Fires burning in most savannas result in very low mortality of woody individuals except for young woody seedlings (Trollope 1974; Wright *et al.* 1976; Hulbert 1985; Callaway & Davis 1993; Howe 1995) as most woody plants coppice from the base. Bond & van Wilgen (1996) attribute the higher mortality of young woody seedlings to their small carbohydrate reserves for supporting regrowth due to small storage capacity. Fire was also reported to suppress flowering activity and to destroy seed crops on plants in Australia (Hodgkinson & Harrington 1985, Harrington & Driver 1995). It is important to mention that all these results were obtained when hot head fires were applied which are achieved under atmospheric conditions of 30% or less relative humidity, air temperature of 25°C or more, and a fully cured fuel load of 4 tons/ha or more (Trollope 1983b). Owing to the ability of the woody plants to coppice and cause further encroachment, Trollope (1974) hypothesised that an ecological effect of fire in controlling bush encroachment is to maintain bush at an available height for browsing animals. Hence fire should be coupled with browsing animals for successfully controlling bush encroachment. He further confirmed this hypothesis with an experimental evidence (Trollope 1983b).

2.6 Herbaceous and woody responses to goats

Goats were reported to reduce bush density by 81, 90 and 22% in three years in three different savannas of southern Africa respectively (du Toit 1972a; Trollope 1974; Sweet & Mphinyane 1986). The varying levels of reduction could possibly be explained by different proportions of bush acceptable to goats that were present in each study site. Greatest reduction in bush density was achieved during the first season of browsing (Sweet & Mphinyane 1986), and this was attributed to tannins produced by bush as the season of browsing progressed which act as a defensive mechanism against browsing by goats (Teague 1989), thus resulting in reduced browsing. Goats therefore keep savannas open and afford the herbaceous layer beneath the bush canopies an opportunity to grow and thereby increase herbaceous production (Trollope 1983b). Wild ungulates would be more adaptable in terms of utilising the woody vegetation and thereby reducing bush densities (Glover 1963; Leuthold 1977; Owen-Smith & Cooper 1985; Stuart-Hill 1992; Lock 1993; Trollope *et al.* 1997), but difficulty in handling these ungulates have ruled them out in favour of domestic goats in many farming situations.

2.7 Economics of fire and goats

The direct costs of burning are currently around R20/ha, making burning an economic alternative to the huge direct costs of mechanical and chemical clearing. However, there is an indirect cost attached to burning and this involves the loss of potential grazing, especially in sweetveld areas (Trollope 1983b).

Direct costs involved in using goats to control bush include the capital invested in purchasing goats. The current price for a ewe is around R220 and considering the high fecundity of goats, particularly Boer goats, the invested capital in purchasing goats can be recovered within eight or less years. Introduction of goats has further implications, the most important one being increased fencing costs (Trollope *et al.* 1989). It is difficult to control the movement of goats with conventional fencing and this dictates the use of goat-proof fencing that will certainly inflate production costs. However, a goat enterprise can boost the economic returns of the whole farming operation by as much as 148 % (Aucamp *et al.* 1983; Stuart-Hill 1987).

It is important to note that despite all the positive attributes of fire and goats, these practices have rarely been used in many farming situations. Research has not fully evaluated the ecological benefits of using these practices as follow-up management strategies to clearing methods for retarding the recovery of bush, and thereby improving financial soundness of the clearing methods. The shortcomings in the control of bush encroachment identified in the literature review formed the basis of this study and the following hypotheses were formulated for testing in a field trial.

(I) Herbaceous production and quality increase following bush clearing both beneath and between former bushclumps as a result of increased soil fertility and reduced competition from the woody plants.

(ii) Oversowing cleared lands with grass seed encourages quick establishment of a dense herbaceous layer which strongly competes with a re-establishing coppicing woody layer (coppice and seedlings) thereby delaying re-encroachment in terms of both density and height of woody plants.

(iii) The increased herbaceous production declines with time owing to declining soil fertility and coppicing of woody plants that cause further encroachment and hence competition for resources.

(iv) Mechanical clearing and chemical clearing methods are not completely successful for controlling different bush species due to the ability of bush to coppice and also to escape clearing as a result of flexible stems.

(v) Fire and goats retard the re-establishment of bush and keep savannas open provided the woody species are acceptable to goats, thereby sustaining increased herbaceous production.

CHAPTER THREE

EXPERIMENTAL PROCEDURE

3.1 SITE LOCATION

The experimental site was situated on the farm "Lily-park" (32°41´S, 27°41´E) located approximately 21 km from Kei Road in the King Williams Town district of the Eastern Cape. This commercial ranch has been grazed by livestock (mainly cattle and sheep) for the past 46 years at least. Fire has generally not been used as a veld management practice. Although stocking rates could not be quantified, it was probably moderate as no obvious signs of over-utilization were evident except a high frequency of *Aristida congesta* and *Cynodon dactylon* on the north-facing slopes, suggesting that heavy grazing occurred on these slopes. The 10 ha experimental site was situated at ± 600 m above sea level on a moderate (5%) north-east facing slope.

3.2 CLIMATE AND SOILS

The site is mesic with a mean annual rainfall (1948-1996) of 650 mm, with peaks in November, February and March (Figure 3.1). Dry winters and midsummer droughts are common (Kopke 1988; Jury & Levey 1993). The annual rainfall is highly variable with an average coefficient of variation (CV) of 24.2 %.

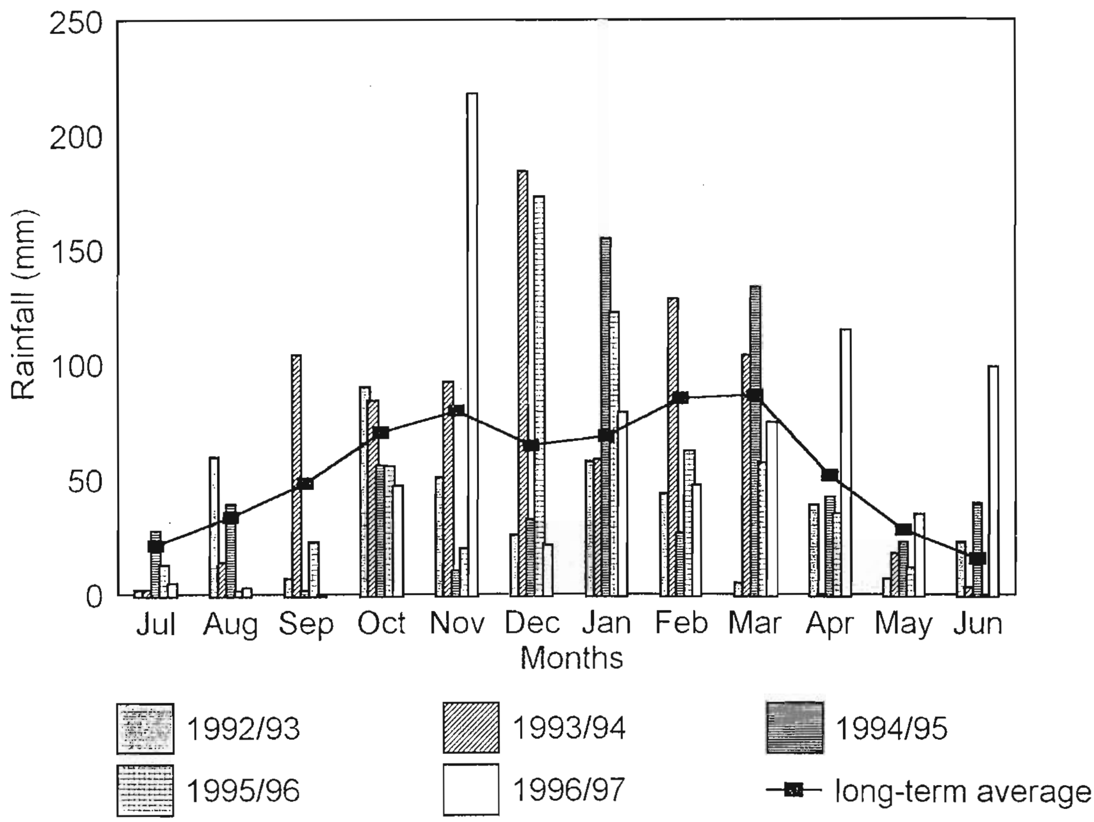


Figure 3.1. Monthly rainfall recorded during the experimental period July 1992 to June 1997 at Lily-park. The line shows the long term average rainfall over 48 years.

Rainfall during the study period was recorded about 500 m from the experimental site and the monthly rainfall for the period July 1992 to June 1997 is presented in figure 3.1. Rainfall during this period was fairly reliable although it was usually below the long-term mean except for some months in 1993/94 and 1996/97. Annual rainfall (July to June inclusive) for the five years of study was 412 mm, 792 mm, 588 mm, 575 mm and 744 mm respectively. Frost does not occur. The mean monthly temperatures at this site varied between 8.6°C (minimum) in winter and 31.8°C (maximum) in summer.

The soils of the experimental site were derived from dolerite and are classified as of Hutton 3100 form (S.A. Binomial classifications 1991). The soils are up to 800 mm in depth, with clay content of between 35 and 55% that increased with depth. There were no free boulders in the soil profile.

3.3 VEGETATION

The nomenclature of the grass species and woody plants follow Gibbs-Russell *et al.* (1985) and Arnold & de Wet (1993).

This study site falls into the mesic bush-grass communities of the eastern Cape known as the Eastern Province Thornveld (Acocks 1953). It occurs in the districts of Komga, King Williams Town, East London, Albany and Alexandria and constitutes 7.3 % of the Eastern Cape (O'Reagain & Hobson 1989). Depending largely on the successional stage of the vegetation, the vegetation consists of a mosaic of open grasslands, scattered to dense bushclumps within a grassland matrix, and thick woodland and forest patches (O'Reagain & Hobson 1989; Scogings 1992).

The bushclumps consist of a wide variety of woody species that coexist in close proximity. The woody species that occur in the early stages of the succession include *Acacia karroo*, *Scutia myrtina*, *Maytenus heterophylla*, *Rhus* spp., *Diospyros* spp. and *Ziziphus mucronata* (Scogings 1992). *Acacia karroo* is believed to be the pioneer species in this vegetation that provides the environmental conditions for invasion by other woody species such as *Scutia myrtina* (du Toit 1967; Aucamp *et al.* 1983). With further successional development species such as *Grewia occidentalis*, *Ehretia rigida*, *Cassine aethiopica*, *Hippobromus pauciflorus*, *Clerodendrum glabrum*, *Ptaeroxylon obliquum* and *Canthium* spp. occur (Jarvel 1996). See appendix 1 for the woody species that occurred at the study site. This successional pattern seems to resemble the autogenic succession of the subtropical grassland to thorn woodland in Texas (Archer *et al.* 1988; Archer 1989, 1990).

The herbaceous sward consists mainly of perennial, tufted grasses that includes *Themeda triandra*, *Hyparhennia hirta*, *Eragrostis* spp., *Sporobolus fimbriatus*, and *Digitaria eriantha* in open grassland areas, whilst *Panicum maximum* and *Helictotrichon capense* are common species under bush canopies (Jarvel 1996). This vegetation is similar to that of the False Thornveld of the Eastern Cape.

3.4 TREATMENTS

The experimental design was a single randomized block design with three primary treatments, namely chemical poisoning, mechanical clearing and a control (Table 3.1). Each primary treatment was replicated eight times and randomly assigned to 0.36 (60 m x 60 m) hectare plots. Follow-up treatments including goats, fire, fire-goat combination and no follow-up treatment, were randomly superimposed on each primary treatment and were replicated twice per initial treatment. Two additional mechanically cleared plots were oversown with *Chloris gayana*. Figure 3.2 shows the plan of the experimental layout. The experimental plots were separated by a ten strands fence that ensured successful control of goat movements.

Table 3.1. Primary and follow-up treatments that were tested for controlling bush encroachment in the mesic grass-bush communities of the eastern Cape on the farm, "Lily-park"

Primary treatments	Follow-up treatments	Plot Numbers
Control	None	1 &14
Control	Goats	2 & 15
Control	Fire	3 & 16
Control	Fire & Goats	4 & 17
Mechanical	None	5 & 18
Mechanical	Oversown	6 & 19
Mechanical	Fire	7 & 20
Mechanical	Goats	8 & 21
Mechanical	Fire & Goats	9 & 22
Chemical	None	10 & 23
Chemical	Fire	11 & 24
Chemical	Goats	12 & 13
Chemical	Fire & Goats	25 & 26

3.4.1 Primary treatments

(I) Chemical poisoning

A mixture of diesel and 1% Tordon Super was used for chemical poisoning as the high clay content of the soil excluded the use of common soil-applied herbicides which would have been ineffective. Tordon Super with picloram and trichlopyr active ingredients, inhibits photosynthesis and respiration of the plant and the synthesis of nucleic acids, thus causing the plant to die (Trollope *et al.* 1989). The herbicide was applied with knapsack sprayers to all stems as a 20 cm wide band from ground level. Chemical poisoning took place in December 1992.

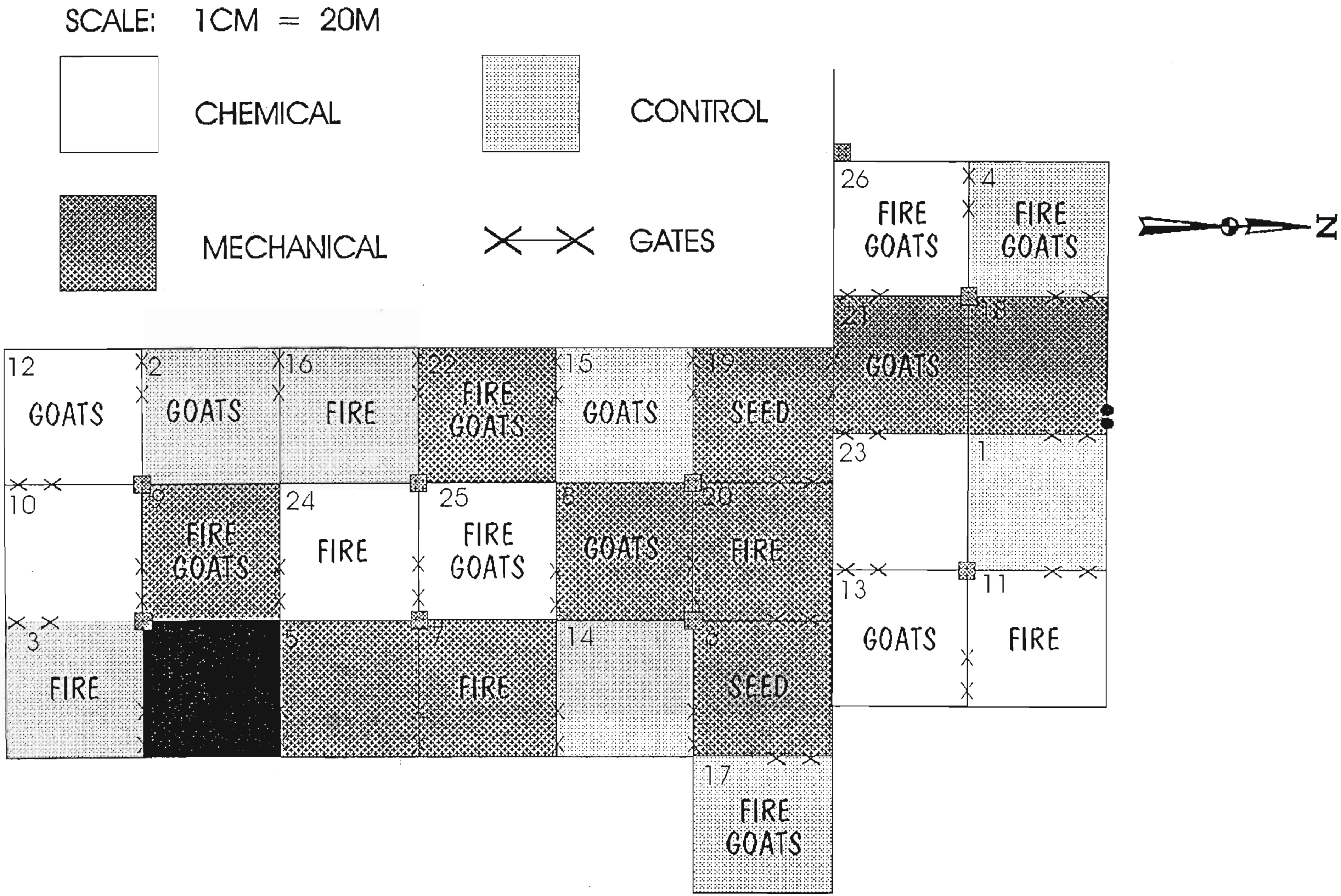


Figure 3.2: Layout of the experiment to control bush encroachment located on the farm Lilly park situated in the King Williams Town district of the Eastern Cape. Each plot is 60m x 60m (0.36 hectares). (The black square is not an experimental plot).

(ii) Mechanical clearing treatment

A bulldozer was used to clear the bush non-selectively during October 1992. Debris of the cleared areas was pushed out of the experimental plots. The bulldozer blade was used to uproot and push-over large woody individuals and the ripper was used to sever intact roots. The soil was only disturbed in the vicinity of bushclumps as the bulldozer blade was always kept above the soil surface when pushing the debris.

(iii) Oversown

A week after mechanical clearing was completed two of the cleared plots, without further preparation, were sown by hand-broadcasting with *Chloris gayana* seed (6 kg/ha). This was done to improve grass cover relative to other mechanical plots because it was anticipated that there was a shortage of grass seeds in the seedbank.

(iv) Control treatment

There was no initial clearing or chemical poisoning on the control treatment. The woody vegetation was left undisturbed.

3.4.2 Follow-up treatments

(I) Goats

The goats were rotated through the goat plots (total area of 4.32 ha) to simulate an ever-present browsing pressure and impact on bush as quickly as possible, thus preventing the bush, particularly coppice, growing out. The goat plots were stocked with goats from the end of the second season of the experiment (1993/94) at a stocking rate of 2.7 goats/ha. The average body mass of the goats used was 60 kg. During the early part of 1995/96 season the stocking rate of goats was increased to 4.6 goats/ha in order to achieve a greater impact on the bush. At the end of 1995/96 the stocking rate was reduced to 3.5 goats/ha due to excessive browsing pressure and the stocking rate during late 1996/97 was 0.92 goats/ha, the lowest stocking rate since the initiation of the experiment. These stocking rates were not based on objective assessment of the available browse but were intended to impact bush as severely as possible while limiting the use of grass. In late 1995/96 and 1996/97 destocking was done because of the unavailability of browse in winter. Goats were moved from a camp every fourth day or when available browse was depleted to a level where the goats were grazing more than 20% of the time.

(ii) Fire

The fire treatments were applied as head fires on all fire plots for the first two seasons (1994/95 and 1995/96) in which fire was applied. In the third season (1996/97) of fire application, mechanical-fire plots were burnt with back fire. The latter change was made in order to burn the short coppice growth of bush because back fires are hottest at ground level (Trollope 1983b). Fires were applied when at least 2000 kg/ha of grass fuel had accumulated to support a moderate to hot fire. The rationale for this was that very hot fires are not necessary to burn short bush. All fires were applied during the dormant season of the grass, during late winter. The fire plots were burnt in three consecutive years although the first fire (during 1994/95 season) was not as successful as the fires for the last two seasons. A summary of the atmospheric conditions and fuel characteristics that prevailed during the different fires is presented in Table 3.2. Average fire intensities of the different fires were estimated using regression equations (FI = 2729 + $0.8684x_1$ -$530\sqrt{x_2}$ -$0.907x_3^2$ -596 $1/x_4$) developed by Trollope (1995), in which FI= fire intensity (kJ/s/m), x_1= fuel load (kg/ha), x_2= fuel moisture (%), x_3= relative humidity (%) and x_4= wind speed (m/s), are shown in table 3.2.

All non-fire plots were grazed with cattle in winter in order to clean up the plots and to avoid the development of moribund grass. Ten steers, each weighing about 350 kilograms were grazed in each treatment plot for an average of ten days.

Table 3.2. Average values of fuel and atmospheric variables prevalent during the three different fires

Variable	1994/95	1995/96	1996/97
Air temperature (°C)	23.8	22.3	24.7
Relative humidity (%)	29.2	27.2	29.0
Wind speed (km/hour)	4	7	8
Fuel loads (kg/hectare)	3200	2500	2300
Fuel moisture (%) (wet basis)	45.7	28.2	29.3
Estimated fire intensity ($kJ.s^{-1}.m^{-1}$)	638	1170	985

CHAPTER FOUR

SOIL AND HERBACEOUS RESPONSES TO BUSH CONTROL METHODS

4.1 INTRODUCTION

The mesic savannas of the Eastern Cape have shown increased bush cover in recent times (O'Connor & Crow 1999) that has been associated with a high reduction of grass production of up to 90% (Jarvel 1996; Mapuma 1998), hence of grazing capacity. Bush clearing has been shown to result in increased grass production in many savanna regions throughout the world. There is, however, a dearth of published literature detailing the response of both soil and herbaceous composition to bush clearing particularly in multi-species bushclump savanna regions similar to Eastern Cape mesic savannas. Studies conducted in other savanna regions reported only on their initial successes and made no mention of what happened after several years when bush had possibly started to re-encroach the cleared areas. Different savannas are functionally unique (Teague & Smith 1992) and therefore, the results from other savannas cannot be simply extrapolated to these multi-species bushclump savannas. This chapter is, therefore, aimed at investigating the soil and herbaceous responses to different methods of controlling bush over a sufficient number of years in order to accommodate rainfall variability, and to examine if responses are maintained over time. The hypotheses developed in chapter two namely; I), (ii) and (v), formed the basis of this chapter.

4.2 PROCEDURE

4.2.1 Variables measured and techniques

(I) Soil fertility

Two randomly selected monitoring sites in each treatment plot were permanently marked for repeated sampling. The vegetation at each monitoring site was stratified into two vegetation zones: under the canopy of bushclumps or ex-bushclump in the case of cleared plots (hereafter referred to as bushclump zone) and interclump open grassland zone (hereafter referred to as grassland zone). Two soil samples per site per vegetation zone were taken from a depth of 0-20 cm, freshly drawn each year. All treatments were sampled in May/June at the end of each growing season.

The soils were analysed for soil density, pH, magnesium, calcium, phosphorus, potassium, and total nitrogen. pH was determined in KCl solution. Total nitrogen was determined by the Kjeldahl method (liberation of ammonia by distillation in presence of excess NaOH and Devarda's alloy and titration with HCl using a mixed indicator). Extractable phosphorus was determined using an AMBIC extractant and the absorbance noted on a spectrophotometer. Extractable potassium, calcium and magnesium were determined by atomic absorption spectrophotometry after extracting with an AMBIC solution and using a strontium solution as an ionic buffer. The methods used for soil analyses follow the methods published by FSSA (1974).

(ii) Herbaceous production, quality and composition

Two randomly selected monitoring sites in each treatment plot were permanently marked for repeated sampling. For sampling of the herbaceous layer, the vegetation at each monitoring site was stratified into three vegetation zones: interior bushclump or ex-bushclump zone, periphery of the buschclump zone (defined as two-metre-wide interface between the bushclump and the adjacent grassland zone) and interclump grassland zone. Ten random quadrats (50 cm x 50 cm) per vegetation zone per treatment plot, freshly drawn each year, were used for sampling. The ten resultant measurements per vegetation zone per treatment plot were meaned to one measurement and used as such in the analysis because the sampling unit was a treatment plot. All herbaceous species rooted within each quadrat were identified, from which frequency was derived. Dry-weight ranking (t'Mannetijie & Haydock 1963) was used to quantify botanical composition according to contribution to the above-ground herbaceous biomass. The published multiplication numbers of t'Mannetjie & Haydock (1963) were used to weight the scores of individual species. Quadrat samples were then clipped at ground level, separated into grasses and forbs, oven-dried at 60°C for 48 hours, and then weighed to determine herbaceous production. Sampling took place in May/June at the end of the growing season. There was however, an underestimation of grass production of an unknown amount in the goat treatments because goats did graze during the growing season.

Thereafter the samples were milled for nutrient analysis and variables of interest were total nitrogen, phosphorus, potassium, calcium and magnesium. Plant calcium, magnesium, potassium and phosphorus were digested with HNO_3 and $HClO_4$ at 150°C. Calcium, magnesium and potassium in the digest were determined by atomic absorption spectrophotometry, while phosphorus was determined by colorimetry using a spectrophotometer. Total Kjeldahl nitrogen was determined by converting nitrogen in the sample to NH_4^+ in the presence of H_2SO_4 and a catalyst. The NH_4^+ was determined colorimetrically on an auto-analyzer at 660 nm. The ten samples per vegetation zone per treatment plot were pooled together before the analysis to get representative samples. Methods used for the analyses of foliage chemistry follow the methods publshed by Venter (1993).

4.2.2 Data analysis

Preliminary investigation into the data indicated a complex pattern over time that depended on treatment, hence a most meaningful manner in which the effect of treatments could be ascertained was by systematically testing each year using one-way analysis of variance. General Linear Models (Proc GLM) (SAS 1989) was employed to analyse the effects of both primary treatments, and the combination of follow-up with primary treatments on soil chemistry, grass production and foliage chemistry on a year-by-year basis. The data was split into two vegetation zones for soil and foliage chemistry and into three vegetation zones within each treatment for grass production, because the effects of the treatments were found, during preliminary analysis, to depend the on spatial variability of the vegetation. Tukey's test was used to compare treatment means for both primary treatments and the combination of follow-up and primary treatments.

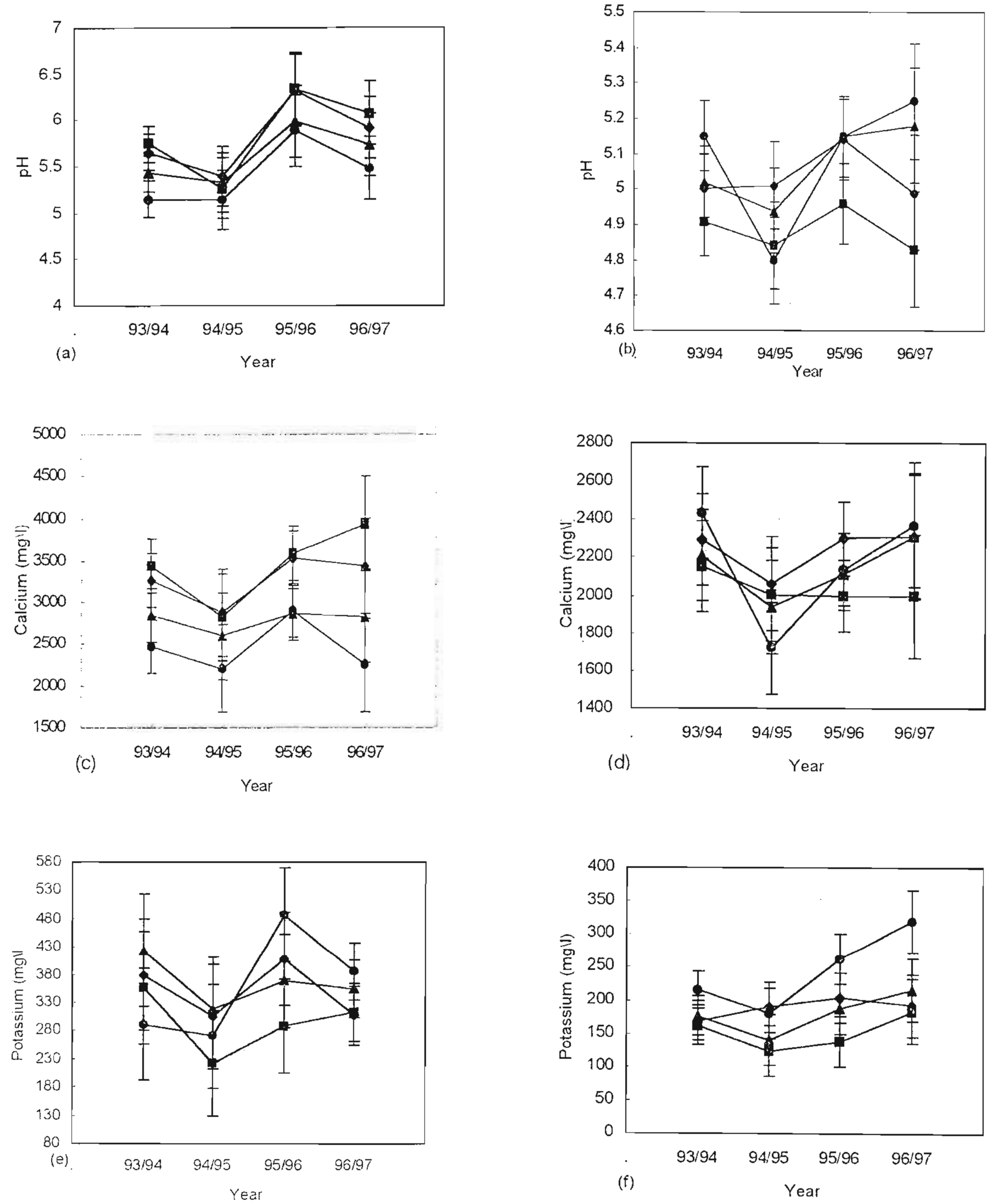
Differences among the follow-up treatments were tested using linear contrasts. The contrasts investigated were defined as: Fire versus Goats, Fire versus No fire, Fire versus Fire and Goats, Goats versus Fire and Goats, Goats versus No Goats, Fire and Goats versus No fire-goats. To achieve this, the data were centred for each primary treatment and a new set of observations was created and linear contrasts were run on these created data on a year-by-year basis as from the 1994/95 season. This was done to accommodate the effect of the primary treatments prior to making comparisons. The follow-up treatments were only applied at the end of the second season (1993/94) hence the analysis of the effects of the follow-up treatments only started with the 1994/95 data.

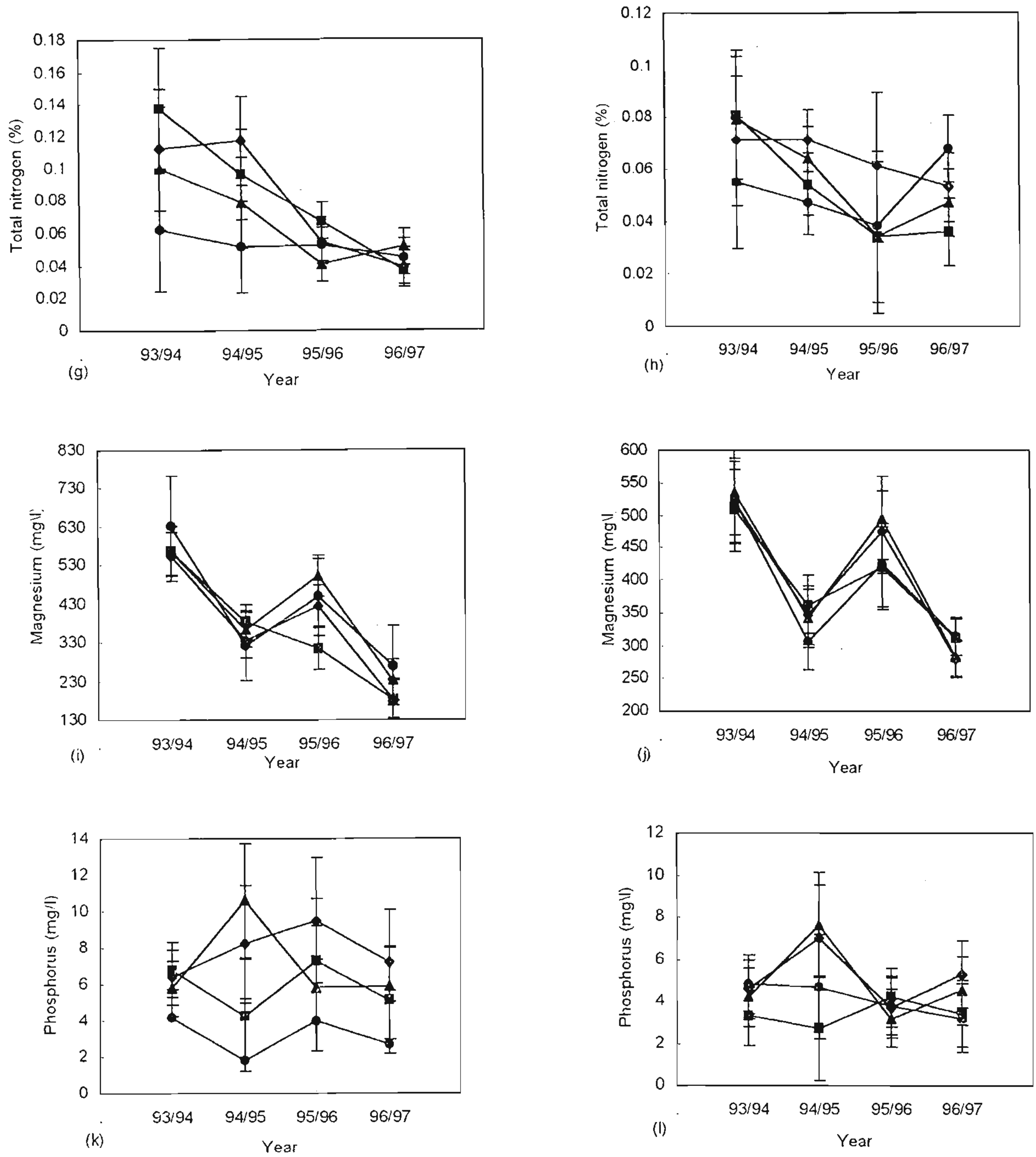
The species composition data was expressed in a percentage form for each species. To quantify the effects of the treatments on each grass species, abundance of each species during the first season (1992/93) after the establishment of the experiment was subtracted from the abundance of the same species during the last season (1996/97). The differences were subjected to the analysis of variance using General Linear Models (Proc GLM) to establish the effects of primary treatments and treatment combinations on change of species composition. The vegetation was also stratified into three vegetation zones for this purpose, namely ex-or bushclump, periphery and interclump grassland zone. Contrast statements for the follow-up treatments were also investigated.

Differences over time within each treatment were investigated using the analysis of variance.

4.3 RESULTS

4.3.1 Soil chemistry





Figures 4.1 a-l: Change in the mean (± 95% confidence interval) of soil chemical variables in the two vegetation zones of the oversown (●), mechanical (▲), chemical (◆) and control (■) treatments. Left aligned graphs are for the bushclump zones and right aligned are for the grassland zones.

Chemical poisoning and mechanical clearing of woody vegetation affected the levels of soil chemical variables over the last four years of the experimental period but the nature of the effects depended on soil chemical variable, vegetation zone and time. For the bushclump zone, mechanical clearing with oversowing reduced (df=3, F≥3.88, P≤0.0228) pH compared to the controls during 1993/94 and 1996/97 seasons (Figure 4.1a). This was probably related to low (df=3, F≥4.25, P≤0.0163) calcium levels in the ex-bushclumps of the oversown treatments during these two seasons compared to the controls (Figure 4.1c).

Table 4.1. Changes of soil nitrogen, magnesium and pH over time in the two vegetation zones. Different letters between years in a treatment indicate significant differences at P=0.05 using Tukey's test

Treatment	Vegetation zone	Nitrogen (%)		Magnesium (mg/l)		pH	
		Bushclump	Grassland	Bushclump	Grassland	Bushclump	Grassland
Chemical	1993/94	0.1125 a	0.0178 a	554 a	520 a	5.7 b	5.0 a
	1994/95	0.1170 a	0.0715 a	426 b	347 b	5.4 b	5.0 a
	1995/96	0.0544 b	0.0613 a	335 c	474 a	6.4 a	5.2 a
	1996/97	0.0389 b	0.0531 a	183 d	280 b	5.9 ab	5.0 a
Control	1993/94	0.1370 a	0.0808 a	571 a	508 a	5.8 b	4.9 a
	1994/95	0.0965 b	0.0545 b	383 b	362 bc	5.3 c	4.9 a
	1995/96	0.0666 bc	0.0343 b	315 b	419 b	6.4 a	5.0 a
	1996/97	0.0374 c	0.0363 b	185 c	312 c	6.1 a	4.9 a
Mechanical	1993/94	0.0990 a	0.0795 a	569 a	535 a	5.5 ab	5.1 a
	1994/95	0.0785 ab	0.0644 a	365 b	341 b	5.3 b	4.9 a
	1995/96	0.0413 c	0.0339 b	503 a	495 a	6.0 a	5.2 a
	1996/97	0.0513 bc	0.0469 b	232 a	281 b	5.8 ab	5.2 a
Oversown	1993/94	0.0620 a	0.1120 a	634 a	523 a	5.2 a	5.2 a
	1994/95	0.0510 a	0.0475 a	324 a	307 b	5.2 a	4.9 a
	1995/96	0.0515 a	0.0375 a	449 a	424 ab	5.9 a	5.2 a
	1996/97	0.0445 a	0.0685 a	269 a	318 b	5.5 a	5.3 a

Total soil nitrogen and magnesium levels showed a declining trend from the 1993/94 to 1996/97 in the bushclump zone of the control, chemical and mechanical treatments (Table 4.1). The declining trend of total nitrogen may be explained by the high grass production sustained since 1993/94 season or possibly increased mineralization. Unexplainable high levels of phosphorus ($df=3$, $F\geq3.43$, $P\leq0.0347$) were observed for both vegetation zones of chemical and mechanical without oversowing treatments during the 1994/95 season (Figure 4.1k & l).

The combination of primary and follow-up treatments had little influence on soil chemical properties over the study period (Tables 4.2a-d) and their effects varied with vegetation zone and soil chemical variable. The treatment combinations had no effect ($df=12$, $F\leq2.00$, $P\geq0.1144$) on pH. The combination of mechanical clearing and fire significantly increased levels of phosphorus compared with the control-fire and control-goat combinations in the bushclump zone in the 1993/94 season (Table 4.2b). Higher levels of potassium ($df=12$, $F>3.32$, $P\leq0.0204$) occurred with chemical-fire and goat combination than with the control-fire combination during 1995/96, in both vegetation zones (Table 4.2c). These treatment effects were rather inconsistent over the experimental period and across vegetation zones which suggest that they were of a minor nature. A declining trend between years, although not significant, was observed for soil nitrogen and phosphorus particularly in the combinations involving mechanical and chemical treatments, especially in the bushclump zone.

Table 4.2 a-d. Changes of soil variables in the two vegetation zones as influenced by treatment combinations during the last three years of the study. Different letters within a column indicate significant difference at P=0.05 using Tukey's test

(a) pH

Treatment combination	Bushclump zone			Grassland zone		
	1994/95	1995/96	1996/97	1994/95	1995/96	1996/97
Mechanical-fire	5.3 a	6.1 a	5.4 a	4.9 a	5.3 a	5.4 a
Mechanical-fire & goats	5.4 a	6.3 a	6.5 a	4.8 a	5.0 a	5.0 a
Mechanical-goats	5.1 a	5.7 a	5.5 a	4.9 a	5.2 a	5.0 a
Mechanical-none	5.6 a	5.9 a	5.5 a	5.2 a	5.2 a	5.3 a
Chemical-fire	5.6 a	6.7 a	6.2 a	5.0 a	5.1 a	4.9 a
Chemical-fire & goats	5.4 a	7.0 a	6.3 a	5.0 a	5.2 a	5.1 a
Chemical-goats	5.4 a	5.9 a	5.4 a	5.1 a	5.2 a	4.8 a
Chemical-none	5.3 a	5.7 a	5.8 a	5.0 a	5.1 a	5.2 a
Control-fire	5.0 a	6.2 a	6.1 a	4.8 a	4.8 a	4.8 a
Control-fire & goats	5.5 a	6.6 a	6.3 a	4.9 a	5.1 a	4.9 a
Control-goats	4.9 a	6.3 a	6.1 a	4.8 a	5.0 a	4.8 a
Control- none	5.7 a	6.4 a	5.9 a	5.0 a	5.0 a	4.9 a
Oversown	5.2 a	5.9 a	5.5 a	4.8 a	5.2 a	5.3 a

(b) Phosphorus (mg/l)

Treatment combination	Bushclump zone			Grassland zone		
	1994/95	1995/96	1996/97	1994/95	1995/96	1996/97
Mechanical-fire	17.9 a	7.2 a	8.1 a	12.4 a	5.4 a	4.9 a
Mechanical-fire & goats	8.2 ab	7.2 a	3.8 a	4.6 a	2.8 a	3.2 a
Mechanical-goats	9.7 ab	4.7 a	7.5 a	7.2 a	3.6 a	5.7 a
Mechanical-none	6.7 ab	4.1 a	4.4 a	6.1 a	1.2 a	4.4 a
Chemical-fire	10.6 ab	15.3 a	12.3 a	6.5 a	3.9 a	6.5 a
Chemical-fire & goats	4.1 b	12.1 a	7.2 a	4.6 a	3.9 a	4.8 a
Chemical-goats	7.9 ab	6.6 a	5.7 a	8.2 a	3.4 a	4.1 a
Chemical -none	10.8 ab	3.9 a	3.8 a	8.8 a	3.7 a	5.7 a
Control-fire	3.0 b	6.4 a	4.6 a	1.5 a	5.1 a	3.1 a
Control-fire & goats	5.6 ab	8.9 a	3.7 a	2.7 a	2.9 a	2.6 a
Control-goats	1.3 b	7.3 a	6.6 a	3.2 a	4.4 a	3.6 a
Control- none	7.2 ab	6.5 a	5.6 a	3.5 a	4.3 a	4.4 a
Oversown	1.8 b	4.0 a	2.8 a	4.7 a	3.8 a	3.2 a

c) Potassium (mg/l)

Treatment combination	Bushclump zone			Grassland zone		
	1994/95	1995/96	1996/97	1994/95	1995/96	1996/97
Mechanical-fire	330 a	382 ab	419 a	171 a	177 ab	221 a
Mechanical-fire & goats	293 a	380 ab	352 a	126 a	198 ab	198 a
Mechanical-goats	303 a	300 ab	342 a	158 a	185 ab	229 a
Mechanical-none	345 a	412 ab	307 a	105 a	185 ab	231 a
Chemical-fire	274 a	376 ab	321 a	172 a	201 ab	153 a
Chemical-fire & goats	425 a	621 a	332 a	160 a	301 a	259 a
Chemical-goats	311 a	325 ab	302 a	223 a	151 ab	174 a
chemical-none	217 a	312 ab	274 a	200 a	166 ab	184 a
Control-fire	98 a	153 b	280 a	90 a	110 b	145 a
Control-fire & goats	318 a	359 ab	378 a	130 a	139 ab	177 a
Control-goats	143 a	337 ab	250 a	114 a	146 ab	199 a
Control- none	332 a	304 ab	346 a	163 a	157 ab	211 a
Oversown	270 a	487 ab	387 a	180 a	262 a	342 a

(d) Nitrogen (%)

Treatment combination	Bushclump zone			Grassland zone		
	1994/95	1995/96	1996/97	1994/95	1995/96	1996/97
Mechanical-fire	0.060 a	0.042 a	0.042 ab	0.067 a	0.027 a	0.043 a
Mechanical-fire & goats	0.081 a	0.050 a	0.077 a	0.061 a	0.040 a	0.057 a
Mechanical-goats	0.091 a	0.030 a	0.042 ab	0.057 a	0.038 a	0.040 a
Mechanical-none	0.082 a	0.043 a	0.043 ab	0.073 a	0.031 a	0.047 a
Chemical-fire	0.150 a	0.042 a	0.035 ab	0.067 a	0.036 a	0.063 a
Chemical-fire & goats	0.100 a	0.049 a	0.039 ab	0.064 a	0.033 a	0.047 a
Chemical-goats	0.101 a	0.054 a	0.046 ab	0.087 a	0.044 a	0.055 a
Chemical-none	0.118 a	0.072 a	0.036 ab	0.068 a	0.132 a	0.048 a
Control-fire	0.073 a	0.067 a	0.040 ab	0.046 a	0.039 a	0.048 a
Control-fire & goats	0.069 a	0.064 a	0.058 ab	0.059 a	0.028 a	0.047 a
Control-goats	0.095 a	0.060 a	0.018 b	0.056 a	0.038 a	0.023 a
Control- none	0.149 a	0.075 a	0.035 ab	0.056 a	0.032 a	0.026 a
Oversown	0.051 a	0.052 a	0.045 ab	0.047 a	0.038 a	0.068 a

Fire treatment had higher levels of pH, calcium, potassium and total nitrogen in the bushclump zone compared with goats, no fire, and fire and goats (Table 4.3a-f) but this effect was only evident during the 1996/97 and 1995/96 seasons for some variables. This was attributed to the addition of ash from burnt plant residues into the soil. The lack of consistency with these effects over time illustrates their minor nature. Linear contrasts revealed that there were no significant effects in the grassland zone.

Table 4.3a-f. Comparisons of the effects of the follow-up treatments on soil chemical variables in the bushclump zone using linear contrasts. Significant effects (alpha=0.06) are shown in bold

(a) pH in bushclump zone

Contrast statement	Years 1994/95 F value	1994/95 Pr > F	1995/96 F value	1995/96 Pr > F	1996/97 F value	1996/97 Pr > F
Fire versus Fire and goats	0.40	0.5355	1.46	0.2416	4.83	**0.0399**
Fire versus Goats	1.68	0.2097	6.95	**0.0158**	10.25	**0.0045**
Fire versus No fire	0.12	0.7298	5.98	**0.0238**	8.15	**0.0098**
Goats versus Fire and goats	0.44	0.5133	2.04	0.1684	1.01	0.3279
Goats versus No goats	2.71	0.1153	0.04	0.8508	0.12	0.7321
Fire and goats versus No fire and goats	0.96	0.3384	1.53	0.2298	0.43	0.5195

(b) Calcium in bushclump zone

Contrast statement	Years 1994/95 F value	1994/95 Pr > F	1995/96 F value	1995/96 Pr > F	1996/97 F value	1996/97 Pr > F
Fire versus Fire and goats	0.10	0.7508	1.56	0.2265	0.20	0.6625
Fire versus Goats	0.24	0.6318	1.49	0.2369	1.09	0.3080
Fire versus No fire	0.58	0.4538	2.27	0.1473	4.23	**0.0509**
Goats versus Fire and goats	0.65	0.4283	0.00	0.9775	2.22	0.1521
Goats versus No goats	1.56	0.2255	0.08	0.7761	1.06	0.3146
Fire and goats versus No fire and goats	0.20	0.6632	0.07	0.7977	6.35	**0.0203**

c) Potassium in bushclump zone

Contrast statement	Years					
	1994/95		1995/96		1996/97	
	F value	Pr > F	F value	Pr > F	F value	Pr > F
Fire versus Fire and goats	2.82	0.1086	7.38	**0.0137**	2.65	0.1191
Fire versus Goats	1.96	0.1767	5.74	**0.0265**	5.27	**0.0327**
Fire versus No fire	0.51	0.4853	4.00	**0.0592**	4.25	**0.0525**
Goats versus Fire and goats	0.08	0.7832	0.09	0.7633	0.44	0.5127
Goats versus No goats	0.48	0.4984	0.16	0.6966	0.05	0.8179
Fire and goats versus No fire and goats	0.94	0.3444	0.49	0.4914	0.19	0.6696

(d) Nitrogen in bushclump zone

Contrast statement	Years					
	1994/95		1995/96		1996/97	
	F value	Pr > F	F value	Pr > F	F value	Pr > F
Fire versus Fire and goats	0.25	0.6252	0.22	0.6447	7.18	**0.0144**
Fire versus Goats	0.33	0.5706	0.70	0.4138	10.31	**0.0044**
Fire versus No fire	2.34	0.1420	1.21	0.2848	7.81	**0.0112**
Goats versus Fire and goats	0.01	0.9367	0.13	0.7180	0.28	0.6011
Goats versus No goats	0.91	0.3524	3.74	**0.0674**	0.17	0.6820
Fire and goats versus No fire and goats	1.07	0.3141	2.46	0.1328	0.01	0.9092

(e) Phosphorus in bushclump zone

Contrast statement	Years					
	1994/95		1995/96		1996/97	
	F value	Pr > F	F value	Pr > F	F value	Pr > F
Fire versus Fire and goats	3.94	**0.0611**	0.01	0.9341	2.40	0.1371
Fire versus Goats	0.02	0.8795	1.69	0.2083	0.57	0.4588
Fire versus No fire	1.01	0.3268	3.37	0.0812	0.02	0.8814
Goats versus Fire and goats	3.35	0.0820	1.92	0.1816	0.63	0.4369
Goats versus No goats	0.73	0.4045	0.29	0.5977	0.82	0.3754
Fire and goats versus No fire and goats	0.96	0.3390	3.69	0.0692	2.89	0.1047

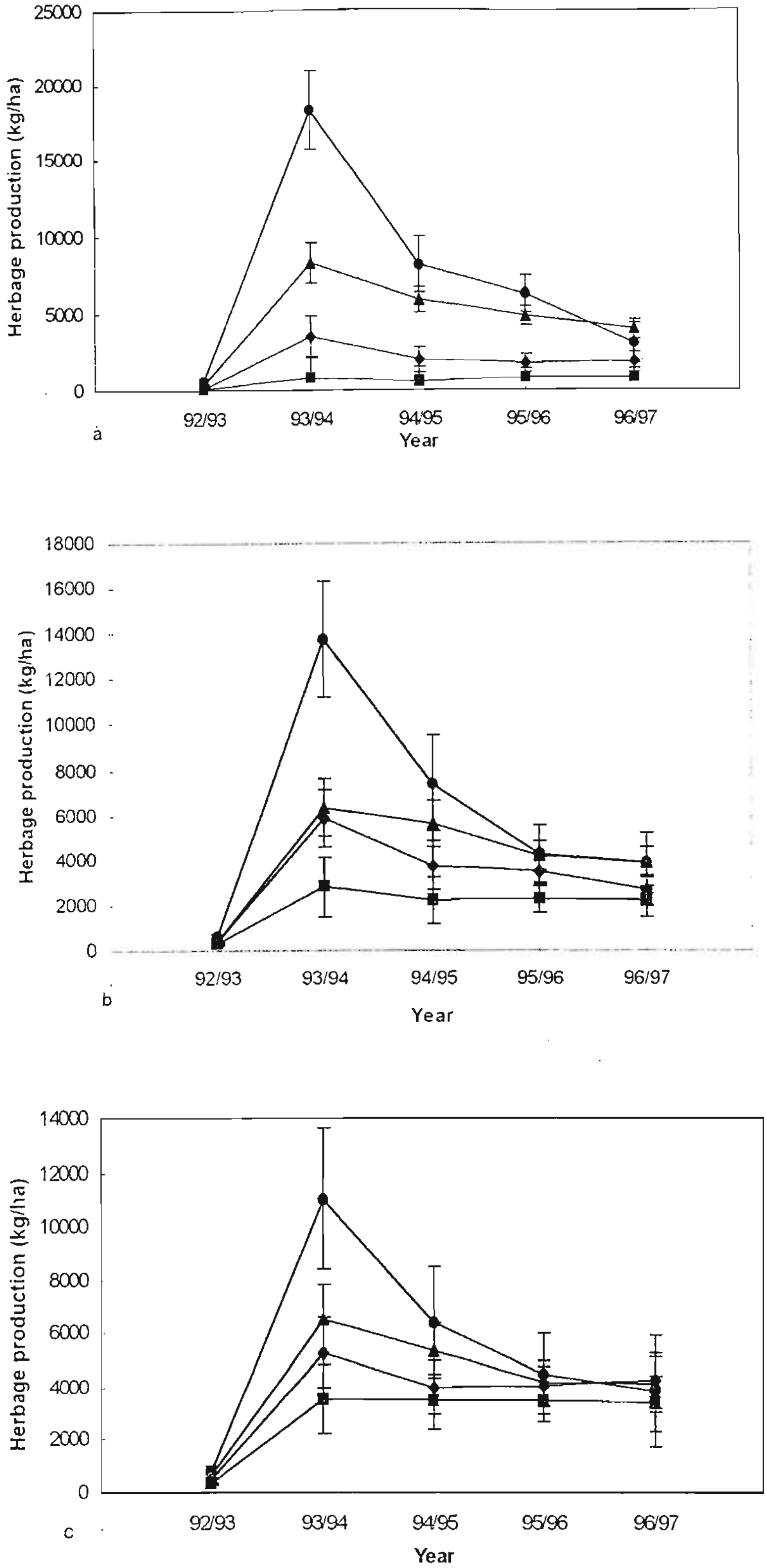
(f) Magnesium in bushclump zone

Contrast statement	Years					
	1994/95		1995/96		1996/97	
	F value	Pr > F	F value	Pr > F	F value	Pr > F
Fire versus Fire and goats	2.96	0.1009	1.10	0.3076	3.28	0.0852
Fire versus Goats	3.20	0.0889	0.02	0.8875	2.46	0.1326
Fire versus No fire	0.60	0.4477	0.00	0.9460	2.41	0.1363
Goats versus Fire and goats	0.00	0.9462	0.82	0.3769	0.06	0.8105
Goats versus No goats	6.57	**0.0186**	0.01	0.9412	0.00	0.9876
Fire and goats versus No fire and goats	6.22	**0.0215**	0.96	0.3395	0.07	0.7985

4.3.2 Herbaceous production

Herbage production over five years following establishment of the experiment showed a response to the primary treatments, follow-up treatments, the passage of time and rainfall of a growing season. Mechanical clearing resulted in the greatest herbage of all treatments but the differences with other treatments depended on vegetation zone, number of years of the experiment and rainfall, whilst oversowing had an effect additional to that of mechanical clearing (Figure 4.2a-c). The response to treatments was most pronounced within the bushclump zone (df=3, $F \geq 18.06$, $P \leq 0.0001$) and least pronounced in the grassland zone (df=3, $F \geq 4.19$, $P \leq 0.0174$), with the pattern of response of the periphery (df=3, $F \geq 11.23$, $P \leq 0.0001$) intermediate between these two until 1995/96.

For the bushclump zone, herbage was consistently greatest on the oversown treatment (1100 % of the control), second greatest on the mechanically-cleared treatment (700 % of the control) for the first four years, and least on the



Figures 4.2 a-c. The effect of the oversown (●), mechanical (▲), chemical (◆) and control (■) treatments on mean herbage production (±95% confidence intervals) in the different vegetation zones. a=bushclump, b=periphery and c=grassland zones respectively. Note the different scale for each vegetation zone.

chemical and control treatments that did not differ ($P>0.05$) except for greater herbage on the chemical treatment during the very wet season of 1993/94. By contrast, for the grassland zone, the greater herbage production on the oversown treatment ($df=3$, $F\geq4.19$, $P\leq0.0174$) endured for only the first two to three seasons relative to the mechanical and chemical treatments respectively.

Table 4.4. Mean herbage (kg/ha) produced in the three vegetation zones during the five seasons of the experiment. Different letters within a treatment indicate significant differences at P=0.05 using Tukey's test

Treatment	Vegetation zone			
	Years	Bushclump	Periphery	Grassland
Chemical	1992/93	122 c	422 c	499 c
	1993/94	3555 a	5906 a	5302 a
	1994/95	2015 b	3752 b	3982 b
	1995/96	1775 b	3524 b	4034 b
	1996/97	1839 b	2680 b	4284 b
Control	1992/93	133 b	301 b	395 b
	1993/94	814 a	2834 a	3572 a
	1994/95	649 a	2233 a	3446 a
	1995/96	774 a	2331 a	3455 a
	1996/97	772 a	2220 a	3375 a
Mechanical	1992/93	401 d	424 c	629 c
	1993/94	8325 a	6374 a	6544 a
	1994/95	5939 b	4751 b	5374 ab
	1995/96	4868 bc	4215 b	4237 b
	1996/97	3973 c	3923 b	4109 b
Oversown	1992/93	650 c	622 b	791 b
	1993/94	18356 a	13785 a	11032 a
	1994/95	8177 b	7439 ab	6404 ab
	1995/96	6285 b	4308 ab	4496 ab
	1996/97	3129 bc	3878 ab	3858 ab

By the fourth season, herbage within the grassland zone was uniform across all treatments (df=3, $F \leq 0.99$, $P > 0.4145$) including the control.

The 1992/93 drought season, in which only 60 % of the mean annual rainfall was received, resulted in poor herbage production on all treatments (Table 4.4). Rainfall received in seasons subsequent to 1992/93 increased dramatically, especially in 1993/94, and was associated with substantial herbage production in all treatments. The treatment effects declined with time although that was confounded with rainfall patterns.

Table 4.5. The effects of the combination of primary and follow-up treatments on herbage production (kg/ha). Different letters within a column indicate significant differences at P=0.05 using Tukey's test

Treatment combination	Bushclump zone			Grassland zone		
	1994/95	1995/96	1996/97	1994/95	1995/96	1996/97
Oversown	8177 a	6285 a	3128 abc	6403 ab	4496 a	3858 a
Mechanical-none	6866 ab	4632 abc	4905 a	7991 a	4876 a	3506 a
Mechanical-goat	6439 abc	4060 abc	4885 a	4280 ab	3660 a	4604 a
Mechanical-fire	5427 abcd	5380 ab	3469 ab	5103 ab	3302 a	3331 a
Mechanical-fire & goats	5024 abcd	5400 ab	2633 abc	4142 ab	5110 a	4992 a
Chemical-fire & goats	2311 bcd	2407 bcd	2476 abc	4013 ab	4713 a	4364 a
Chemical-none	2168 bcd	916 d	1023 bc	4620 ab	3981 a	4585 a
Chemical-fire	1810 bcd	2081 bcd	2285 abc	3814 ab	4005 a	3879 a
Chemical-goat	1772 bcd	1693 cd	1573 bc	3481 ab	3437 a	4165 a
Control-none	910 d	769 d	410 c	4189 ab	3942 a	2344 a
Control-goat	711 d	741 d	1167 bc	3452 ab	3336 a	2966 a
Control-fire & goats	545 d	839 d	578 c	2367 b	3065 a	3048 a
Control-fire	430 d	745 d	929 c	3778 ab	3478 a	5143 a

The 1993/94 and 1996/97 seasons, that are only two seasons apart, were not much different in rainfall received during each season, but herbage production decreased by at least 43% in the mechanically cleared (with or without oversowing) treatments and decreased less in chemical and control treatments between these two seasons.

The combination involving mechanical clearing with goats, fire, or fire and goats, resulted in the greatest herbage of all treatments but again the differences with other treatment combinations depended on vegetation zone and the number of years of treatment application (Table 4.5). The influence of treatment combinations was most pronounced in the bushclump zone and least pronounced in the grassland zone. Herbage production was uniform across all treatments in the 1996/97 season, except for the mechanical-goat and mechanical-fire combinations that were different (df=12, F=9.23, P=0.0002) to the combinations involving the controls in the bushclump zone. The increasing trend of herbage production, although not significantly different between years, in the treatment combinations involving fire and goats suggests that, with time, the follow-up treatments had started to open up the bushclumps, thereby positively affecting herbage production. This was particularly true for control and chemical primary treatments. The beneficial effects of clearing appeared to be limited to a few years (Table 4.5). The treatment combinations involving chemical poisoning were consistently not different (P>0.05) to the combinations involving the control in all vegetation zones.

Even though there was low herbage production across all treatments during the dry season of 1992/93, rainfall was poorly related to herbage production for all treatments (Figure 4.3a-d) suggesting that it had no influence on herbage production.

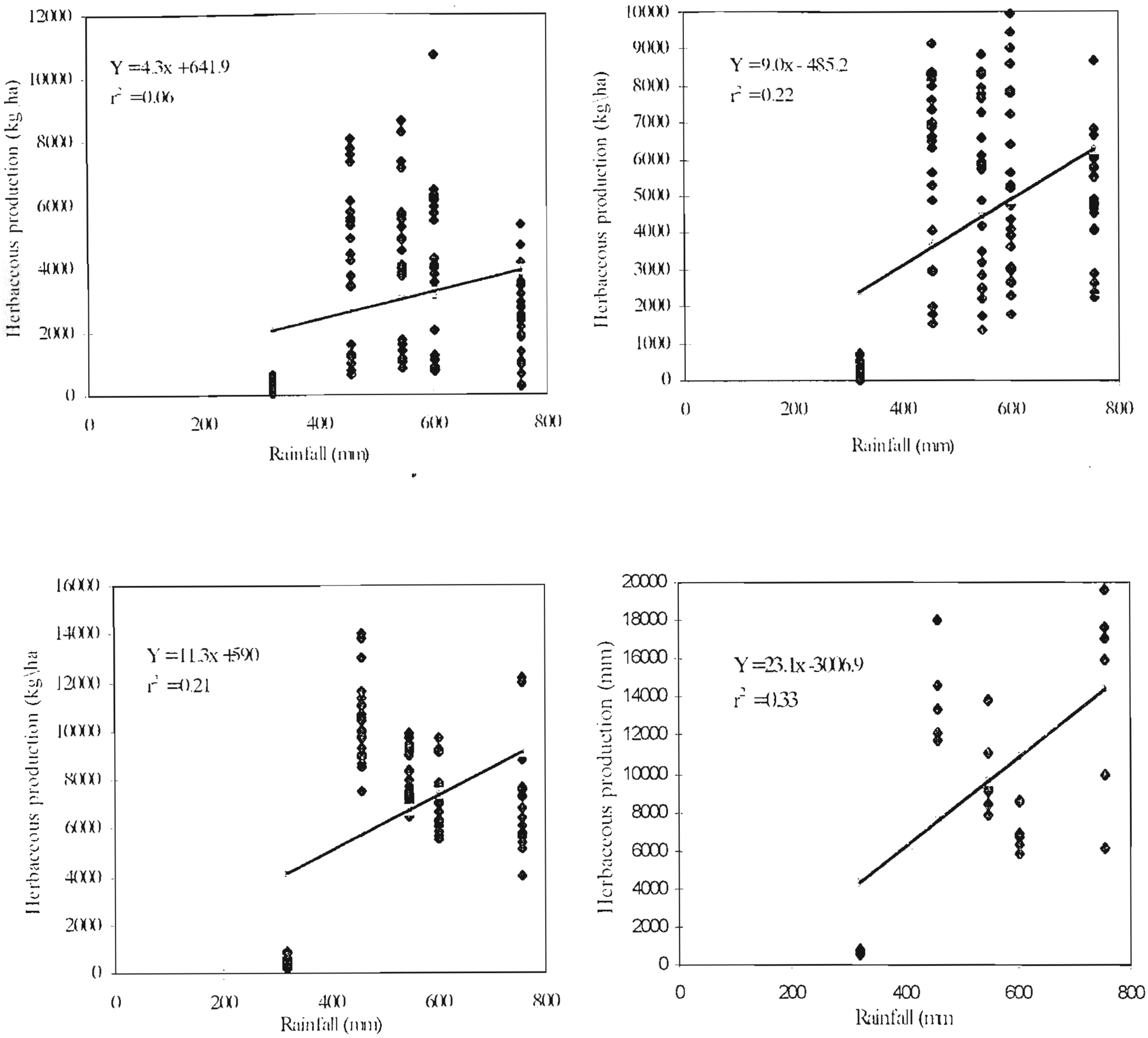


Figure 4.3 a-d. The relationship between annual rainfall and yearly herbage production all different vegetation zones (a) control, (b) chemical, c) mechanical and (d) oversown plots.

The effect of mechanical clearing, with or without oversowing, on herbage production showed a declining trend over the five years of the study and that decline was confounded with annual rainfall variations (Figure 4.4c&d). Chemical poisoning did not increase herbage in the bushclump zone to the levels of periphery and grassland zones over the five years of the study (Figure 4.4a).

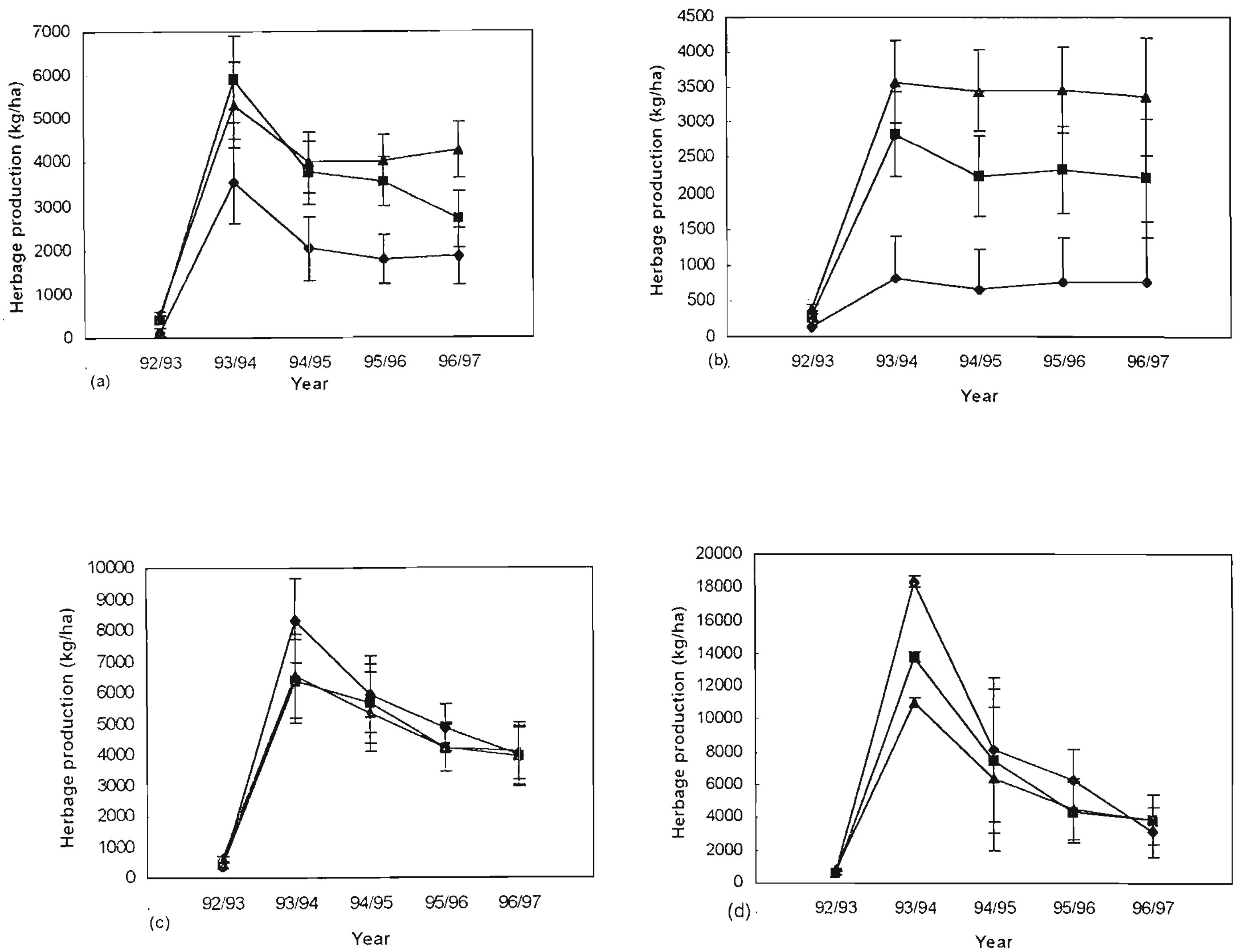


Figure 4.4a-d. Mean herbage production (±95% confidence intervals) in the bushclump (◆), periphery (■) and grassland (▲) zones of the (a) chemical, (b) control, c) mechanical and (d) oversown at Lily-park.

Goats, and fire and goats reduced herbage but treatment differences depended on vegetation zone. This reduction was more pronounced in the grassland and periphery zones in 1994/95 and 1995/96 respectively (Table 4.6 b&c) and was attributed to grazing by goats.

Table 4.6a-c. Comparisons of the effect of the follow-up treatments on herbage production in the three vegetation zones using linear contrasts. Significant effects (alpha=0.06) are shown in bold

(a) Bushclump zone

Contrast	Year					
	1994/95		1995/96		1996/97	
	F value	Pr > F	F value	Pr > F	F value	Pr > F
Fire vs Fire & Goats	0.01	0.9083	0.17	0.6862	0.42	0.5265
Fire vs Goats	0.33	0.5744	3.99	**0.0595**	1.58	0.2238
Fire vs No fire	1.28	0.2715	4.68	**0.0428**	0.18	0.6776
Goats vs Fire & Goats	0.47	0.4996	2.52	0.1279	0.37	0.5482
Goats vs No goats	0.31	0.5819	0.03	0.8708	0.69	0.4145
Fire & Goats vs No fire & goats	1.56	0.2267	3.07	0.0950	0.05	0.8261

(b) Periphery zone

Contrast	Year					
	1994/95		1995/96		1996/97	
	F value	Pr > F	F value	Pr > F	F value	Pr > F
Fire vs Fire & Goats	0.40	0.5360	1.88	0.1857	0.25	0.6222
Fire vs Goats	1.34	0.2602	7.72	**0.0116**	0.64	0.4331
Fire vs No fire	0.07	0.7955	0.42	0.5230	2.00	0.1729
Goats vs Fire & Goats	3.20	0.0888	1.98	0.1742	0.09	0.7675
Goats vs No goats	0.80	0.3809	4.53	**0.0459**	4.90	**0.0386**
Fire & Goats vs No fire & goats	0.80	0.3827	0.52	0.4797	3.66	0.0701

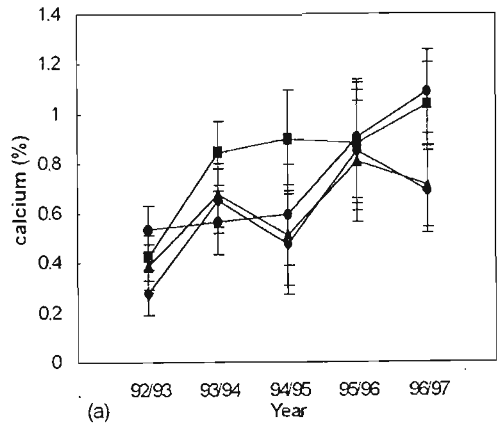
c) Grassland zone

Contrast	Year					
	1994/95		1995/96		1996/97	
	F value	Pr > F	F value	Pr > F	F value	Pr > F
Fire vs Fire & Goats	1.21	0.2846	1.45	0.2430	0.00	0.9836
Fire vs Goats	0.12	0.7307	1.97	0.1755	0.07	0.7890
Fire vs No fire	10.03	**0.0049**	0.00	0.9600	0.64	0.4348
Goats vs Fire & Goats	0.56	0.4617	0.04	0.8426	0.06	0.8048
Goats vs No goats	7.94	**0.0106**	1.83	0.1910	0.28	0.6048
Fire & Goats vs No fire & goats	4.27	**0.0519**	1.33	0.2628	0.60	0.4467

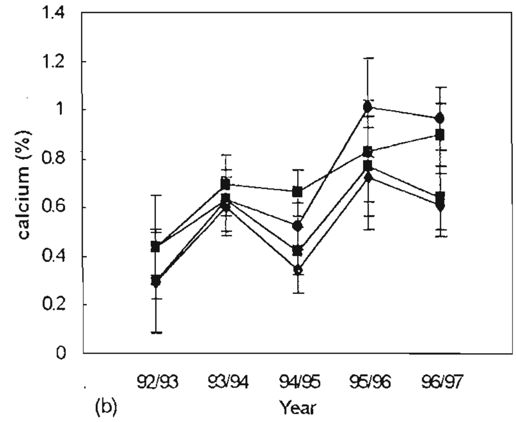
More herbage accumulated in the bushclump and periphery zones with fire than with goats in the 1995/96 season. Fire appeared to have opened up bushclumps and favoured grass growth. This latter effect might have been confounded with heavy grazing by goats. However, the inconsistency of all these effects over time illustrates their minor nature.

4.3.3 Foliage chemistry

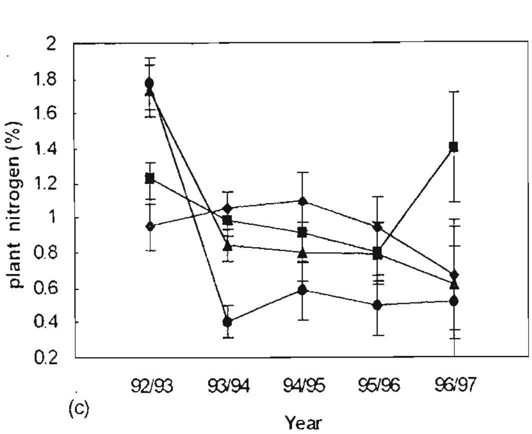
The concentration of the foliage chemical variables over five years following the implementation of the experimental treatments was a response to primary treatments and follow-up treatments. However, treatment responses depended on chemical variable and vegetation zone. For the ex-bushclumps, mechanical clearing with or without oversowing had foliage with a greater (df=3, F=9.04, P=0.0004) plant nitrogen concentration than the control and the chemical treatments but only during first season following clearing (Figure 4.5c&d). This was related to the low grass production that accumulated during this season. Mechanical clearing with oversowing had foliage with the lowest concentration of plant nitrogen in 1993/94, 1994/95, 1995/96 and 1996/97 seasons in both vegetation zones but this was significantly lower than the controls only in 1993/94 and 1994/95 in the bushclump zone and in 1993/94 in the grassland zone. No treatment differences (df=3, $F \leq 2.30$, $P \geq 0.1057$) were observed for phosphorus and magnesium in either vegetation zone over the study period except for magnesium in the 1992/93 season (Figure 4.5e-h). This season was characterised by significantly higher concentrations of magnesium in foliage on mechanically cleared treatments than on chemical treatments in the bushclump zone (Figure 4.5e).



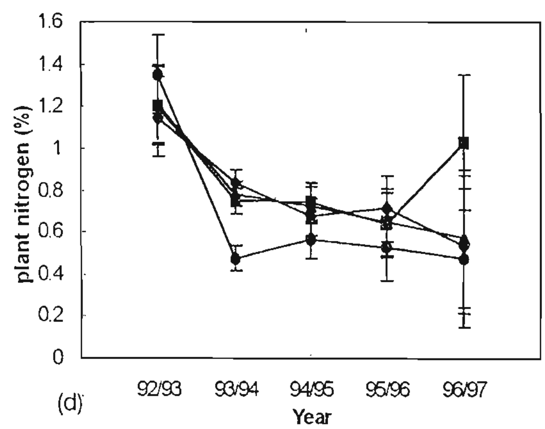
calcium (%)
Year
(a)



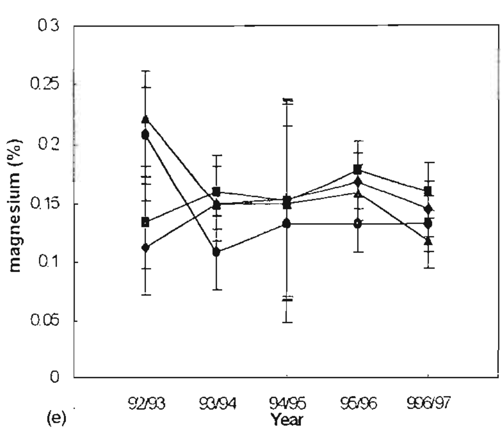
calcium (%)
Year
(b)



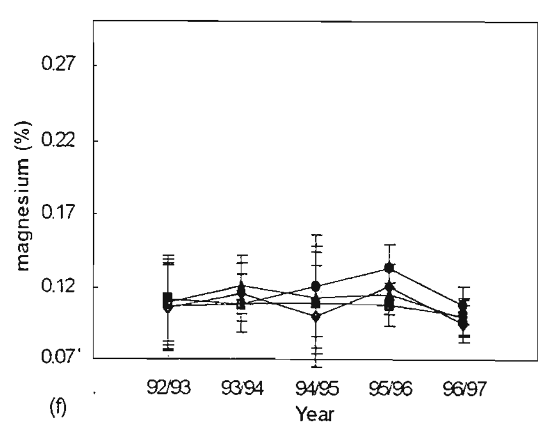
plant nitrogen (%)
Year
(c)



plant nitrogen (%)
Year
(d)



magnesium (%)
Year
(e)



magnesium (%)
Year
(f)

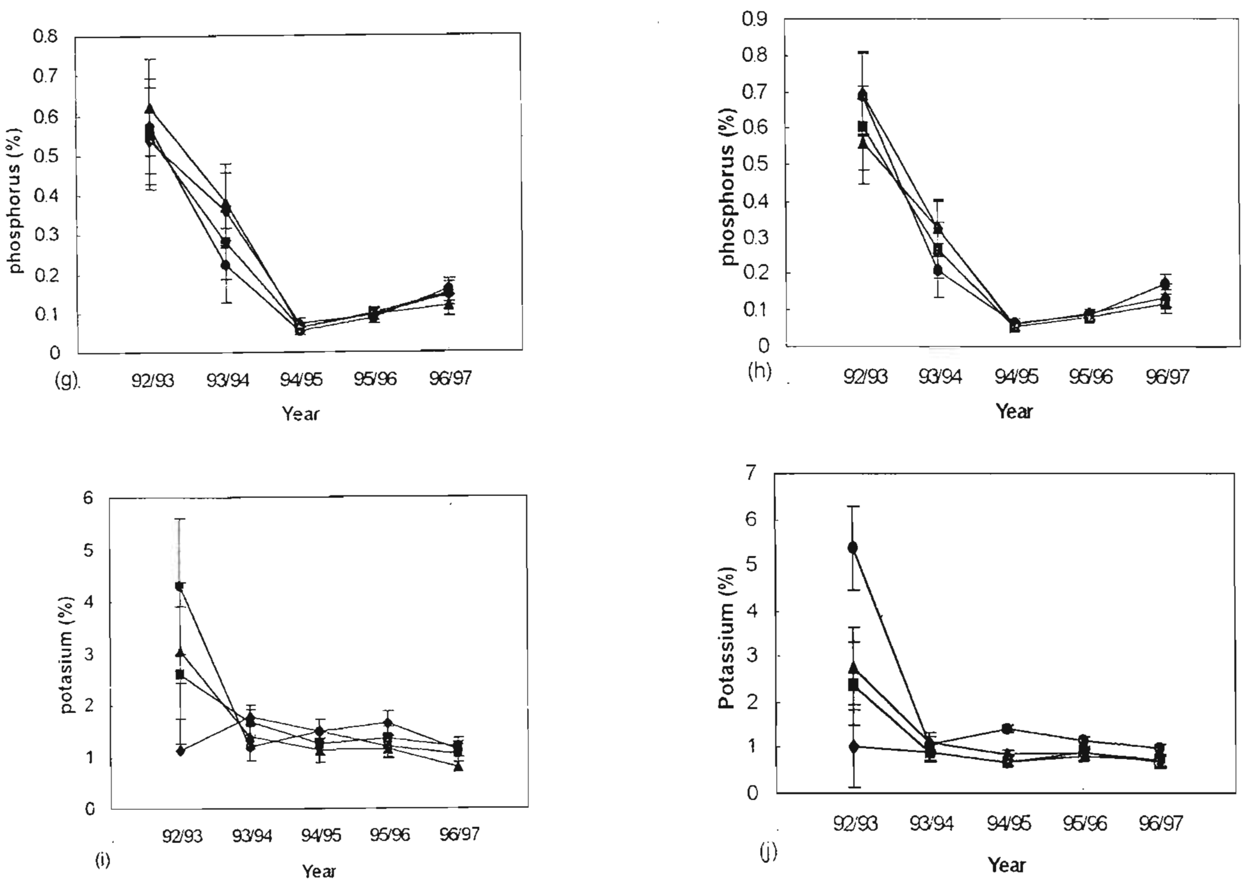


Figure 4.5 a-j. Mean concentration (±95% confidence limits) of different forage chemical variables on forage from the two vegetation zones of oversown (●), mechanical (▲), chemical (◆) and control (■) treatments. Left aligned graphs are for the bushclump zones and right aligned are for the grassland zones.

For chemical, control, and mechanical clearing without oversowing treatments, forage produced in 1992/93 and 1993/94 had greater (df=3, $F \geq 28.23$, $P \leq 0.0001$) concentrations of phosphorus compared with forage produced in the last three seasons of the experiment (Table 4.7). However, forage produced during the last three seasons, from 1994/95, showed a slow increasing trend of phosphorus concentrations in both vegetation zones of all treatments. Plant nitrogen in the mechanically cleared treatments without oversowing showed a declining trend over the study period in both vegetation zones, with forage produced in the 1992/93 season having significantly higher concentrations of plant nitrogen compared with other years (Table 4.7).

Table 4.7. Changes in plant nitrogen (%), calcium (%) and phosphorus (%) over time in the two vegetation zones. Different letters between years in a treatment show significant differences at P=0.05 using Tukey's test

Treatment	Vegetation zone	Nitrogen		Calcium		Phosphorus	
		Bushclump	Grassland	Bushclump	Grassland	Bushclump	Grassland
Chemical	1992/93	0.9569 ab	1.1513 a	0.2810 c	0.2903 b	0.5325 a	0.6944 a
	1993/94	1.0544 a	0.8344 b	0.6512 ab	0.5983 a	0.3621 b	0.3268 b
	1994/95	1.0938 a	0.6744 c	0.4751 bc	0.3461 b	0.0741 c	0.0609 c
	1995/96	0.9431ab	0.7113 bc	0.8528 a	0.7188 a	0.0948 c	0.0891 c
	1996/97	0.6694 b	0.5413 d	0.6863 ab	0.6098 a	0.1459 c	0.1322 c
Control	1992/93	1.2281 ab	1.2038 ab	0.4230 b	0.4350 c	0.5486 a	0.6013 a
	1993/94	0.9819 ab	0.7469 bc	0.8366 a	0.6915 b	0.2798 b	0.2649 b
	1994/95	0.9094 ab	0.7406 bc	0.8909 a	0.6608 b	0.0630 c	0.0533 c
	1995/96	0.8044 b	0.6356 c	0.8811 a	0.8312 ab	0.0997 c	0.0921 c
	1996/97	1.3981 a	1.2700 a	1.0349 a	0.8953 a	0.1474 c	0.1179 c
Mechanical	1992/93	1.7306 a	1.2138 a	0.3875 c	0.3004 b	0.6206 a	0.5609 a
	1993/94	0.8413 b	0.7769 b	0.6738 ab	0.6283 a	0.3819 b	0.3234 b
	1994/95	0.8044 bc	0.7238 b	0.5117 bc	0.4216 b	0.0618 c	0.0526 c
	1995/96	0.7869 bc	0.6469 b	0.8091a	0.7682 a	0.0935 c	0.0736 c
	1996/97	0.6219 c	0.5694 b	0.7082 ab	0.6368 a	0.1069 c	0.1154 c
Oversown	1992/93	1.7725 a	1.3475 a	0.5356 a	0.4388 a	0.5733 a	0.6880 a
	1993/94	0.4025 b	0.4375 b	0.5568 a	0.6345 a	0.2218 b	0.2068 b
	1994/95	0.5825 b	0.5600 b	0.5930 a	0.5235 a	0.0548 b	0.0653 b
	1995/96	0.4950 b	0.5225 b	0.8978 a	1.0078 a	0.0860 b	0.0868 b
	1996/97	0.5150 b	0.4750 b	1.0833 a	0.9613 a	0.1563 b	0.1730 b

Contrary to expectations the treatment combinations involving fire had no significant influence on plant nitrogen (Table 4.8e) or probably this effect may be revealed with a greater sample size. No treatment differences (df=12, F≤1.25, P≥0.3159) were observed for magnesium and phosphorus for all treatment combinations on either vegetation zone (Table 4.8c&d). The control-fire combination had greater concentration of calcium compared to the combination of mechanical clearing and goats in the grassland zone during the 1994/95 and 1996/97 seasons (Table 4.8b).

Most variations in foliage chemical variables were explained by vegetation zone. For control and chemical treatments, the grass from the bushclumps always had significantly greater concentrations of calcium, nitrogen, potassium and magnesium compared with the grassland zone.

Table 4.8a-e. Changes in the concentration of foliage chemical variables in forage from the two vegetation zones as influenced by treatment combinations. Letters within a column indicate significant differences at P=0.05 using Tukey's test

(a) Potassium (%)

Treatment combination	Bushclump zone			Grassland zone		
	1994/95	1995/96	1996/97	1994/95	1995/96	1996/97
Mechanical-fire	1.068 a	1.183 a	0.836 b	0.923 ab	0.937 a	0.778 a
Mechanical-fire & goats	1.068 a	1.034 a	0.739 b	0.786 b	0.816 a	0.699 a
Mechanical-goats	1.134 a	1.185 a	0.811 b	0.882 b	0.982 a	0.762 a
Mechanical-none	1.213 a	1.204 a	0.826 b	0.754 b	0.873 a	0.658 a
Chemical-fire	1.646 a	1.919 a	1.166 ab	0.604 b	0.932 a	0.770 a
Chemical-fire & goats	1.521 a	1.468 a	1.259 ab	0.733 b	0.757 a	0.691 a
Chemical-goats	1.250 a	1.971 a	1.088 ab	0.678 b	0.913 a	0.614 a
Chemical-none	1.434 a	1.229 a	0.906 b	0.725 b	0.974 a	0.642 a
Control-fire	0.826 a	1.204 a	0.853 b	0.484 b	0.917 a	0.591 a
Control-fire & goats	1.516 a	1.396 a	1.658 a	0.800 b	0.786 a	0.741a
Control-goats	1.218 a	1.258 a	0.939 b	0.864 b	0.828 a	0.814 a
Control- none	1.398 a	1.484 a	1.238 ab	0.626 b	0.755 a	0.703 a
Oversown	1.476 a	1.184 a	1.051 ab	1.398 a	1.125 a	0.959 a

(b) Calcium (%)

Treatment combination	Bushclump zone			Grassland zone		
	1994/95	1995/96	1996/97	1994/95	1995/96	1996/97
Mechanical-fire	0.381a	0.836 a	0.656 a	0.319 c	0.711 a	0.529 ab
Mechanical-fire & goats	0.449 a	0.805 a	0.672 a	0.345 bc	0.768 a	0.600 ab
Mechanical-goats	0.374 a	0.739 a	0.546 a	0.319 c	0.823 a	0.456 b
Mechanical-none	0.844 a	0.857 a	0.959 a	0.704 ab	0.772 a	0.962 ab
Chemical-fire	0.539 a	0.895 a	0.660 a	0.373 abc	0.804 a	0.646 ab
Chemical-fire & goats	0.400 a	0.489 a	0.804 a	0.282 c	0.402 a	0.656 ab
Chemical-goats	0.462 a	1.218 a	0.648 a	0.427 abc	0.745 a	0.531 ab
Chemical-none	0.500 a	0.808 a	0.633 a	0.303 c	0.924 a	0.606 ab
Control-fire	0.571 a	0.863 a	0.904 a	0.725 a	0.978 a	1.027 a
Control-fire & goats	1.040 a	0.981 a	1.355 a	0.649 abc	0.784 a	0.930 ab
Control-goats	0.730a	0.810 a	1.048 a	0.630 abc	0.935 a	0.896 ab
Control- none	1.223a	0.870 a	0.832 a	0.640 abc	0.628 a	0.729 ab
Oversown	0.593 a	0.898 a	1.083 a	0.524 abc	1.008 a	0.961 ab

c) Magnesium (%)

Treatment combination	Bushclump zone 1994/95	Bushclump zone 1995/96	Bushclump zone 1996/97	Grassland zone 1994/95	Grassland zone 1995/96	Grassland zone 1996/97
Mechanical-fire	0.133 a	0.157 a	0.110 a	0.103 a	0.128 a	0.093 a
Mechanical-fire & goats	0.167 a	0.174 a	0.131 a	0.112 a	0.114 a	0.105 a
Mechanical-goats	0.157 a	0.162 a	0.118 a	0.107 a	0.111a	0.097 a
Mechanical-none	0.143 a	0.145 a	0.117 a	0.129 a	0.110 a	0.103 a
Chemical-fire	0.149 a	0.192 a	0.158 a	0.092 a	0.118 a	0.096 a
Chemical-fire & goats	0.146 a	0.150 a	0.149 a	0.097 a	0.101 a	0.091 a
Chemical-goats	0.166 a	0.195 a	0.155 a	0.102 a	0.127 a	0.098 a
Chemical-none	0.156 a	0.140 a	0.116 a	0.111 a	0.139 a	0.097 a
Control-fire	0.112 a	0.216 a	0.157 a	0.114 a	0.139 a	0.116 a
Control-fire & goats	0.124 a	0.152 a	0.181 a	0.113 a	0.087 a	0.086 a
Control-goats	0.166 a	0.171 a	0.148 a	0.111a	0.119 a	0.116 a
Control- none	0.204 a	0.176 a	0.157a	0.097 a	0.088 a	0.083 a
Oversown	0.132 a	0.132 a	0.133 a	0.121 a	0.143 a	0.108 a

(d) Phosphorus (%)

Treatment combination	Bushclump zone 1994/95	Bushclump zone 1995/96	Bushclump zone 1996/97	Grassland zone 1994/95	Grassland zone 1995/96	Grassland zone 1996/97
Mechanical-fire	0.057 a	0.086 a	0.107 a	0.051 a	0.088 a	0.097 a
Mechanical-fire & goats	0.070 a	0.100 a	0.136 a	0.065 a	0.075 a	0.137 a
Mechanical-goats	0.068 a	0.103 a	0.107 a	0.050 a	0.090 a	0.102 a
Mechanical-none	0.052 a	0.085 a	0.117 a	0.045 a	0.072 a	0.131 a
Chemical-fire	0.075 a	0.100 a	0.157 a	0.062 a	0.091 a	0.142 a
Chemical-fire & goats	0.080 a	0.072 a	0.139 a	0.064 a	0.069 a	0.105 a
Chemical-goats	0.073 a	0.120 a	0.165 a	0.063 a	0.110 a	0.154 a
Chemical-none	0.069 a	0.087 a	0.124 a	0.055 a	0.087 a	0.129 a
Control-fire	0.052 a	0.103 a	0.175 a	0.053 a	0.084 a	0.119 a
Control-fire & goats	0.076 a	0.090 a	0.136 a	0.056 a	0.073 a	0.119 a
Control-goats	0.072 a	0.108 a	0.144 a	0.064 a	0.090 a	0.131 a
Control- none	0.053 a	0.099 a	0.135 a	0.040 a	0.083 a	0.104 a
Oversown	0.055 a	0.086 a	0.156 a	0.065 a	0.087 a	0.173 a

(e) Nitrogen (%)

Treatment combination	Bushclump zone			Grassland zone		
	1994/95	1995/96	1996/97	1994/95	1995/96	1996/97
Mechanical-fire	0.720 a	0.870a	0.575 a	0.665 a	0.670 a	0.485 a
Mechanical-fire & goats	0.858 a	0.743 a	0.608 a	0.805 a	0.583 a	0.570 a
Mechanical-goats	0.798 a	0.870 a	0.643 a	0.710 a	0.783 a	0.600 a
Mechanical-none	0.843 a	0.665 a	0.663 a	0.715 a	0.553 a	0.623 a
Chemical-fire	1.155 a	1.005 a	0.648 a	0.670 a	0.725 a	0.470 a
Chemical-fire & goats	1.018 a	1.088 a	0.640 a	0.645 a	0.748 a	0.383 a
Chemical-goats	0.960 a	0.868 a	0.790 a	0.668 a	0.585 a	0.735 a
Chemical-none	1.243 a	0.813 a	0.600 a	0.715 a	0.788 a	0.578 a
Control-fire	0.743 a	0.895 a	1.558 a	0.725 a	0.700 a	1.330 a
Control-fire & goats	1.178 a	0.773 a	1.413 a	0.830 a	0.570 a	1.130 a
Control-goats	0.888 a	0.775 a	1.333 a	0.795 a	0.730 a	1.370 a
Control- none	0.830 a	0.775 s	1.290 a	0.613 a	0.543 a	1.250 a
Oversown	0.583 a	0.495 a	0.515 a	0.560 a	0.523 a	0.475 a

The follow-up treatments affected foliage chemistry. Greater concentration of phosphorus was recorded with goats than with no goat treatment on both vegetation zones during the 1994/95 and 1995/96 seasons (Table 4.9a&b). Fire also resulted in a greater concentration of phosphorus than the no-fire or goat treatments in both vegetation zones in 1994/95 and 1995/96 respectively. The inconsistency of these effects over time illustrates their minor nature.

Table 4.9a-d. Comparisons of the effects of follow-up treatments on foliage chemistry in the two vegetation zones using linear contrasts. Significant effects (alpha=0.06) are shown in bold

(a) Phosphorus in bushclump zone

Contrast statement	Years					
	1994/95		1995/96		1996/97	
	F value	Pr > F	F value	Pr > F	F value	Pr > F
Fire versus Fire and goats	4.19	**0.0541**	1.27	0.2739	0.20	0.6623
Fire versus Goats	0.37	0.5508	7.56	**0.0084**	0.01	0.9377
Fire versus No fire	6.30	**0.0208**	0.16	0.6960	0.30	0.5883
Goats versus Fire and goats	2.07	0.1654	3.24	0.0870	0.13	0.7196
Goats versus No goats	3.62	0.0714	6.39	**0.0200**	0.40	0.5362
Fire and goats versus No fire and goats	0.22	0.6476	0.53	0.4747	0.99	0.3323

(b) Phosphorus in grassland zone

Contrast statement	Years					
	1994/95		1995/96		1996/97	
	F value	Pr > F	F value	Pr > F	F value	Pr > F
Fire versus Fire and goats	1.04	0.3193	3.07	0.0951	0.00	0.9634
Fire versus Goats	0.18	0.6797	7.60	**0.0122**	0.20	0.6622
Fire versus No fire	5.68	**0.0272**	0.93	0.3456	0.00	0.9634
Goats versus Fire and goats	0.36	0.5537	1.01	0.3274	0.24	0.6295
Goats versus No goats	3.86	**0.0635**	3.20	0.0886	0.16	0.6956
Fire and goats versus No fire and goats	1.85	0.1884	0.62	0.4410	0.01	0.9269

c) Potassium in bushclump zone

Contrast statement	Years					
	1994/95		1995/96		1996/97	
	F value	Pr > F	F value	Pr > F	F value	Pr > F
Fire versus Fire and goats	0.89	0.3580	0.60	0.4461	4.47	**0.0473**
Fire versus Goats	0.69	0.4161	0.97	0.3375	4.66	**0.0432**
Fire versus No fire	0.00	0.9663	0.00	0.9719	3.27	0.0855
Goats versus Fire and goats	0.01	0.9132	0.04	0.8393	0.00	0.9647
Goats versus No goats	0.62	0.4401	0.90	0.3549	0.12	0.7306
Fire and goats versus No fire and goats	0.81	0.3798	0.55	0.4670	0.09	0.7640

(d) Potassium in grassland zone

Contrast statement	Years					
	1994/95		1995/96		1996/97	
	F value	Pr > F	F value	Pr > F	F value	Pr > F
Fire versus Fire and goats	1.66	0.2126	4.63	**0.0438**	0.00	0.9757
Fire versus Goats	0.22	0.6468	3.34	0.0825	0.05	0.8313
Fire versus No fire	0.79	0.3834	1.49	0.2364	0.21	0.6487
Goats versus Fire and goats	3.07	0.0950	0.11	0.7490	0.03	0.8551
Goats versus No goats	1.84	0.1901	0.37	0.5505	0.46	0.5054
Fire and goats versus No fire and goats	0.16	0.6961	0.87	0.3627	0.24	0.6272

4.3.4 Herbaceous composition

Herbaceous composition after five years since the establishment of the experiment was a function of primary treatments (mainly mechanical clearing and chemical poisoning), but treatment effects depended on vegetation zone and species.

The frequency of *Panicum maximum* increased ($F \geq 10.36$, $P \leq 0.0002$) in the periphery and ex- or bushclump zones of the chemical, control and mechanically-cleared treatments (Figure 4.6d). These effects probably resulted from radical alteration of the growth environment associated with bush canopies. However, the frequency of *Helictotricon capense*, a species associated with bushclumps, did not (F=0.51, P=0.0618) change. The frequencies of *Panicum maximum*, *Themeda triandra*, *Eragrostis curvula*, *Sporobolus africanus* and *Cynodon dactylon* did not show significant changes across all vegetation zones in all treatments. Mechanically cleared treatments oversown with *Chloris gayana* reduced the frequency of *Panicum maximum* in the periphery and ex-bushclump (Figure 4.6d).

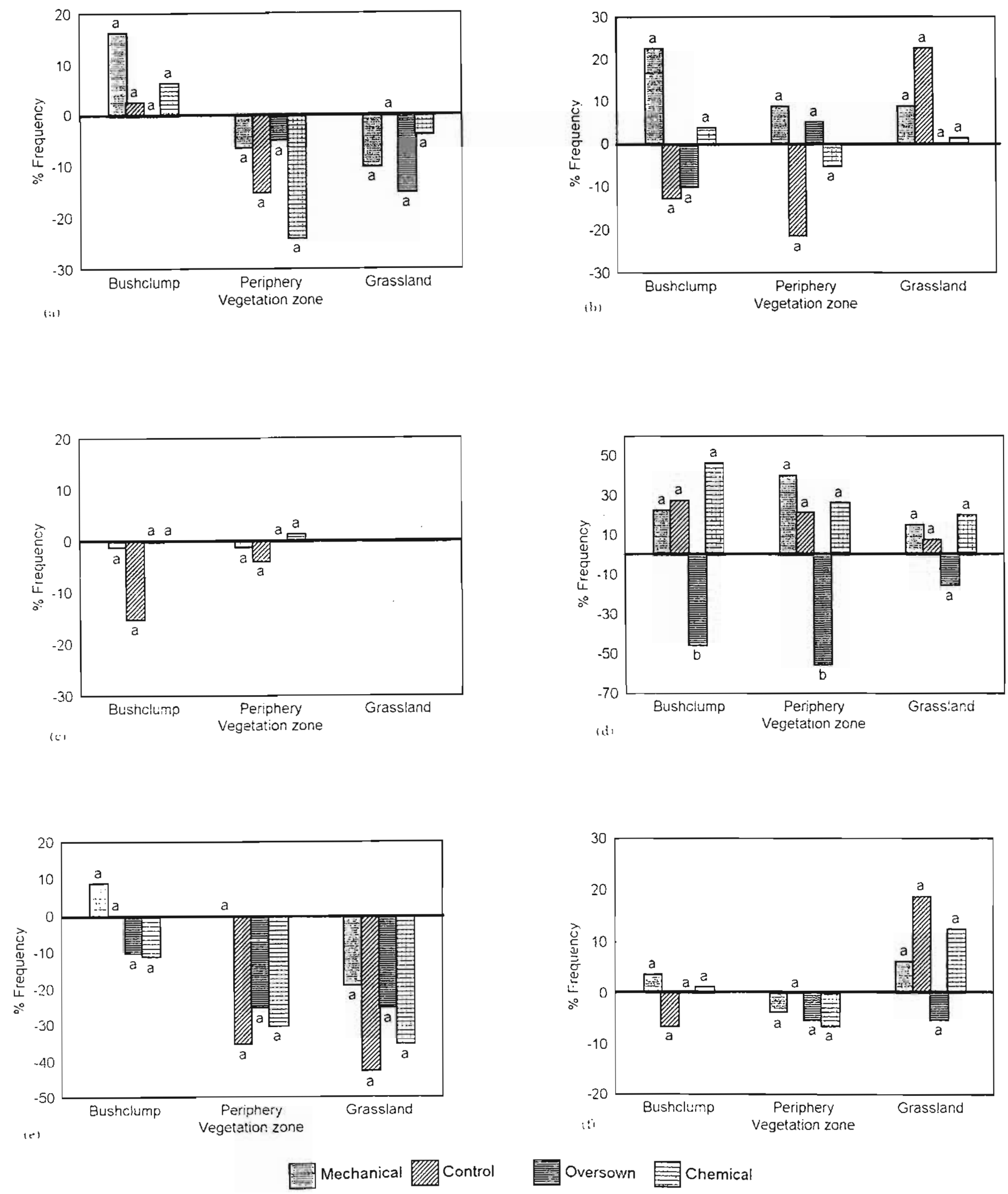


Figure 4.6a-f: Changes in composition of key species in the three vegetation zones as influenced by the primary treatments over a five year period of the experiment. Different letters indicate significant differences between treatments. (a) *Cynodon dactylon*, (b) *Eragrostis curvula*, c) *Helictotricon capense*, (d) *Panicum maximum* , (e) *Sporobolus africanus* and (f) *Themeda triandra*.

The combination of primary and follow-up treatments had no marked effect ($F \leq 0.46$, $P > 0.7751$) on changes in species frequency.

4.4 DISCUSSION

Monitoring of soil nutrient status in the last four seasons of the study revealed a continuous decline in concentrations of total nitrogen in the chemically and mechanically cleared treatments. This was despite increased concentrations of other soil chemical variables (e.g. phosphorus and potassium). The decline in concentrations of soil nitrogen could be explained in several ways. First, subsequent to 1992/93 season high levels of herbaceous production were maintained, and therefore soil nitrogen might have been utilized in the process. Mineralization of organic matter results in a release of nitrogen as ammonium that is highly volatile and therefore nitrogen was possibly lost into air. Although the above may explain the decline in soil nitrogen, no data on mineralization was recorded to support these speculations. Jarvel (1996) attributed a decline in soil nitrogen to high levels of grass production sustained subsquent to bush clearing and this might well be the case even in this study as high levels of grass production were maintained. However, the control treatments had the greatest decline of nitrogen levels yet these treatments had lowest herbaceous production, thus suggesting that the high levels of herbaceous production maintained subsequent to bush clearing are not the main reason for the declining levels of soil nitrogen. Leaching out of nitrogen in the form of nitrates could well be the reason for the declining nitrogen levels because above average rainfall was recorded during the post-clearing seasons.

Rainfall and herbage production data showed a very poor linear relationship in this study, indicating that rainfall had a minor influence on herbage production. These results are contrary to the findings of Dye & Spear (982) that rainfall influenced grass production after clearing in the studies conducted in different veld types of Zimbabwe. They suggested that soils with a high clay content resulted in reduced infiltration of rain water and penetration of a given amount of rain to a relatively shallow depth due to a high water holding capacity. In such soils there is a greater chance for loss of moisture to the atmosphere through evaporation compared with sandy soils. Consequently the herbaceous layer shows more sensitivity to availability of moisture, especially where rainfall is less than 700 mm and hence low herbage production during drought years (Dye & Spear 1982). As a result grass production in these studies showed greater variation, thus following patterns of rainfall (Dye & Spear 1982).

Mechanical clearing with or without oversowing resulted in a significant increase of herbage production in the first four years of the study, especially in the ex-bushclump zones. This clearly demonstrated the suppressive effect of the woody layer on grass in this savanna system. The significant increase in herbage production with relatively unchanged herbaceous composition indicated a release of nutrients, particularly nitrogen, to the herbaceous layer following the mechanical removal of the woody layer, especially in the first two seasons. Soil moisture might have also increased as some woody plants died back, and hence it might also have contributed to increase in herbage production. These results are in accordance with the findings reported by Donaldson & Kelk (1970) and Pratchett (1978) that the suppressive effect of woody layer is brought about largely through competition for nutrients. Scanlan (1992), Belsky (1994), and Jarvel (1996) reported shading and moisture as other factors that bring about a suppressive effect from the woody layer, especially in thick bushclump savannas similar to this study site. *Panicum maximum* with increased colonization within the periphery and ex-bushclumps, had increased productivity presumably as a result of the reduced competition for light, moisture and soil nutrients, amongst other factors, that explains the increased herbage production in the periphery and ex-bushclumps of these treatments. Oversowing with *Chloris gayana* was very successful because not only did it provide immediate cover but it was also very productive. The increased herbage production in oversown treatments can be explained in two ways. First, it may suggest that the seed of grasses was a factor limiting production, especially of ex-bushclumps. Second, it may be explained by the fact that *C. gayana*, a pasture species, has been bred for high productivity amongst other factors.

Chemical poisoning of the woody vegetation did not have a marked impact on herbage production despite increased colonization by *P. maximum* in the bushclumps. Mortality of some woody individuals had little positive impact on the productivity of *P. maximum*. These findings contradict the results from the studies conducted in the Thorn Woodlands of Texas and the Northern Cape. An increase of 100 to 300% and 200 to 740% in grass production following chemical poisoning was reported in these studies respectively (Scrifes & Welch 1982; Moore *et al.* 1985). Bosch & van Wyk (1970) reported increased productivity of *P. maximum* after removal of bush canopies. The findings by Bosch & van Wyk (1970) would suggest that shading was the cause for the lack of response in grass production in this study, especially if one considers that chemical poisoning was less successful (chapter five).

Increased herbage production in this study endured for only four seasons following removal of woody plants. This time period is far shorter than the results from the different veld types in Zimbabwe (Barnes 1979; Dye & Spear 1982) where increased herbaceous production was sustained for more than ten years. The suppressive effect of the woody layer was reported to have had influence on herbaceous production within nine years after bush clearing in the *Eucalyptus* savanna of Australia (Walker *et al.* 1986). Harrington & Johns (1990) suggest that rainfall has a major influence on the number of years for which increased herbaceous production is sustained. The lack of significant differences in herbage production between the control and cleared treatments during the fifth year demonstrates the poor effect of mechanical and chemical clearing methods, thus questioning the sustainability of these clearing methods for this vegetation structure.

Fire increased herbage production in the bushclump and periphery zones that may be explained by the increased soil fertility recorded in this particular treatment. Sweet (1982) working in the Botswana Thornveld also reported a tendency of soil fertility to increase after the application of fire. Increase in soil fertility under the bushclumps, especially in control and chemical treatments, would not have resulted in increased herbage production because a lack of irradiance is reported to be a major factor inhibiting grass production under bushclumps in similar savannas (Mordelet 1993; Belsky 1994; Jarvel 1996). Slow reduction of the area covered by bush and better irradiance resulting from the application of fire (McNaughton 1985; Wu *et al.* 1985), might explain the increased herbage production in the fire treatments. However, such an explanation remains speculative as no data or information was recorded for those factors in this study. Contrary to the findings of

Trollope (1983b) and Ducey *et al.* (1996) that fire increased the frequency of some grass species, fire had no effect on herbage composition in this study. The effect of fire on composition in this study may possibly be detected over a longer period of monitoring herbaceous composition.

Goats significantly reduced the standing crop of grass, especially in the periphery and grassland zones, owing to a high browsing pressure. The stocking rate of goats in this study was subjectively formulated and this might have resulted in overstocking in relation to available browse in some seasons, hence goats grazed more. The years in which goats reduced standing crop of herbage were the years in which destocking was done, suggesting that destocking was done too late or the technique used was unreliable. These results conform with the findings of Trollope (1983b) that goats grazed more grass with increasing browsing pressure. In the Botswana Thornveld goats were reported to have reduced grass production in seasons subsequent to the first season of browsing, and that was attributed to less browse available during those seasons (Sweet & Mphinyane 1986). However, this scenario suggests that goats had a marked impact on bush during at least these years, which was the intention.

Mechanical clearing improved forage quality during the first season (1992/93) of the experiment. As from the 1993/94 season soil nutrient status declined significantly and this was associated with significant reduction in forage quality. This could be an indication of a decline in soil nutrient status or could equally be explained by high levels of herbage production maintained subsequent to the 1992/93 season. Field observations suggested that the ratio of stems to leaves in the mechanically cleared treatments was very narrow. Grass stems generally have high levels of lignin hence poor quality, so that plant structure may have accounted for the decline in grass quality, if at least have not confounded the trend. There was, however, no empirical data from this study to support this speculative proposal. If one considers that total nitrogen content in the standing crop of grass in the mechanical treatments declined from 68.9 kg.ha^{-1} in 1993/94 to 15.5 kg.ha^{-1} in 1996/97, then the decline in forage quality was clearly due to drop in soil total nitrogen. In contrast, Barnes (1979) attributed the decline in the quality of forage on offer to replacement of the preferred species, *P. maximum* by *Urochloa mosambicensis*. Increase in the density of *Eragrostis lehmanniana*, a sub-climax species, was advanced as the reason for the decline in forage quality in a study conducted in the Northern Cape (Moore *et al.* 1985). Conversely, increased colonization of preferred grass species following bush clearing in the Botswana Thornveld was associated with an increase in quality of forage (Anon 1979). In this study species composition could not explain the decline in forage quality as the herbaceous composition remained relatively unchanged.

Herbaceous quality and composition in the chemically treated plots mirrored that of the controls. Contrary to expectations fire treatment did not improved grass quality, particularly plant nitrogen. West (1965) and Tainton *et al.* (1977) found that amongst other reasons burning is aimed at improving grass quality. Fire does this by burning up the dead plant material, thus resulting in fresh leafy growth.

In conclusion, mechanical clearing resulted initially in increased soil fertility that explained the initial dramatic response in grass production. These effects were coupled with increase in foliage quality. However, all these effects endured for a short time, especially increased soil fertility. Chemical poisoning of the woody vegetation was even less successful in terms of increasing grass production in this savanna, except when followed up with burning. The increase in herbaceous production while soil fertility was declining suggests that improved illumination was responsible for increased herbaceous production.

CHAPTER FIVE

WOODY RESPONSES TO BUSH CONTROL METHODS

5.1 INTRODUCTION

Studies on clearing of woody vegetation have focused mainly on herbaceous responses to bush control owing to the role of grass as forage for livestock. As a result there is dearth of published literature detailing the responses of the woody vegetation to such operations (Scholes 1990). In the sparse literature, it has been reported that bush recovers from clearing through coppicing from rootstocks (Donaldson 1970; Barnes 1972; Walker *et al.* 1986; Glen-Leary 1990; Jarvel 1996). Depending on rainfall the woody vegetation may reach the pre-clearing levels within fourteen years after clearing (Pratchett 1978; Scholes 1990). Most studies on the control of bush focused on mono-species savannas (e.g. du Toit 1972b; Trollope 1974; Sweet 1982) while very little work has been done on multi-species bushclump savannas (Jarvel 1996). This is a serious shortcoming in the study of controlling bush because each savanna is functionally unique (Teague & Smith 1992) resulting in a variety of responses. The rate of bush recovery is not considered in most economic analyses of bush control operations. Many land mangers justify the financial soundness of the bush control operations by the increased grass production after clearing, without discounting the subsequent recovery of the woody plants.

This chapter is, therefore, aimed at testing the efficacy of mechanical clearing and chemical poisoning in controlling woody plants and to quantify rates of re-encroachment and woody responses. It also reports upon the effectiveness of fire and goats as follow-up management strategies. The hypothesis developed in chapter two namely (iii), (iv) and (v) namely; formed the basis of this chapter.

5.2 PROCEDURE

5.2.1 Variables measured and techniques

Two randomly selected transects in each treatment plot, each 30 metres long and three metres wide, were permanently marked with two iron pegs for repeated sampling. All the woody individuals within these transect belts were assigned co-ordinates or mapped for easy relocation. Any one rooted plant irrespective of the number of stems was treated as an "individual".

The woody plants were divided into two size classes: the small individuals consisted of woody seedlings, or shrubs smaller than 0.5 m in height (here referred to as small individuals), and established individuals that were greater than 0.5 m in height or with stem basal circumference greater than 5 cm (here referred to as large individuals). This division of woody plants into size classes only applied to chemical and control treatments and not to cleared treatments.

For monitoring the woody component, the vegetation in each treatment plot was stratified into three vegetation zones: interior of the bushclump, periphery of the bushclump, and interclump grassland zones. The vegetation in the mechanically cleared treatments was not stratified.

All the large individuals along the transect were measured and monitored. Because small individuals were abundant, a preliminary survey was undertaken to determine the optimum sub-sample size that would efficiently reflect the species richness and abundance of the small individuals within each vegetation zone in each treatment. The optimum sub-sample size that met the above criteria was found to be measuring all small individuals in the grassland zone, a single quadrat of 4 m^2 in the bushclump zone and two quadrats of 3 m^2 in the peripheral zone per transect.

Variables recorded for each woody individual within the transect belts were species, height, vegetation zone, number of stems, state of health (dead or alive), and whether recruitment had occurred from coppice or seed in the case of small individuals. Baseline measurements and mapping of the individual plants were done prior to the implementation of the treatments or a week after in the mechanically cleared plots.

In determining the effects of the treatments, mortality, recruitment and coppicing of the woody individuals and density of the woody plants per unit area were investigated.

Mortality was determined from the examination of the wood beneath the bark. In the case of multi-stemmed woody plants, individuals were classified dead when all stems had succumbed. Percentage mortality was calculated as the number of individuals that died during each season divided by the total number of individuals at the beginning of the season. Individuals that recruited during that particular season and mortalities of the previous season were excluded.

Recruitment was expressed as the number of small individuals recruited per m^2, that is, new seedlings that were not present during the previous season were classified as recruitment.

Height increment was expressed as a percentage of individuals in the three height classes of 0-0.5m, 0.5-1m, and > 1m. Density of bush was expressed as the number of stems per m^2, and included only the live individuals at the end of each season.

Mechanical clearing completely altered the vegetation structure of the mechanically cleared plots and thus obviously eliminated the possibility of comparing the mechanical treatment with the control. The data from mechanically cleared treatments were reported upon as a descriptive assessment and also compared with the oversown treatment. All vegetation surveys and monitoring were conducted in June/July each year.

5.2.2 Data analysis

The mortality, recruitment, density and height incremental data were subjected to analysis of variance using General Linear Models (Proc GLM) (SAS 1989) on a year-by-year basis, to establish the effects of primary treatments and combination of primary treatments with follow-up treatments. For chemical and control treatments, the data were split into three vegetation zones and species at times because the treatment effects were anticipated to depend on spatial variability of the vegetation and species variability. The data was also split into large and small woody individuals as discussed in the preceding section. Chemical treatment was compared to the controls while mechanical treatments were compared to the oversown treatments. Tukey's test for comparison of means was used to compare treatment differences at alpha=0.05.

Contrasts statements investigated were defined as: Fire versus Goats, Fire versus No fire, Fire versus Fire and Goats, Goats versus Fire and Goats, Goats versus No Goats, Fire and Goats versus No fire-goats. To achieve this, the data were centred for each primary treatment, thus creating a new set of observations for each variable. Differences between the mean of each primary treatment and the observations involving that particular treatment were calculated and used as a new set of data. Linear contrasts were run on these created data on a year-by-year basis as from the 1994/95 season. This was done to accommodate the effect of the primary treatments prior to making comparisons.

5.3 RESULTS

5.3.1 Mortality of woody individuals

Control versus Chemical

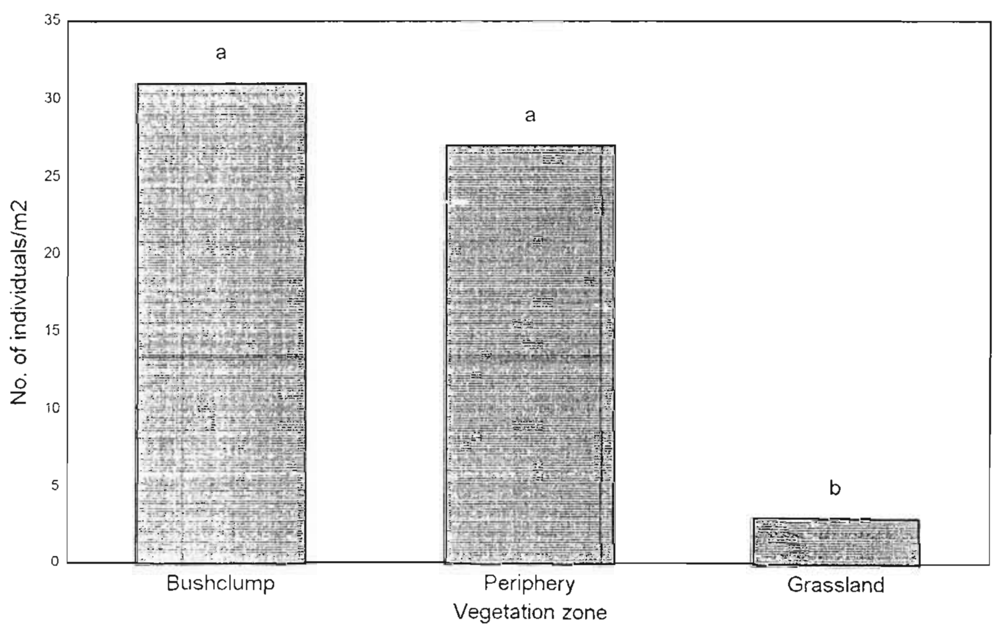


Figure 5.1. Density of small woody individuals in the three vegetation zones prior to treatment implementation. Different letters indicate significant differences at P=0.05.

A baseline dataset clearly revealed that the distribution of small individuals was strongly associated with vegetation zone, with grassland having the least density of small woody individuals (Figure 5.1). The bushclump and periphery zones did not differ (P>0.05) in terms of density of small individuals. Preliminary investigation into the density of woody individuals revealed that there were no difference between the chemical and the control treatment in terms of the density of woody plants at the start of the experiment.

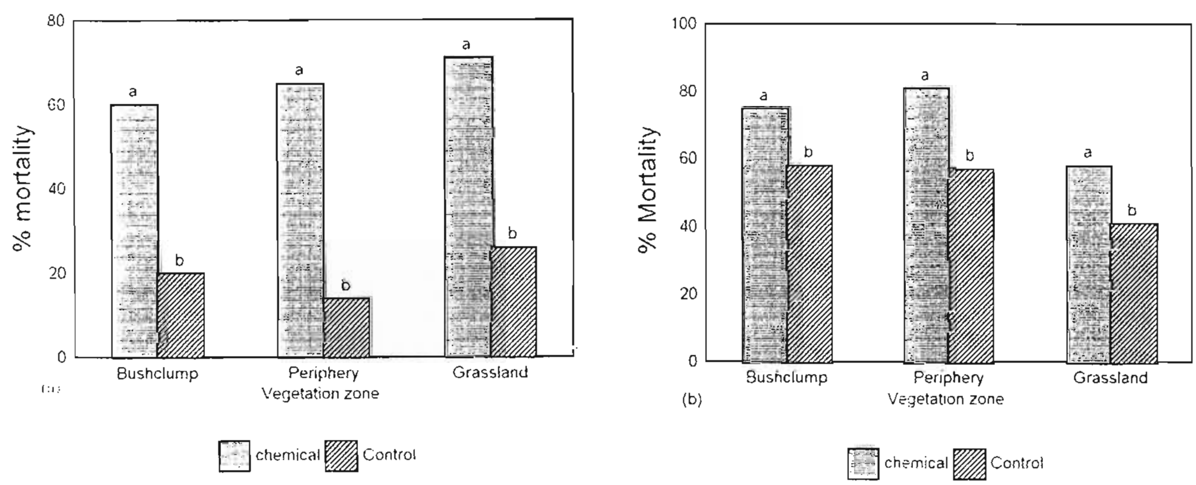


Figure 5.2. Effect of chemical poisoning on mortality of (a) large and (b) small woody individuals in the three vegetation zones after five years. Different letters within each vegetation zones indicate significant differences at P= 0.05.

Chemical poisoning increased (df=1, $F \geq 8.18$, $P \leq 0.0126$) mortality of both large and small woody individuals, but treatment effects varied with vegetation zone, size class of woody plants and species. Least mortality was recorded in the bushclump zone for large woody individuals (Figure 5.2a). This was attributed to dense bushclumps that made gaining access into the interior of the bushclump very difficult compared with the open grasslands. It is therefore likely, that not every individual stem in the bushclumps was treated with chemical poison. Some small woody individuals in the grassland zone might have not been spotted during the application of chemical poison because of a dense grass sward and, as a result, they were not treated, thus resulting in low mortality (Figure 5.2b).

Table 5.1. Mortality (%) of large individuals in response to chemical poison on a species basis in the three vegetation zones after five years. Figure in parenthesis is the sample size for that percentage

Species	Bushclump	Periphery	Grassland
Canthium mundianum	56 (45)	63 (44)	79 (33)
Coddia rudis	55 (86)	64 (211)	82 (125)
Diospyros simii	48 (31)	33 (15)	71 (7)
Grewia occidentalis	81 (27)	60 (20)	100 (2)
Hippobromus pauciflorus	100 (20)	56 (9)	100 (1)
Maytenus heterophylla	72 (58)	72 (39)	63 (41)
Rhus undulata	91 (11)	71 (13)	92 (12)
Scutia myrtina	63 (154)	81 (83)	73 (67)
Trimeria trinervis	67 (33)	67 (15)	100 (5)

The common encroaching species in this vegetation, namely *Scutia myrtina*, *Trimeria trinervus*, *Maythenus heterophylla*, and *Rhus undulata*, showed susceptibility to chemical poisoning (Table 5.1). By comparisons, multiple-stemmed shrubs, namely *Coddia rudis* and *Diospyros simii*, were observed to be less susceptible to chemical poisoning (Table 5.1). This observation is possibly explained by their growth habit that made complete and efficient application of the chemical poison very difficult. Using the Chi-squared (χ^2) test (Sokal & Rohlf 1981) it was found that significantly lower mortality occurred in a bushclump zone than in a grassland zone for *C. mundianum* ($P<0.05$), *C. rudis* ($P<0.025$), *D. simii*

($P<0.005$), and *T. trinervis* ($P<0.025$).

Chemical poisoning resulted in desiccation of the woody individuals, causing them to be highly flammable during burning and that probably explains the increased ($df=7$, $F \geq 6.17$, $P \leq 0.0100$) mortality of woody plants in this treatment combination compared to other treatment combinations (Table 5.2). This was true for all vegetation zones.

Table 5.2: The effect of treatment combination on mortality (%) of large woody individuals in the three vegetation zones after three years. Different letters in a column indicate significant differences at P=0.05 using Tukey's test

Treatment combination	Vegetation zone		
	Bushclump	Periphery	Grassland
Chemical-fire	86 a	88 a	84 a
Chemical-fire & goats	72 a	84 a	73 ab
Chemical-goat	39 b	53 b	61 ab
Chemical-no fire & no goats	42 b	34 bc	65 ab
Control-fire	30 bc	23 cd	19 c
Control-fire & goat	28 bc	20 cd	56 b
Control-goat	15 c	8 d	12 c
Control-no fire & no goats	7 c	4 d	19 c

Higher percentage mortalities were recorded in the bushclump and periphery zones for small woody individuals (Table 5.3) although there were no significant differences in mortalities achieved in different vegetation zones. This is probably explained by the fact that when the arboricide was applied people tended to focus on visible woody plants.

Table 5.3. The effect of treatment combination on mortality (%) of small woody individuals in the three vegetation zones after three years. Different treatments in a column indicate significant differences at P=0.05 using Tukey's test

Treatment combination	Vegetation zone		
	Bushclump	Periphery	Grassland
Chemical-fire	87 a	86 a	61 a
Chemical-fire & goats	86 a	87 a	51abc
Chemical-goat	66 b	82 ab	63 a
Chemical-no fire & no goats	69 ab	70 abc	56 ab
Control-fire	60 b	63 bcd	54 ab
Control-fire & goat	54 b	56 cd	44 abc
Control-goat	64 b	66 abcd	35 bc
Control-no fire & no goats	50 b	44 d	31 c

Fire, and fire and goat treatments resulted in higher mortality of both large and small woody individuals than no fire, or goats by themselves (Tables 5.4 and 5.5). These effects were more pronounced in the bushclump and periphery zone for the large woody individuals and only in the periphery zone for the small individuals. This is interesting because, of the three fires applied during the experimental period only two fires achieved the desired effects on bush.

Table 5.4. Comparisons of the follow-up treatments for the mortality of large woody individuals in the three vegetation zones using linear contrasts. Significant effects (P<0.05)are shown in bold

Contrast	Vegetation zone					
	Bushclump		Periphery		Grassland	
	Fvalue	Pr > F	Fvalue	Pr > F	Fvalue	Pr > F
Fire vs Fire & goats	0.63	0.4431	0.17	0.6885	1.59	0.2316
Fire vs Goats	5.13	**0.0429**	5.37	**0.0390**	7.16	**0.0202**
Fire vs No fire	6.42	**0.0263**	12.79	**0.0038**	4.53	**0.0547**
Goats vs Fire & goats	9.35	**0.0100**	7.44	**0.0183**	2.01	0.1821
Goats vs No goats	0.07	0.7923	1.58	0.2322	0.30	0.5938
Fire & Goats vs No fire & no goat	11.07	**0.0060**	15.89	**0.008**	0.75	0.4021

Table 5.5. Comparisons of the follow-up treatments for the mortality of small woody individuals in the three vegetation zones using linear contrasts. Significant effects (P<0.05)are shown in bold

Contrast	Vegetation zone					
	Bushclump		Periphery		Grassland	
	Fvalue	Pr > F	Fvalue	Pr > F	Fvalue	Pr > F
Fire vs Fire & goats	0.56	0.4677	0.69	0.4227	1.43	0.2542
Fire vs Goats	0.17	0.6879	0.56	0.4669	0.04	0.8477
Fire vs No fire	1.22	0.2911	12.88	**0.0037**	0.23	0.6400
Goats vs Fire & goats	1.35	0.2680	0.01	0.9386	1.00	0.3365
Goats vs No goats	0.48	0.5016	18.83	**0.0010**	0.46	0.5119
Fire & Goats vs No fire & no goat	3.44	0.0884	19.52	**0.0008**	2.81	0.1193

Mechanical versus Oversown

The oversown treatment resulted in a higher (df=1, F=5.69, P=0.0420) percentage mortality of woody individuals than the non-oversown treatments (Figure 5.3). This was attributed to vigourous competition from *Chloris gayana*. *Chloris gayana* is, however, not long-lived hence this effect is not expected to last.

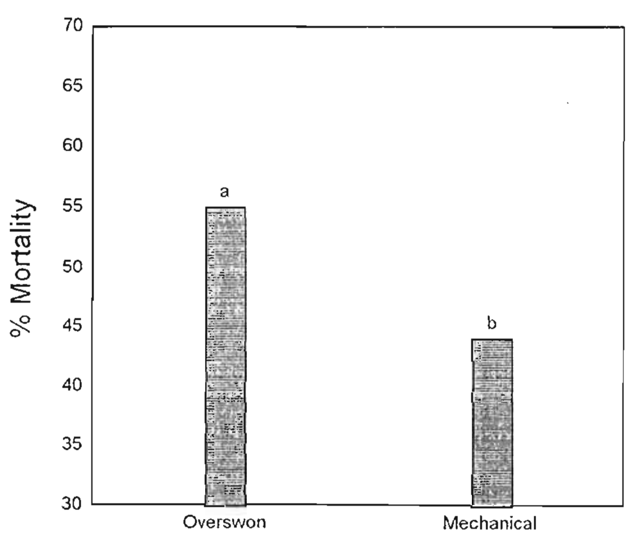


Figure 5.3.
Response of both small and large woody individuals to mechanical clearing. Different letters indicate significant differences at P=0.05 using Tukey's test.

No treatment differences in mortality of woody individuals were observed for the follow-up treatments after three years since implementation of these treatments, except higher mortality of woody individuals recorded in the fire and goat combination compared to fire by itself or the control (Table 5.6). Fire in this treatment probably exposed the woody seedlings to goats hence causing greater mortality.

Table 5.6. Comparisons of the follow-up treatments for the mortality of both small and large woody individuals using linear contrasts after three years since implementation. Significant effects ($P<0.05$) are shown in bold

Contrast	Fvalue	Pr > F
Fire vs Fire & goats	9.18	**0.0291**
Fire vs Goats	1.04	0.3537
Fire vs No fire	4.03	0.1010
Goats vs Fire & goats	0.00	0.9627
Goats vs No goats	3.84	0.1075
Fire & Goats vs No fire & no goat	8.88	**0.0308**

Fire did not burn well in the mechanically cleared plots. This was attributed to the high density of *Panicum maximum* (Figure 4.6d), which is known to be poorly flammable. Low fire intensities were therefore experienced, thus leading to a lower percentage mortality of woody individuals in the fire treatment.

5.3.2 Recruitment of woody individuals

Chemical versus Control

Chemical poisoning and the combination of primary (chemical and control) treatments and follow-up (fire, goats, and fire and goats) treatments had no marked effect ($df=1$, $F\leq0.19$, $P\geq0.7061$) on the recruitment of woody individuals over the study period. Vegetation zone however, affected (df=2, F≥26.55, P≤0.0001) recruitment and recruitment varied with rainfall.

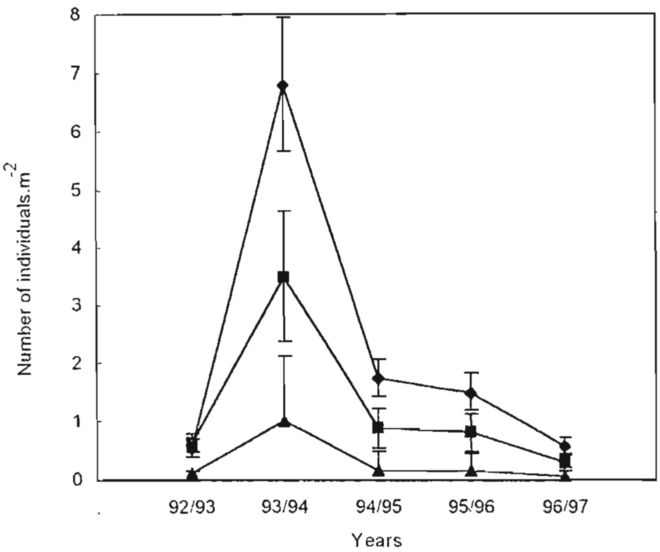


Figure 5.4. Mean density (± 95% confidence interval) of the recruiting individuals in the bushclump (◆), periphery (■) and grassland (▲) zones of the chemicals over the study period.

Bushclumps had the greatest recruitment (F≥26.55, P≤0.0001) throughout the study period although the margin of the difference in recruitment narrowed with time (Figure 5.4). Greatest recruitment was recorded during the second (1993/94) season that was characterized by very high rainfall following a poor year (Figure 3.1) and therefore provided conditions conducive for seed germination and establishment.

The goat treatment had a lower recruitment of woody plants in the grassland zone compared with the fire and no goats treatment during the 1994/95 season (Table 5.7). Field observation during this season suggest that the grass sward was less dense compared to the previous season in this particular treatments and therefore the woody seedlings were exposed to impact by goats. This result is in agreement with the findings by Owen-Smith & Cooper (1985) that goats do feed on young woody seedlings unlike kudus that concentrate on browse from established woody vegetation for their forage.

Table 5.7. Comparisons of the follow-up treatments for recruitment of woody individuals in the three vegetation zones of the chemically treated plots, three seasons after application. Significant effects (P<0.05) are shown in bold

Bushclump zone

Contrast	Year					
	1994/95		1995/96		1996/97	
	Fvalue	Pr > F	Fvalue	Pr > F	Fvalue	Pr > F
Fire vs Fire & goats	0.01	0.9165	0.58	0.4607	2.50	0.1402
Fire vs Goats	0.95	0.3482	0.39	0.5446	0.03	0.8436
Fire vs No fire	0.14	0.7144	0.31	0.5896	0.03	0.8636
Goats vs Fire & goats	0.76	0.4018	0.02	0.8921	3.08	0.1047
Goats vs No goats	1.83	0.2016	1.39	0.2617	0.12	0.7316
Fire & Goats vs No fire & no goat	0.24	0.6387	1.73	0.2126	1.97	0.1856

Periphery zone

Contrast	Year					
	1994/95		1995/96		1996/97	
	Fvalue	Pr > F	Fvalue	Pr > F	Fvalue	Pr > F
Fire vs Fire & goats	0.02	0.8827	0.27	0.6112	0.72	0.4120
Fire vs Goats	0.48	0.4996	0.14	0.7172	2.87	0.1157
Fire vs No fire	0.62	0.4451	0.56	0.4704	3.76	0.0765
Goats vs Fire & goats	0.30	0.5954	0.80	0.3895	0.72	0.4143
Goats vs No goats	2.21	0.1632	1.25	0.2862	0.06	0.8124
Fire & Goats vs No fire & no goat	0.88	0.3656	0.05	0.8270	1.18	0.2979

Grassland zone

Contrast	Year					
	1994/95		1995/96		1996/97	
	Fvalue	Pr > F	Fvalue	Pr > F	Fvalue	Pr > F
Fire vs Fire & goats	0.24	0.6298	1.03	0.3301	0.52	0.4853
Fire vs Goats	4.94	**0.0463**	0.01	0.9154	0.61	0.4499
Fire vs No fire	0.00	0.9448	0.19	0.9272	0.60	0.4537
Goats vs Fire & goats	2.98	0.1098	0.82	0.3824	0.00	0.9523
Goats vs No goats	5.26	**0.0407**	0.04	0.8435	0.00	0.9947
Fire & Goats vs No fire & no goat	0.32	0.5823	1.23	0.2894	0.00	0.9576

Mechanical versus Oversown

Owing to missing data, recruitment of woody individuals between the oversown and the non-oversown cleared treatments could not be compared for the first two seasons of the study. Suffice it to report that extensive recruitment occurred as shown by the increased number of individuals and stems during these two seasons (see section 5.3.4). No differences between oversown and non-oversown cleared treatments ($F \leq 2.11$, $P \geq 0.1840$) were observed in terms of recruiting woody individuals during the last three (third to the fifth) seasons of the study period (Figure 5.5), although the oversown plots showed numerically lower recruitment of woody plants. This latter effect was interpreted as a result of vigorous competition from the dense *Chloris gayana*.

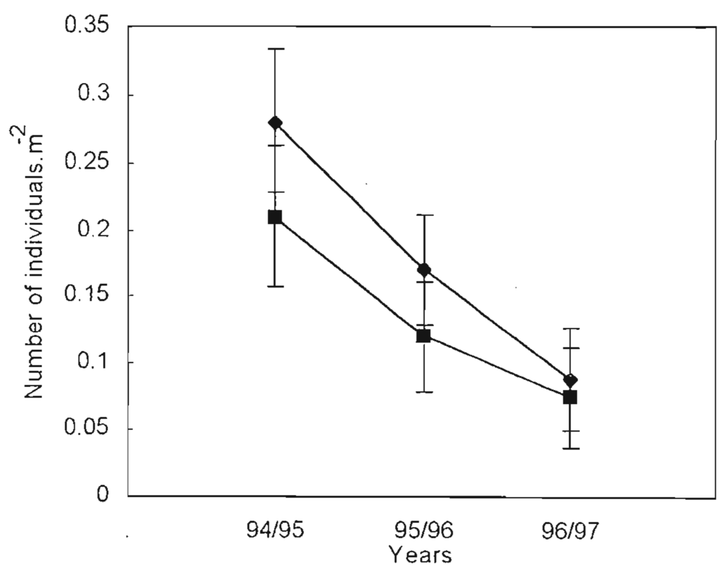


Figure 5.5: Mean density (± 95% confidence interval) of the recruiting individuals in the oversown (■) and mechanical (◆) treatments during the last three years of the experiment.

Table 5.8. The effect of mechanical and oversown treatments on recruitment of woody individuals over the last three years of the experiment (number of individuals.m^{-2}). Different letters within a row show significant difference at P=0.05 using Tukey's test

Treatment	Years		
	1994/95	1995/96	1996/97
Mechanical	0.280 a	0.169 b	0.089 c
Oversown	0.205 a	0.120 b	0.075 c

Table 5.9. The effect of follow-up treatments on the recruitment of woody individuals in the mechanically cleared treatments (number of individuals.m^{-2}). Different letters in a column show significant differences at P=0.05 using Tukey's test

Treatment	Years		
	1994/95	1995/96	1996/97
Fire	0.37 a	0.15 a	0.07 a
Fire & goats	0.25 a	0.16 a	0.07 a
Goats	0.28 a	0.16 a	0.07 a
No fire & no goats	0.23 a	0.21 a	0.16 a

Both treatments showed a significant decline of recruiting woody individuals between years over the last three years of the study (Table 5.8). Greatest recruitment occurred during the 1994/95 season that was characterised by high rainfall.

In no year did fire, goats or the two in combination have a discernible effect ($P \geq 0.05$) on recruiting woody individuals (Table 5.9). The significant decline of recruiting woody individuals between years (Table 5.10) is probably explained by decline in the number of rootstocks with a potential to coppice or depletion of seeds in the seedbank (e.g. *A. karroo*) with time.

Table 5.10. Density of recruiting woody individuals as influenced by the follow-up treatments over the last three years of the experiment (number of individuals.m^{-2}). Different letters within a row show a significant difference at P=0.05 using Tukey's test

Treatment	Years		
	1994/95	1995/96	1996/97
Fire	0.370 a	0.145 b	0.065 b
Fire & goats	0.245 a	0.160 b	0.065 c
Goats	0.275 a	0.160 b	0.070 c
No fire & no goats	0.230 a	0.210 ab	0.155 b

Table 5.11. Recruitment of woody individuals, expressed as a percentage of the overall recruitment, illustrating contribution of each form of recruitment (seeds and coppice) to the overall recruitment in the mechanical and oversown treatments during the last three seasons of this study. Different letters in a column show significant differences at P=0.05 using Tukey's test

	Years					
	1994/95		1995/96		1996/97	
	Mech	Over	Mech	Over	Mech	Over
Recruiting woody plants/ha	2580	2100	1560	1250	1000	850
Form of recruitment						
Coppicing	53.8 a	66.5 a	54.3 a	69 a	58.3 a	59.5 a
Seeds	46.2 a	34.5 a	46.7 a	31 a	41.7 a	40.5 a

More recruitment of woody individuals was in the form of coppicing from the rootstocks in both treatments throughout the experimental period (Table 5.11). *A. karroo*, *B. bipinnatifida*, *S. incanum* and *L. javanica* mainly recruited from seedling germination and establishment (Table 5.12). With the exception of *A. karroo*, *B. bipinnatifida*, *S. incanum* and *L. javanicas*, the recruiting woody population generally resembled the original population (Table 5.12 and 5.13).

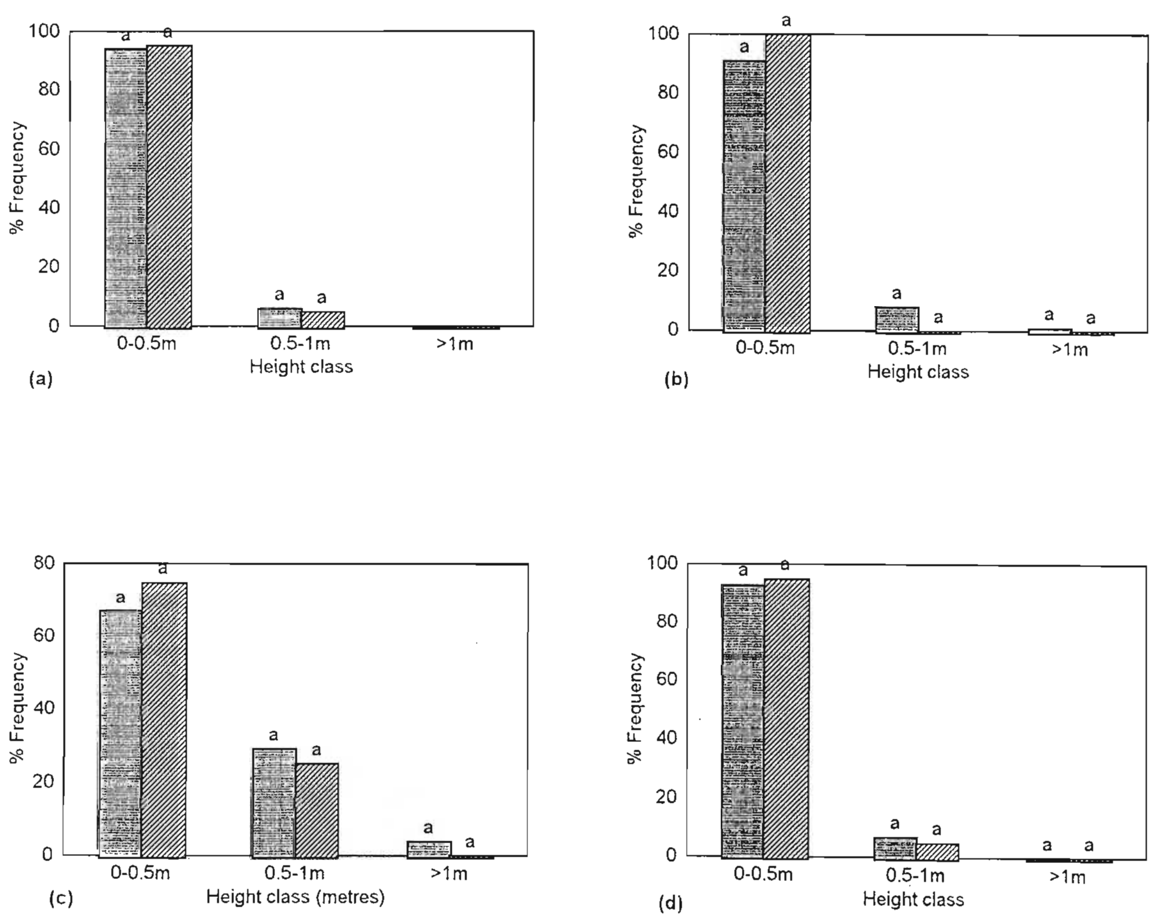
Table 5.12. Percentage frequency of recruiting woody plants for each form of recruitment on a species-basis, as a percentage of total recruitment of a season. Total percentage frequency within a season (coppice plus seed) totals 100

Species	1994/95		1995/96		1996/97	
	Coppice	Seed	Coppice	Seed	Coppice	Seed
Acacia karroo	0.0	12.3	0.7	13.8	0.7	18.7
Berkheya bipinnatifida	0.0	8.5	0.0	10.3	0.0	1.3
Canthium ciliatum	1.0	0.0	0.0	0.0	1.3	0.0
Canthium mundianum	4.0	1.0	1.8	0.0	2.6	0.0
Coddia rudis	9.2	0.2	5.3	0.0	3.9	0.0
Cussonia spicata	0.2	1.0	0.7	0.0	0.7	0.0
Diospyros lycioides	0.2	0.0	0.4	0.0	0.7	0.0
Diospyros simii	2.5	0.0	2.0	0.4	2.6	0.0
Grewia occidentalis	2.3	0.0	2.8	0.0	3.9	0.0
Hippobromus pauciflorus	4.8	1.0	10.0	0.4	9.0	1.3
Jasminum angulare	5.0	1.3	5.7	0.4	1.3	1.3
Lippea javanica	0.0	6.9	0.0	3.5	0.0	7.7
Maytenus heterophylla	2.3	0.8	3.5	1.8	3.2	1.3
Rhus undulata	0.2	0.0	0.0	0.0	1.9	0.0
Scutia myrtina	5.6	0.0	1.4	0.0	2.6	0.0
Solanum incanum	0.0	6.2	0.0	0.4	0.0	5.2
Trimeria grandifolia	3.7	0.6	5.7	0.0	4.5	0.0
Trimeria trinervis	11.6	1.3	12.0	0.4	16.8	0.0
Others	4.8	1.5	3.5	0.1	4.3	3.2
Total	57.4	42.6	55.8	44.2	60.0	40.0

5.3.3 Height increase

Mechanical versus Oversown

Mechanical clearing completely altered the structure of the woody vegetation, thus reducing the height of all woody individuals. Woody individuals in the oversown treatments were statistically not different to woody individuals in the non-oversown treatment in terms of height (Figure 5.6a-h), even though field observations suggested that woody individuals in the oversown treatments were generally shorter than those in the non-oversown treatments. Within five years following mechanical clearing, *Diospyros simii* and *Scutia myrtina* had at least 28 % and 11 % of their individuals in the second height class respectively (Figure 5.6 c&g), thus reflecting the potential of these species to recover following clearing. *Acacia karroo*, *Canthium mandianum*, *Hippobromus pauciflorus*, *Maytenus heterophylla* and *Grewia occidentalis* appeared to have slow growth rates as indicated by a high percentage frequency of their individuals within a height of less than 0.5m.



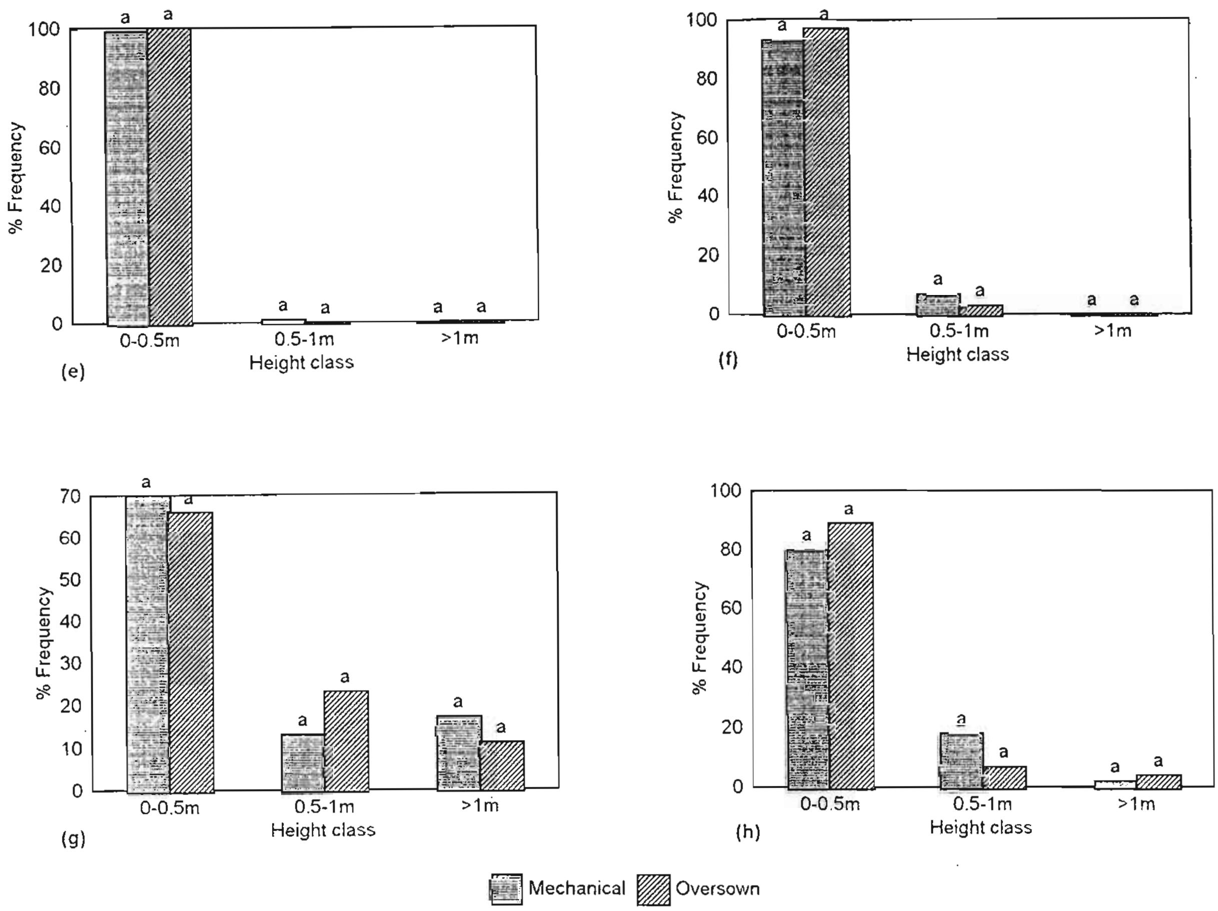
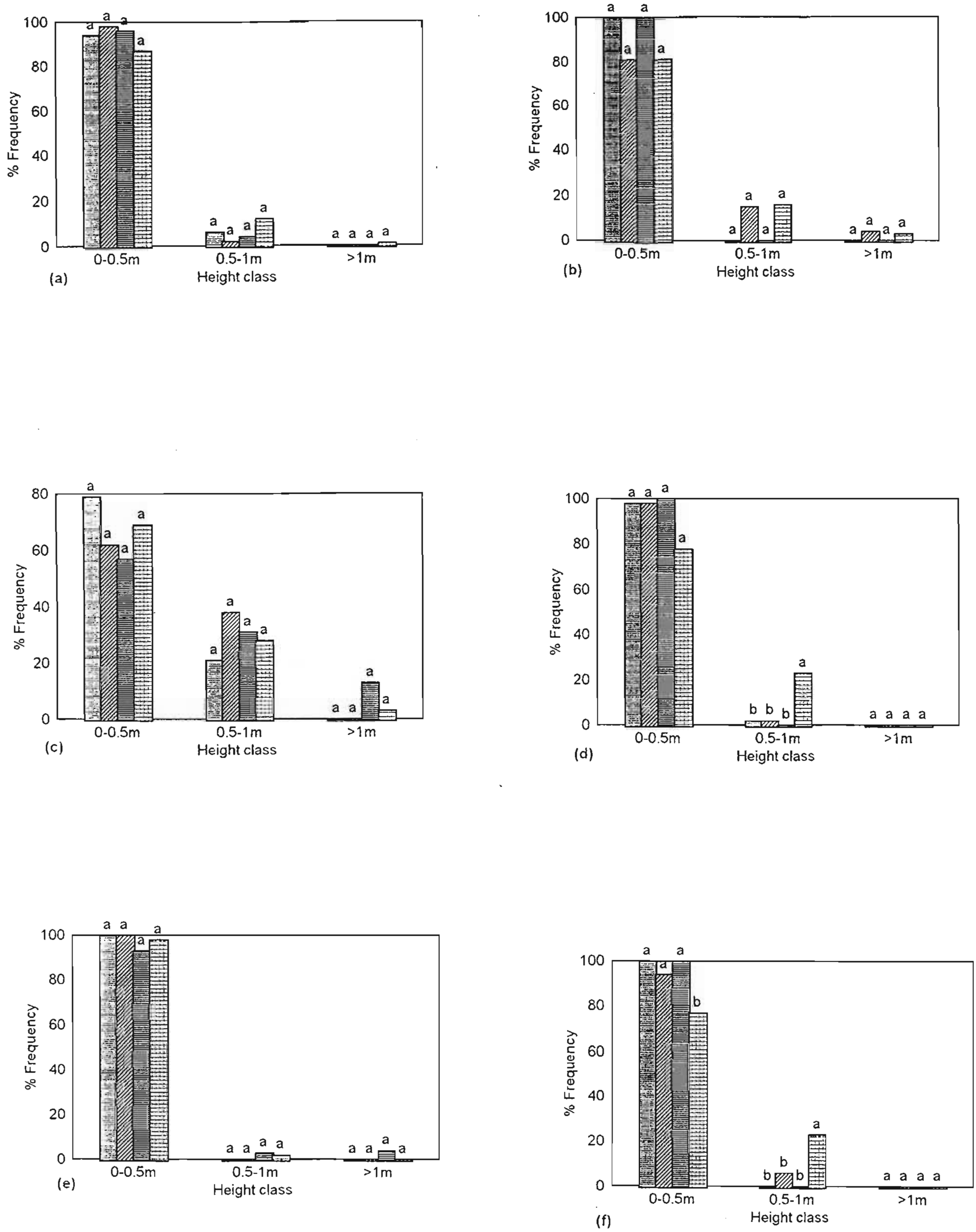


Figure 5.6 a-h. Frequency of individuals of the key woody species in the three height classes after five years since clearing. Different letters indicate significant differences between treatments within a height class at P=0.05. a) *Acacia karroo*. b) *Canthium mundianum*. c) *Diospyros simii*. d) *Grewia occidentalis*. e) *Hippobromus pauciflorus*. f) *Maytenus heterophylla*. g) *Scutia myrtina* and h) *Trimeria trinervis*.

Fire and goats had retarded (df=3, $F \geq 4.27$, $P \leq 0.0161$) 67 % or more of *Grewia occidentalis*, *Scutia myrtina* or *Maytenus heterophylla* individuals to a height of less than 0.5 m by the 1996/97 season (Figure 5.7a-h). Considering that these species are the main encroaching woody species in this region, fire and goats had, therefore, had a marked impact on the woody component of this vegetation. The poor impact of goats on *Diospyros simii* was attributed to poor acceptability of *Diospyros* species to goats (de Bruyn & Scogings 1994).


% Frequency
0-0.5m
0.5-1m
>1m
Height class
(a)
(b)
(c)
(d)
(e)
(f)

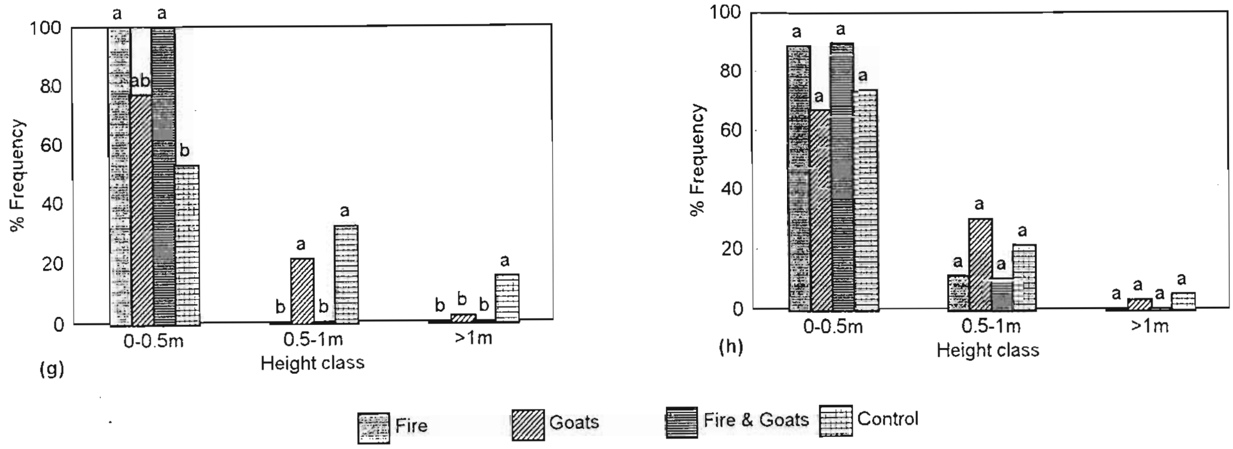


Figure 5.7 a-h. Frequency of individuals for the key woody species in the three height classes after five years after clearing. Different letters indicate significant differences among treatments within a height class at P=0.05. a) *Acacia karroo*. b) *Canthium mundianum*. c) *Diospyros simii*. d) *Grewia occidentalis*, e) *Hippobromus pauciflorus*. f) *Maytenus heterophylla*. g) *Scutia myrtina* and h) *Trimeria trinervis*

5.3.4 Density of woody individuals

Mechanical versus oversown

There were no differences detected between oversown and non-oversown treatments prior to clearing in terms of the density of woody individuals. Clearing was non-selective, hence resulted in complete change of the woody structure.

Non-oversown treatments had at least 1.5 times more woody plants compared with the pre-clearing densities by the end of the first season after clearing (Table 5.13). The non-oversown treatments always had more (df=1, $F \geq 12.30$, $P \leq 0.0080$) woody plants than oversown during each season after clearing. This is surprising if one considers that the first season after clearing was characterised by drought where only about 60 % of the long term average rainfall was received. Non-oversown cleared treatments were also characterised by high ($F \geq 4.81$, $P \leq 0.0380$) densities of *Berkheya bipinnatifida* and *Solanum incanum*

Table 5.13. Mean density of woody individuals on a species basis for large individuals prior to bulldozing and all woody individuals at the end of the 1992/93 and 1996/97 seasons in the non-oversown and oversown mechanically cleared treatments. Different letters in a row within a treatment indicate significant differences at P=0.05 using Tukey's test

Species	Mean number of individuals.ha^{-1}					
	Mechanical			Oversown		
	Pre-bulldozing	1992/93	1996/97	Pre-bulldozing	1992/93	1996/97
Acacia karroo	77 b	3 051 a	3 426 a	0 c	1 613 b	2 363 a
Berkheya bipinnatifida	49 b	320 b	1 286 a	28 b	0 b	528 a
Canthium ciliatum	619 a	35 c	202 b	640 a	0 b	56 b
Canthium mundianum	2 620 a	653 b	1 070 b	2085 a	334 b	84 b
Coddia rudis	118 c	2 808 b	4 135 a	56 b	2 502 a	2 586 a
Cussonia spicata	70 a	83 a	125 a	0 b	28 b	111 a
Diospyros lycioides	222 a	21 b	63 b	362 a	0 b	28 b
Diospyros simii	49 b	493 a	633 a	0 b	251a	334 a
Grewia occidentalis	549 a	146 b	362 ab	556 a	56 b	139 b
Hippobromus pauciflorus	243 b	695 a	876 a	84 b	1 084 a	806 a
Jasminum angulare	535 a	1 188 a	1 932 a	306 a	250 a	417 a
Lippea javanica	431 b	1 161 a	1 070 a	92 b	1 196 a	973 a
Maytenus heterophylla	7 b	772 a	806 a	0 b	695 a	973 a
Rhus undulata	264 a	313 a	250 a	334 a	139 a	362 a
Scutia myrtina	1 758 a	139 b	577 b	2 085 a	445 b	612 b
Solanum incanum	125 a	459 a	584 a	0 b	0 b	251 a
Trimeria grandifolia	97 a	236 a	646 a	84 a	334 a	584 a
Trimeria trinervis	0 b	1 460 a	2 523 a	28 b	779 a	1 279 a
Other	313 b	639 ab	1 390 a	390 a	390 a	528 a
Total	8 146 c	14 672 b	21 957 a	7 131 a	10 088 a	13 014 a

compared with the oversown treatments. There was a continuous, significant increase in the number of woody plants in the non-oversown treatments. This can be attributed to the large increase (as much as 20 times) showed by *C. rudis*, *A. karroo*, *H. pauciflorus*, *T. trinervis*, *D. simii* and *M. heterophylla* (Table 5.13). Conversely, *G. occidentalis*, *S. myrtina*, *C. mundianum* and *D. lyciodices* showed delayed coppicing and recruitment in both treatments during the same periods. The lack of significant differences between years in the number of woody plants in the oversown treatments (Table 5.13) suggests that the dense *C. gayana* played an important role by competing with woody plants for the available growth resources.

Table 5.14. Density of woody individuals in the mechanically cleared treatments as influenced by the follow-up treatments. Different letters within a treatment indicate significant differences at P=0.05 using Tukey's test

Treatments	Mean density of individuals (number.ha^{-1})		
	1994/95	1995/96	1996/97
Fire	33 333 a	28 551 a	26 132 a
Fire and Goats	32 165 a	26 271 ab	23 296 b
Goats	30 552 a	26 855 ab	22 185 b
Control	31 998 a	30 080 a	26 883 a

The follow-up treatments, particularly goats and the combination of fire and goats, significantly reduced the density of woody individuals during the 996/97 season (Table 5.14).

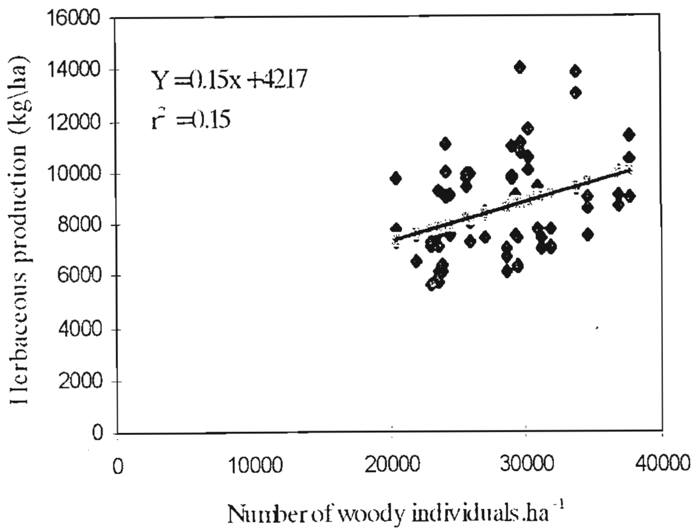


Figure 5.8. The relationship between density of woody individuals and herbaceous production after mechanical clearing. The line shows the fitted regression line.

There was no relationship between the two parameters (Figure 5.8), suggesting that the increasing density of woody plants after clearing do not explain the declining herbaceous production as yet. This finding strengthened the speculations that soil fertility, that is a system run down, explains the decline in herbaceous production.

5.3 DISCUSSION

Mechanical clearing resulted in complete removal of the woody plants except for woody plants with flexible, thinner stems such as small individuals that "escaped" clearing. As a result there was high frequency of individuals of these woody species, such as *C. rudis* and *L. javanica*, in the season immediately after clearing (June 1993) although clearing took place in October 1992. Almost all species showed ability to coppice from rootstocks, causing further encroachment. Similar responses of bush to clearing were also reported in other parts of the world

(Donaldson 1969; Barnes 1972; Beale 1973; Strang 1974). Most coppicing occurred during the season immediately after clearing as reflected by a significant increase in the density of woody individuals compared with pre-clearing levels. The dynamics of soil moisture may hold the key to the success of coppicing during the dry season. During drought there is mortality of perennial grasses (Danckwerts & Stuart-Hill 1988; O'Connor 1994; Milton *et al.* 1995), thus probably reducing the usage of moisture resulting from sporadic rains in the topsoil and in that way benefit the coppicing woody plants. Woody plants are also principal users of subsoil moisture owing to their deep rooting system (Trollope 1981; Brown & Archer 1990) hence suffer less moisture stress and remain growing during drought, provided it is not severe. These theories might explain the vigorous coppicing during the dry season after clearing. *Acacia mellifera* (Blackthorn) and other species also showed vigorous coppicing after clearing in the Molopo area (Donaldson 1969). Studies conducted near Nylsvley in the Transvaal and in *Burkea africana* woodland also reported vigorous coppicing of woody plants after pruning and clearing, growing at a rate of 0.4 m^2/ha/yr (Rutherford & Kelly 1977; Milton 1988). It is therefore clear that mechanical clearing does not kill bush but alters the structure of the vegetation. With the massive recruitment recorded during the first two seasons of the study, the density of woody individuals exceeded the pre-clearing levels within the first two seasons although the majority of the plants remained very short. This result does not conform with those of Tausch & Teuller (1977) and Scholes (1990) who predicted that cleared Pinyon-Juniper and Mopane woodlands would recover to pre-clearing densities in fifteen and fourteen years respectively. Slow growth recorded in this experiment reflects an experimental situation. No grazing took place in the experiment during the growing season of the grass, thus perhaps providing the grass with a competitive advantage over young woody seedlings. This resulted in slow growth of the woody vegetation, hence delayed the negative effect the re-establishing woody plants would have on grass production. Under farming conditions grazing during the growing season of the grass could take place, thus removing the effect of shading and reducing the competitive effect of the grass on re-establishing woody plants. Increased recruitment and faster growth of woody individuals would therefore occur, leading to reduced grass production within a short space of time. Although the woody vegetation did not grow much in the cleared treatments, the woody plants, especially *C. rudis*, *M. heterophylla*, *S. myrtina*, *D. simii* and *T. trinervus*, had assumed a shrubby form of growth, thus starting to form small bushclumps and as a result part of the available grass would have been inaccessible to livestock. These effects make the operation of mechanical clearing even more inefficient.

Acacia karroo was present in very low frequencies prior to bulldozing and recruited from seedling germination and establishment owing, in part, to its dormant seedbank (O'Connor 1995). It is also considered to be an important precursor for successional development of this savanna by creating a micro-climate suitable for establishment of broadleaved species (Acocks 1953; Comins 1962) that is a characteristic of this savanna.

Oversowing cleared treatments with *C. gayana* had an added benefit in that it significantly reduced density of woody plants in terms of both number of individuals and stems per hectare compared with the non-oversown treatments. It also reduced the abundance of "woody weeds" such as *B. bipinnatifida*, *S. incanum* and *L. javanica* that characterised non-oversown cleared treatments. Field observations during the last season of the study suggest that *C. gayana* is starting to die back although it was only grazed in winter after it has produced and shed seeds and the woody plants appeared to be gaining more growth and abundance because of this effect.

Chemical control of bush with plant applied poison did not achieve the desired results. Significantly high mortalities of 60 to 85% compared to the controls only endured for the first two seasons after poisoning. Juvenile small woody plants suffered more mortality than large plants. Similar results of 80 to 100% mortality were achieved with hormonal herbicide on *A. mellifera* in the Molopo area (Donaldson 1969). Fisher *et al.* (1959) and Darrow & McCully (1959) (cited by Donaldson 1969) reported mortalities of 15 to 60 % and 35 to 60 % of the woody population after aerial spraying with poison in the mesquite and blackjack oak savannas respectively. The different levels of mortalities recorded in these studies might be explained by difficulties in gauging the minimum amount of spray required for different plants. Multi-stemmed woody plants such as *C. rudis* and *D. simii*, that have a high contribution in the reduction of grass production because of their shrubby form of growth, were less susceptible to the chemical poison. This result confirms the findings of Donaldson (1969) who worked in the Molopo area. The poor effect of chemical poisoning on multi-stemmed plants resulted in a non-significant reduction of the density of woody individuals compared to the controls and that probably explains the similar herbage production between these two treatments.

The results showed that fire and goats can greatly retard growth of resprouting woody plants, thereby improving the financial soundness of the clearing methods. In this study fire killed young bush with greater success while causing the majority of large woody plants to coppice from the base, thus keeping them short. It also suppressed recruitment especially in the latter seasons of the study, thereby keeping the vegetation open. High mortality of young plants due to fire, and coppicing of large woody individuals after burning, was also recorded in the False Thornveld of the Eastern Cape (Trollope 1974), Texas, America (Wright *et al.* 1976), Botswana Thornveld (Sweet 1982) and Queensland, Australia (Grice 1997). The greater percentage mortality achieved with young bush is probably explained by small carbohydrate reserves these plants have to support regrowth due to small storage capacity (Bond & van Wilgen 1996). Goats further contained 67% of the bush to a height of less 0.5 m after three seasons, with no significant reduction in density of woody individuals when compared with the controls and fire by itself. The failure of goats to reduce density of woody coppice contradicts the success achieved by du Toit (1972a) and Trollope (1974) who reported 81-90% reduction in bush density after three and five seasons of browsing respectively. Sweet & Mphinyane (1986) reported 23% and 52% reduction in bush density in low and high stocking rates respectively. This was only after three years of browsing. The differences recorded in the ability of goats to reduce bush density in these studies might be explained by the presence of woody species acceptable to goats in each study site and susceptibility of the different woody species to browsing. The morphology of the different species present in each study site could be equally important as that affects browsing behaviour of goats (Teague 1989a).

CHAPTER SIX

GENERAL CONCLUSIONS AND RECOMMENDATIONS

The study revealed that control of bush encroachment using mechanical and chemical methods was unattractive and expensive in the medium term. This was mainly due to the fact that the benefits of increased grass production across all vegetation zones due to competitive release of growth resources by woody plants, increased colonization of *P. maximum* and other grass species that are not normally associated with bushclumps in the ex-bushclumps, increased soil fertility and reduced density of woody plants and retarded growth of resprouting woody plants due to oversowing of cleared areas, endured for only four seasons since clearing. This was even worse with chemical poisoning of bush because it was no different to the controls in aspects such as grass production, grass composition and woody recruitment. The capital invested in the clearing operations at a rate of R1 750 and R1 200 per hectare for chemical and mechanical clearing respectively in 1992 would, therefore, not have been recovered in a five year period even if a small area was cleared. These results have serious implications in terms of advice given to land-users in this regard.

The results suggest that the economics of chemical and mechanical control of bush do not justify the use of these methods. These methods should be considered as a last resort only under specific circumstances such as circumstances where the bush component is so dense that the fuel load needed to support a fire sufficiently intense to kill topgrowth of tall woody plants cannot be accumulated, where the bush component is largely unacceptable to browsing animals or where it is impossible to incorporate browsers into a livestock system for a variety of reasons. In such circumstances it is important that bush clearing operations are not applied in areas where replacement of good forage species by largely unproductive and unpalatable species may lead to reduced grass production. Again, thinning areas such as valley systems should be avoided because such areas naturally carry a high density of woody plants (O'Connor & Crow 1999) that make the thinning operation even more expensive. Such areas usually have dense and thick stands of woody vegetation that make gaining access into the bushclumps to treat the stems of woody plants with chemical poison very difficult, causing high wastage of the chemical. Similar results were recorded in this study as the site had very dense bushclumps. Bush clearing using a bulldozer, for example, can cause soil disturbance that generally affects the grass layer and that may result in soil erosion or even encourage the establishment of a large number of woody seedlings, such as *A. karroo* in the case of this study, that may result in time in a woody population that is more dense than the original population. Therefore, oversowing such areas with grass species such as *Digitaria eriantha* or any grass species with good longevity that would not need further seedbed preparation should be considered. This will go a long way towards reducing soil erosion and density of resprouting woody plants and seedlings through immediate cover and competition.

The results from this study showed that woody plants respond to clearing by prolific sprouting from the rootstocks and the base of the stems. Time taken by the woody vegetation to reach pre-clearing densities and competitive ability depends on rainfall (Scholes 1990; Harrington & Johns 1990), with drought retarding the re-invasion process and high rainfall accelerating the process. This suggests that control of bush encroachment cannot be achieved with a single clearing or thinning operation and implementation of bush control measures must therefore be continuous. The main aim of post-clearing or thinning management should be to slow down the process of re-invasion as much as possible. The combination of fire and goats showed promising results as post-clearing or thinning management strategies. Both grass production and mortality of bush in chemically treated plots followed up with fire increased significantly (chapters four and five). Both fire and goats managed to contain the majority of woody plants in the cleared plots to a height of less than one metre. However, they did not have a marked impact on bush density. The results from studies in other parts of the continent (du Toit 1972b; Trollope 1974; Sweet & Mphinyane 1986) reported the combination of both fire and goats to be an effective strategy for reducing bush density and volume. A marked impact on density of coppicing individuals is achieved when the vegetation is continuously stocked with goats (du Toit 1972b). Alternatively, goats can be allowed to utilise an area on a rotational basis but they should be stocked at high stocking pressure so that the frequency of browse utilisation is increased. This latter situation could mean sacrifice of the grass component especially in times when the woody plants produce tannins (Teague 1989) as a defensive strategy against browsing. The standard stock fences are not adequate to control the movement of goats and hence a goat proof fence is required to keep goats in a specified area long enough to apply the required intensity of browsing. In this study these management strategies appear to have done a good job in slowing down the process of re-invasion after bulldozing and chemical poisoning.

Whenever clearing or thinning of bush is to be done, the benefits of trees and bushes should be borne in mind and hence complete clearing is not normally recommended. Complete tree thinning or clearing may result in reduced grass production. However, this varies with veld types. In the arid Eastern Cape savannas, *A. karroo* trees were found to reduce both available browse and grass yield as it grew beyond 1.8 metres (Stuart-Hill & Tainton 1988). This suggest that larger trees should be removed in tree thinning operations. In other veld types, larger trees provide favourable habitats for the growth of a productive grass species, *Panicum maximum* (Smit & van Romburgh 1993). In such veld types it is recommended that small trees are thinned, as they are the ones that cause bush encroachment.

Cleared areas must be rested for a season or more, that will help to rebuild the disturbed grass layer, thus producing a highly competitive grass sward (Skarpe 1990), thus possibly retarding the resprouting woody plants. In the light of what was discussed herein, it cannot be overemphasised that the economics of clearing and the success of the methods used to control bush vary from one situation to the other.

The study answered the questions it was set to address. Herbaceous production and quality increased beneath and between former bushclumps after clearing as hypothesised. However, soil fertility appeared to have had minor role in influencing herbaceous production, thus contrary to the hypothesis formulated in chapter two. These increases were of short-term as anticipated because bush started competing with the herbaceous layer for growth resources again. Oversowing cleared areas did not only result in increased grass production but also reduced density of the woody plants and "weeds". However, this strategy had no influence on the height of the woody plants. This is probably due to non-fertilization of the oversown areas, thus resulting in less vigorous stand of grass. Mechanical and chemical methods of bush control were not 100% for the majority of the woody species, especially multi-stemmed species and as result follow-up clearing would have been necessary within five years, thus making the operation of clearing very expensive. Fire and goats showed an ability to retard the growth of coppicing woody species and keep the savannas more open, thus improving grass production over a long term.

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APPENDIX

Appendix 1: List of all woody species identified in the experimental area on the farm "Lily-Park".

Acacia karroo
Allophylus decipiens
Aloe ferox
Buddelja dysophylla
Burchellia bubalina
Canthium ciliatum
Canthium inerme
Canthium mundianum
Carissa bispinosa
Cassine aethiopica
Clausena anisata
Clerodendrum glabrum
Coddia rudis
Commiphora harveyi
Cussonia spicata
Diospyros simii
Diospyros villosa
Diospyros whyteana
Dovyalis caffra
Ehretia rigida
Euclea crispa
Euclea natalensis
Euclea undulata
Grewia occidentalis
Hippobromus pauciflorus
Jasminum angulare
Maytenus heterophylla
Maytenus nemerosa
Ochna natalitia
Olea europaea
Rhoicissus tridentata
Rhus chirindensis
Rhus refracta
Rhus undulata
Scolopia zeyheri
Scutia myrtina
Sideroxylon inerme
Tecomaria capensis
Trimeria grandifolia
Trimeria trinervis
Vepris undulata
Zanthoxylum capense
Ziziphus mucronata