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Effects of stocking rate, legume augmentation, supplements and fire on animal production and stability of native pastures

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Abstract

An extensive grazing study was conducted between 1988 and 2001 at Calliope, central Queensland. This study measured the impacts of grazing on native pastures at 5 stocking rates, legume oversowing and animal diet supplement / spring burning both at 3 stocking rates (4 stocking rates in supplement / burning treatments between 1996 and 2001) on pasture and animal production in a *Heteropogon contortus* (black speargrass) pasture.

Seasonal rainfall throughout this study was below the long-term average. This reduced pasture yields and restricted the opportunity to burn treatments grazed at the heavier stocking rates. Averaged across all years, pasture utilisation ranged from 13% at a stocking rate of 8 ha/steer to 52% at 2 ha/steer.

Increasing stocking rate in native pasture reduced total pasture yields while total pasture yields in legume oversown treatments were similar to those in native pasture at the same stocking rate. In years when spring burning was possible, burning reduced total pasture yields in the subsequent autumn. Increasing stocking rate in native pasture tended to reduce *H. contortus* and *Bothriochloa bladhii*, increased the occurrence of “increaser” species and also changed the occurrence of a range of minor species. In the legume oversowing treatments, *Stylosanthes scabra* cv. Seca increased from <1% of the pasture yield in 1988 to 50% in 2000 and was associated with a reduction in *H. contortus* and changes in the occurrence of some minor species.

Neither stocking rate, legume oversowing nor supplement / burning treatments had a significant impact on total perennial grass basal area. By 2001, total perennial grass basal area in native pasture was highest at 2 ha/steer due to the higher basal area of “increaser” grasses than at 5 ha/steer. There were few treatment differences in the basal area of individual perennial grasses.

Between 1988 and 2001, *H. contortus* plant density increased at light but declined at heavy stocking rates. Some individual *H. contortus* plants survived throughout this study although the major changes in plant density resulted from differences in seedling recruitment. This, in turn, reflected the size of the soil seed bank. Legume oversowing reduced *H. contortus* plant density through reduced seedling recruitment while burning at light stocking rates increased seedling recruitment above that in native pasture and so increased *H. contortus* plant density.

Treatment impacts on *H. contortus* as measured by three sampling methods (Botanal, permanent quadrats and wheel point) gave conflicting results. These differences were related to the manner in which each of the methods accounted for the spatial distribution of *H. contortus*.

Annual liveweight gain per head in native pasture was highly variable between years but was always highest at light stocking and decreased with increasing stocking rate. Annual liveweight gain per hectare increased linearly with stocking rate and this rate of increase was higher in the legume oversown compared with both the native pasture and supplement / burning treatments. The average liveweight advantage across all years for legume oversown pastures was 37 kg/steer. Annual liveweight advantage to burning compared with native pasture was variable.

Fistulated steers consistently selected a diet that contained a high proportion of *H. contortus* when it was available. The highest proportion of *H. contortus* was at light stocking rate because increasing stocking rate reduced its availability in the pasture. Increaser species were neither preferred nor rejected while *Bothriochloa bladhii* was seldom preferred despite being a major contributor to total pasture yield. Steers also selected other species such as *Chrysopogon fallax*, forbs and sedges.

Seca stylo was always selected in the legume oversown treatments when they were sampled in autumn.

It was concluded that cattle production is sustainable in *H. contortus* pasture when stocking rates are maintained at 4 ha/steer or lighter which equates to an annual utilisation rate of around 30%. Stocking rates heavier than 4 ha/steer are unsustainable because they reduce pasture yield, increase the occurrence of undesirable species, progressively reduce *H. contortus* density and reduce animal production per head. This conclusion was supported by landscape stability and economic evaluations.

Executive Summary

Native pastures are a prime forage resource for the Queensland beef herd and their management for long term, sustainable production presents a challenge to beef producers and grazing land managers. *H. contortus* (black speargrass) pastures are the most important native pasture in Queensland in terms of carrying capacity and their potential for enhancement. These pastures are also the third most extensive in area after the *Aristida – Bothriochloa* pastures (box-ironbark woodlands) and *Astrebla* (Mitchell) grasslands.

Despite the extent and importance of native pastures for beef production, there have been surprisingly few studies of their management under grazing. In *H. contortus* pastures, most early studies focussed on the replacement of native pastures with introduced pasture species, particularly legumes, to boost animal diets. There was little attempt to study the effect of the animal on the pasture resource because of the widespread assumption that native pastures were of poor quality.

However, it is now clear that the complete replacement of native pastures with exotic species is uneconomic because of high fertiliser costs. Meanwhile low fertility demanding legumes, especially *Stylosanthes* species, have become available for augmenting native pastures. The adoption of new technologies such as dry season supplement technology and the replacement of *Bos taurus* cattle with better adapted *Bos indicus* lines have also increased grazing pressure on native pastures. Associated with these new technologies, stocking rates have increased since the 1960's and by the late 1980's there was evidence of a decline in the condition of some native pasture communities. These factors pointed to an urgent need to improve the understanding of native pastures and to develop sustainable grazing management strategies.

Accordingly, the Australian Meat Research and Development Corporation (now Meat and Livestock Australia) agreed to fund a long term study of the effects of stocking rate, legume oversowing, dry season supplements and fire on the sustainability and productivity of *H. contortus* pastures. This research was located at Galloway Plains, Calliope with the co-operation of the Neill-Ballantine family. Grazing commenced in October 1988 and concluded in June 2001.

The objective of the study was to assess the productivity and stability of native pastures grazed at a range of stocking rates, with or without the addition of legumes or dry season supplement and fire. The study was originally designed as a randomised block with 11 treatments replicated twice. Treatments were 5 stocking rates viz. 8, 5, 4, 3 and 2 ha/steer in native pasture, 3 stocking rates viz. 4, 3 and 2 ha/steer in native pasture with oversown legume and 3 stocking rates viz. 4, 3 and 2 ha/steer in native pasture with a dry season supplement. A number of changes were later made to this design. In 1992, the 3 dry season supplement treatments became spring burning treatments and in 1996 the 8 ha/steer native pasture treatment became a spring burning treatment at a stocking rate of 5 ha/steer. Seasonal rainfall throughout this grazing study was below the long-term average.

The main findings of this project were:

- Across all years, pasture utilisation ranged from 13% at a stocking rate of 8 ha/steer to 52% at 2 ha/steer.
- Increasing stocking rate in native pasture reduced total pasture yields. Total pasture yields in legume oversown treatments were similar to those in native pasture at the same stocking rate. In those years when spring burning was possible, spring burning reduced total pasture yields in the subsequent autumn.

- Increasing stocking rate in native pasture reduced the density of *H. contortus* although this reduction was less marked in terms of yield and frequency. Increasing stocking rate also reduced the occurrence of Ar*istida* spp*.*, increased the occurrence of "increaser" grasses and changed the occurrence of a range of minor species. In the legume treatments, *Stylosanthes scabra* cv. Seca increased from <1% of pasture yield in 1988 to 50% in 2000 and was associated with a reduction in *H. contortus* as well as changes in the occurrence of some minor species.
- Neither stocking rate, legume oversowing nor supplement / burning treatments had a major impact on total perennial grass basal area. By 2001, total perennial grass basal area in native pasture was higher at 2 ha/steer than at 5 ha/steer due to the higher basal area of "increaser" grasses. There were few treatment differences in the basal area of individual perennial grasses.
- Between 1988 and 2001, *H. contortus* plant density in native pasture increased at light but declined at heavy stocking rates. Some individual *H. contortus* plants survived throughout this study. The major changes in density resulted from differences in seedling recruitment which, in turn, reflected the size of the soil seed bank. Legume oversowing reduced *H. contortus* density through reduced seedling recruitment. Spring burning at light stocking rates increased seedling recruitment above that in both native pasture and legume oversown native pasture and so increased *H. contortus* density.
- Treatment impacts on *H. contortus* as measured by three different methods (Botanal, permanent quadrats and wheel point) gave conflicting results. These conflicting results were related to how each of the methods accounted for the spatial distribution of *H. contortus*.
- Soil surface condition was reduced by grazing at 2 ha/steer in both native pasture and legume oversown pasture.
- Annual liveweight gain per head in native pasture was highly variable between years but was always highest at light stocking and decreased with increasing stocking rate. Annual liveweight gain per hectare increased linearly with stocking rate. The rate of increase was higher in the legume oversown compared with both the native pasture and supplement / burning treatments. The average liveweight advantage across all years for legume oversown pastures was 37 kg/steer. There was no consistent liveweight advantage to burning compared with native pasture.
- Fistulated steers consistently selected a diet that contained a high proportion of *H. contortus* when it was available. The highest proportion of *H. contortus* in the diet was at light stocking rate because higher stocking rates reduced its availability in the pasture. Increaser species were neither preferred nor rejected while *Bothriochloa bladhii* was seldom preferred despite being a major contributor to total pasture yield. Steers also selected other species such as *Chrysopogon fallax*, forbs and sedges. Seca stylo was selected in the legume oversown treatments in autumn.
- It was concluded that cattle production is sustainable in *H. contortus* pasture when stocking rates are maintained at 4 ha/steer or lighter. This stocking rate equates to an annual utilisation rate of around 30%. Stocking rates heavier than 4 ha/steer are unsustainable because they: reduce pasture yield, increase the occurrence of undesirable species, progressively reduce *H. contortus* density, reduce soil surface condition and reduce animal production per head.

A number of recommendations are made for further research and these include:

- Identifying the ecological role of individual plant species in relation to stocking rate and how they may contribute to measures of plant species diversity.
- Understanding the ecological role of *Bothriochloa bladhii* in *H. contortus* pastures and what is its overall contribution to animal production.
- Identifying a suitable grass: stylo balance, devising grazing strategies to maintain this balance and defining the optimum level of stylo for animal production.
- Determining the impact of burning on pasture species diversity and identifying those factors that result in increased liveweight gain from burning in spring.
- Promoting extensively the adoption of sustainable stocking rates.

This project has provided a scientific basis for sustainable cattle production in *H. contortus* pastures in central Queensland.

Contents

1 Background

1.1 Background to the project and the industry context

Native pastures are the prime source of forage for the Queensland beef herd. *Heteropogon contortus* (black speargrass) pastures are the most important of these in terms of carrying capacity and its potential for enhancement. They are also the third most extensive in area (after the *Aristida – Bothriochloa* pastures, Eucalypt woodlands and *Astrebla* (Mitchell grass) grasslands). The management of these native pastures for long term, sustainable production presents a major challenge to beef producers and grazing land managers.

Despite the extent and importance of native pastures for beef production, there have been surprisingly few studies of their management under grazing. Most early studies focussed on the replacement of native pastures with introduced pasture species, particularly legumes, to boost animal diet quality. There was little attempt to study the impact of the grazing animal on the pasture resource due to a widespread assumption that native pastures were of 'poor quality'. However, over the years, graziers and researchers have increasingly appreciated that native pastures will remain a major resource for the extensive grazing industries. Complete replacement of native pastures with exotic species is usually uneconomic because of high input costs especially associated with the use of fertilisers. Meanwhile, the opportunity has become available to augment native pastures with low fertility demanding legumes, especially *Stylosanthes* species.

Stocking rates in all pasture communities have increased substantially since the 1960's probably because of increasing economic pressures on producers together with increases in the price for beef. At the same time producers were adopting new technologies such as the oversowing of legumes and the use of dry season supplement technology. These new technologies were also associated with the replacement of *Bos taurus* cattle with better adapted *B. indicus* lines. These changes resulted in substantial increases in the grazing pressure on native pastures. Evidence from the Burdekin River catchment in the late 1980s - early 1990s gave a stark warning of the need to manage these pastures far more carefully than in the past. Furthermore, Tothill and Gillies (1992) reported signs of deterioration in native pastures including the loss of palatable perennial grasses and their replacement by less palatable grasses. These changes increased the urgency to improve the understanding of native pasture communities and to develop management strategies that will sustain their productivity.

These considerations lead to the establishment of a long term grazing study of the effects of different stocking rates, legume oversowing, dry season supplement and fire on the productivity and stability of *H. contortus* pastures in central Queensland. This research was conducted on Galloway Plains, Calliope with the enthusiastic co-operation of the Neill-Ballantine family. Grazing commenced on the experimental paddocks in October 1988 and continued until June 2001. This report outlines the project, details the results and highlights the conclusions.

1.2 Project Team

The Galloway Plains grazing study was a large scale, long term study and involved a large number of staff. Staff who made a major contribution to this study are listed however there were many other people who made a contribution who are not listed.

1.2.1 Research team

- Bill Burrows, formerly Department of Primary Industries and Fisheries, Rockhampton

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1.2.2 Technical and Extension team

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1.2.3 Acknowledgements

Many people contributed to the conduct of this study over a long period of time. It would be impossible to list all these people here but the following people and groups provided major contributions to its success.

Special acknowledgement is made to the Neill-Ballantine family and the Galloway Plains Pastoral Company for the long term use of land for this study. Their long term support and encouragement for this project was a major contributor to its overall success.

Dennis and Denise Quinn, Voewood, Calliope made land and records available in the associated field study aimed at the independent validation of the GRASP model derived from experimental data from the Galloway Plains study.

The Galloway Plains Producer Advisory Committee comprising producers, extension and scientific staff provided constructive advice on the grazing study and made many suggestions for further research.

A large number of Department of Primary Industries and Fisheries and Department of Natural Resources and Mines staff contributed to the conduct of this grazing study in many ways over the 13 years of the study.

This study could not have succeeded without the contributions of Bob Lindley (1988-1991) and Keith Jensen (1991-2001) who competently maintained the experimental site including fences, stock water and animal health and welfare.

Tonia Grundy for preparation of this final report.

2 Project Objectives

1. Assess the productivity and stability of native pastures grazed at a range of stocking rates, with or without the addition of legumes and fire;
2. Use the results recorded between 1988 and 1996 to demonstrate to producer groups that lenient grazing together with other pasture technologies can be both ecologically and economically viable;
3. Promote basic pasture science and monitoring techniques so that producers can recognise ecological processes;

4. Conduct comprehensive economic analyses of animal production from all pasture treatments including the application of the results to commercial case studies. A designated economist will be appointed by 31-12-1997 pending the Beef Institute restructuring;
5. Incorporate results from this study using GRASP to determine optimum stocking rate and economic performance for commercial beef enterprises in the black speargrass region;
6. Promote the results from this study and encourage adoption of optimum stock management strategies as outlined in the draft communication strategy.

3 Methodology

3.1 Study site

The grazing study was established in 1988 in a *H. contortus* pasture at Galloway Plains, Calliope (24°10'S, 150°57'E) in central Queensland. Mean annual rainfall for Calliope Station is 854 mm based on 97 years of records and approximately 70% of this annual rainfall occurs between October and March inclusive. Mean daily maximum temperatures in summer average 30.5°C while mean daily minimum temperatures in winter average 12°C. Frosts occur between June and August.

The two predominant soil types were a duplex (Dy3) and a grey clay (Ug5) soils (Barton 1991) and both soils were of low fertility. The duplex soil was the dominant soil type on the eastern replicate and the grey clay was the dominant soil in the western replicate. The original over-story vegetation had been cleared before this study commenced but was predominantly *Eucalyptus crebra* (narrow-leaved ironbark) and *E. melanophloia* (silver-leaved ironbark) on the duplex soil and *E. populnea* (popular box) on the clay soil. Initial pasture measurements indicated that *H. contortus* and *Bothriochloa bladhii* (forest bluegrass) were co-dominant in the ground story vegetation.

3.2 Grazing study

The grazing study was designed as a randomised block with 11 treatments with 2 replications. Treatments were:

1. Native pasture stocked at 8, 5, 4, 3 and 2 ha/steer
2. Native pasture oversown with legumes and Phosphorous diet supplement stocked at 4, 3 and 2 ha/steer, and
3. Native pasture with dry season supplement stocked at 4, 3 and 2 ha/steer

Five *Bos indicus* crossbred steers grazed each treatment. Paddock sizes varied from 10 to 40 ha to achieve these experimental stocking rates and steers were replaced annually. Six steers were included in four annual drafts (July 1992-September 1993, August 1995–August 1996, July 1999-August 2000 and July 2000-June 2001) in order to accelerate stocking rate effects. (Further details are provided in the Section 4.2 Animal production). The legumes *Stylosanthes scabra* cv. Seca, *S. hamata* cv. Verano and *Chamaecrista rotoundifolia* cv. Wynn were sown into cultivated strips at seeding rates of 4.0, 0.5 and 0.5 kg/ha, respectively, on 13-15 October 1987.

3.3 Changes to experimental design

A number of changes to the original experimental design were made during the study.

- In 1992, the dry season supplement treatments were discontinued and replaced by spring burning treatments because the impact of the dry season supplement treatments on pasture condition and animal liveweight were no different to the native pasture treatments grazed at equivalent stocking rates. Furthermore, graziers at Galloway Plains field days indicated that fire was an important component of their management of native pastures and they believed that we should assess the impact of fire. Consequently, the dry season supplement treatments were changed to measure the impact of spring burning on pasture and animal performance. The aim was to burn 80% of the native pasture leaving 20% of the paddock adjacent to the watering point unburnt.
- By 1996, the impacts of the burning treatments were varied because the stocking rates had reduced pasture yields and the resulting potential fuel loads. This situation was further compounded by below average rainfall. At stocking rates of 2 and 3 ha/steer, burning was possible only in spring 1992 and 1999 while at 4 ha/steer, burning was conducted in spring 1992, 1998 and 1999 while a “patchy” burn was possible in 1996. Consequently, in 1996, the 8 ha/steer native pasture treatment was discontinued because pasture and animal production data were similar to that at the 5 ha/steer treatment. This former 8 ha/steer treatment was then changed to evaluate the impact of burning at the lighter stocking rate of 5 ha/steer. This treatment ensured sufficient fuel load was available to allow annual burning between 1996 and 1999. No treatment was burnt in spring 1997 because of the low value of the Southern Oscillation Index.

3.4 Data presented in this report

The data presented in this report are the complete pasture, animal and animal diet data for the grazing study. The complete data set is presented firstly, to demonstrate that there is a considerable time lag before pasture species changes became apparent in *H. contortus* pastures and secondly to serve as a compendium of all data collected between 1988 and 2001.

4 Results and Discussion

4.1 Impacts of grazing on pastures

4.1.1 Introduction

Evidence of deterioration in the condition of native pastures throughout northern Australian has been reported by Tothill and Gillies (1992). For example, the palatable *Heteropogon contortus* is being replaced by less palatable grasses in both northern (Pressland *et al.* 1991) and southern Queensland (Orr *et al.* 1997). Much of the change in pasture content has resulted from increasing grazing pressure probably as a result of both increasing economic pressures on primary producers and the inappropriate adoption of new technologies. Pasture technologies such as introduced legumes and animal diet supplements (Hendricksen *et al.* 1985) and the introduction of tropically adapted *Bos indicus* cattle (Vercoe and Frisch 1985) have improved dry season forage utilisation and increased grazing pressure. This section reports on the impacts of native pasture stocking rates, legume oversowing and supplement / burning treatments on plant responses at Galloway Plains.

4.1.2 Methods

4.1.2.1 Yield and content

The yield and pasture content of all treatments were recorded every 6 months in autumn (end of summer growing season) and again in spring (end of the dry season) using Botanal (Tothill *et al.* 1992). A total of 150 quadrats, each 50 x 50 cm, were recorded in each paddock at each sampling. Six trained operators assessed 25 quadrats along a transect across each paddock with quadrats spaced approximately 40 metres apart. Major species, such as *H. contortus* (black speargrass) and *Bothriochloa bladhii* (forest bluegrass), were recorded individually. Some species, such as *B. decipiens* (pitted bluegrass), were recorded individually while others, such as *Panicum* spp. (hairy panic), were recorded to genus level and others, such as native legumes, were grouped. The density of sown legumes was also recorded in the legume paddocks.

4.1.2.2 Pasture utilisation

The levels of pasture utilisation achieved at each stocking rate were calculated as part of the associated Department of Natural Resources and Mines modelling project for the Galloway Plains grazing study. Pasture utilisation was calculated as the proportion of forage intake to pasture grown expressed as a percentage for the period of time each draft of steers grazed the pasture. Forage intake was calculated from the steer draft stocking rate based on the intake of a 200 kg steer. Pasture grown was determined for the grazing period for each draft using the pasture growth model GRASP (Littleboy and McKeon 1997).

Data reported here are the mean values of utilisation for each treatment for the 13 years and no data on the annual variation in utilisation is presented. Further analysis of the impacts of annual variation in utilisation for this grazing study will be undertaken in the current modelling project NBP.384 Improved grazing management using modelling.

4.1.2.3 Perennial grass basal area

Perennial grass basal area was measured using a wheel point apparatus (Tidmarsh and Havenga 1955) at two yearly intervals along permanent transects in selected treatments (Table 4.1.1). At each sampling, approximately 2000 points were examined per paddock and the number of “hits” on the base of live perennial grass plants was used to calculate total perennial grass basal area and the basal area of individual perennial grass species. For further analysis, perennial grasses were classified into two broad categories viz. decreaser species (*H. contortus* and *B. bladhii)* and increaser species (*B. decipiens, C. divaricata and Eragrostis* spp.)

Table 4.1.1. Perennial grass basal area (%) measurements made at Galloway Plains, 1989 to 2001.

Treatment	Stocking rate (ha/steer)	1989	1991	1993	1995	1997	1999	2001
Native pasture	8 ha/steer	✓	✓	✓	✓			
Native pasture	5 ha/steer	✓	✓	✓	✓	✓	✓	✓
Native pasture	4 ha/steer	✓	✓	✓	✓	✓	✓	✓
Native pasture	3 ha/steer	✓	✓	✓	✓	✓	✓	✓
Native pasture	2 ha/steer	✓	✓	✓	✓	✓	✓	✓
Legume	2 ha/steer	✓	✓	✓	✓	✓	✓	✓
Supplement / burning	4 ha/steer				✓			
Supplement / burning	2 ha/steer	✓	✓	✓	✓			✓
Burning	5 ha/steer					✓		✓

4.1.2.4 Population dynamics of *H. contortus*

H. contortus was monitored as a key species indicator of pasture change. In 1988, approximately 60 plants were identified in 25 permanently located quadrats in a range of treatments. Treatments measured were the 5, 4, 3 and 2 ha/steer in native pasture and the 4 and 3 ha/steer in the legume oversown and supplement / burning treatments. In spring 1996, an additional 25 permanent quadrats were located in the 5 ha/steer, burnt treatment to measure the impact of burning at this light stocking rate.

The location and diameter of these *H. contortus* plants was recorded in autumn 1988 using a pantograph (Williams 1970). Where plants were not circular, the diameter was measured firstly along the widest diameter and secondly the diameter in the perpendicular direction to this widest diameter. Subsequently, each autumn between 1989 and 2001, further recordings were made of the survival and size of these initial plants together with any new plants, which had been recruited over the previous year (Orr *et al.* 2004a).

Basal area of *H. contortus* was calculated on an individual quadrat basis as the area occupied by all *H. contortus* plants in the quadrat by assuming plants to be circular. (When the plant was not circular, the diameter was assumed to be the mean of the 2 diameters measured for that plant). Individual plant size was determined as the area covered by each plant and was calculated by dividing the total basal area per quadrat by the number of individual plants (incorporating the number of segments making up each of these plants) in that quadrat (Orr *et al.* 2004a).

The germinable soil seed bank of *H. contortus* was measured to interpret differences in seedling recruitment. The germinable soil seed bank was measured each spring between 1989 and 2000 by germinating seed contained in soil cores collected from the area surrounding the permanent quadrats. Four cores, each 5 cm diameter and 5cm deep, were bulked to produce each sample and there were 15 samples (i.e. 60 cores) from each paddock. In the following summer, when dormancy had been overcome, each sample was spread as a 2 cm thick layer on top of compacted sand in a 15 cm diameter drained plastic pot. Seed in these samples was germinated by watering with an overhead sprinkler for 30 minutes daily for 6-8 weeks (Orr *et al.* 1996). *H. contortus* seedlings were identified and counted and only 1 wetting cycle was conducted (Orr 1999). In addition to *H. contortus*, the germinable seed banks of *Stylosanthes spp.* were recorded in the legume oversown treatments.

4.1.2.5 Landscape function analysis

(Note: This research was undertaken by Ms Emily Davies as part of an MLA funded, final year student project for a Bachelor of Environmental Science degree at the University of Queensland, St. Lucia. A brief summary of this LFA study is included here to further substantiate the overall conclusions regarding what constitutes sustainable grazing).

In December 2000, a landscape function analysis (Tongway & Hindley 1995) was undertaken in the native pasture treatments at 5 and 2 ha/steer and the legume oversown treatment at 2 ha/steer. In each of these treatments, measurements were taken along 3 transects each of 50 m in length. Transects were directed downslope and had a similar aspect. Data are summarised here as transect composition in relation to major zone types as well as indices of landscape stability, landscape infiltration and landscape nutrient cycling.

4.1.2.6 Statistical analysis

The grazing experiment was a randomised complete block design consisting of two replicates of 11 treatments. The treatments were set up in a factorial structure made up of 5 stocking rates and 3 pasture types with four treatment combinations missing during 1988–1996 and 4 stocking rates and

3 pasture types with one treatment combination missing during 1997-2001. Given the lack of balance in the treatment structure, the data was analysed using analysis of variance (AOV) with an appropriate nested factorial structure in GenStat (GenStat 4.21, Reference Manual). All measurements were analysed separately for each year. Transformations were used as required.

An angular transformation (ang(p)= 1 80/π x arcsin(√(p/ 100)) where 0 < p < 100) was used for the content and frequency of intermediate species and the frequencies of minor species.

For the wheel point data, the nested factorial used was dependent on data collected in a given year but, generally, investigated the stocking rate and pasture type effects and their interactions. Examination of residual indicated that there was no need to transform the basal area percent data prior to analysis.

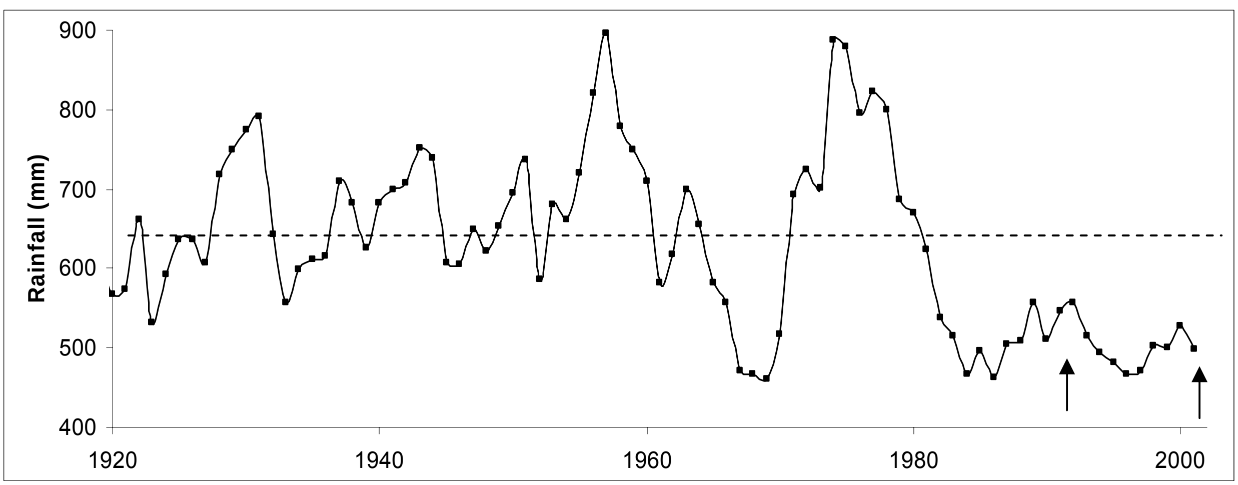
For the permanent quadrats, data were measured in a subset of treatments that consisted of 4 stocking rates and 3 pasture types with four treatment combinations missing. A logarithmic transformation (log(x + 1)) was used for seedling recruitment of *H. contortus.* Plant survival was analysed using a proportional hazards survival model (Cox 1972)

4.1.3 Results

4.1.3.1 Climate

Trends in the 5-year moving average summer (October to March) rainfall for Calliope Station (20 km from Galloway Plains) indicate that the experiment was conducted during the driest period of recorded rainfall history (Figure 4.1.1a). At Galloway Plains, summer rainfall in some years, for example 1990-91 and 1996-97, approached the long term mean rainfall while other years, for example 1992-93 and 1994-95, were very much below the long term mean (Figure 4.1.1b).

(a)



(b)

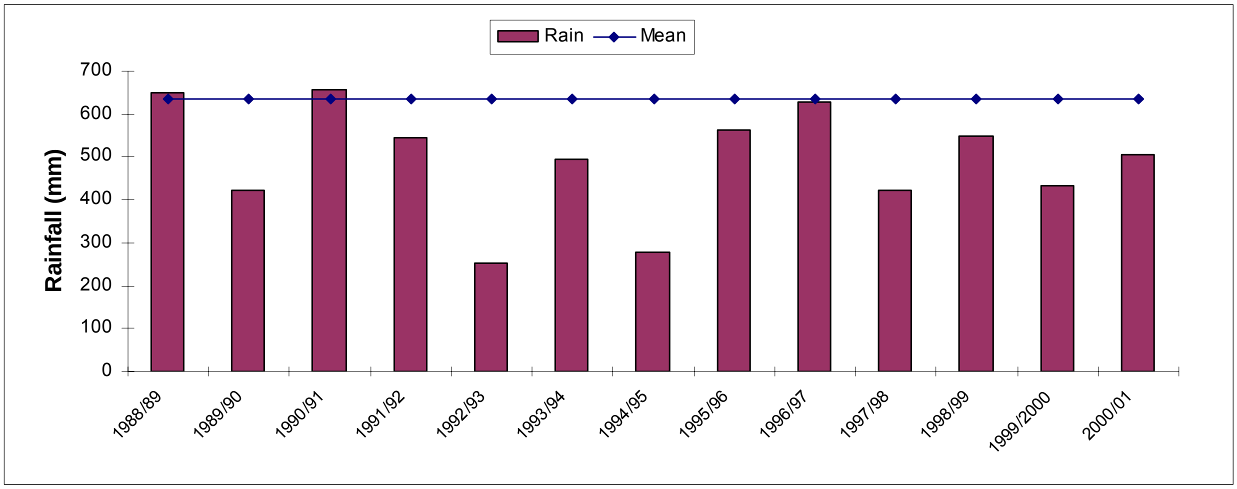


Figure 4.1.1 Rainfall (mm) trends for (a) the 5 year moving average summer rainfall (solid line) for Calliope Station in relation to the long term mean (dashed line) (Arrows indicate the start and end of this experiment) and (b) summer rainfall recorded between 1988-89 and 2000-01 at Galloway Plains.

4.1.3.2 Pasture utilisation

Over the period of this study, mean pasture utilisation increased with increasing stocking rate in the 5 native pasture treatments (Figure 4.1.2). Long-term safe stocking rates are usually achieved when pasture utilisation is less than 30% in most years and this was achieved at stocking rates of 8, 5 and 4 ha/steer. Stocking rates of 3 and 2 ha/steer exceeded this threshold suggesting that these stocking rates may be unsustainable in the long term because of deleterious changes in pasture that are documented below. Utilisation was consistently higher on the texture contrast soil than on the grey clay reflecting the higher pasture yields on the grey clay than on the texture contrast soil.

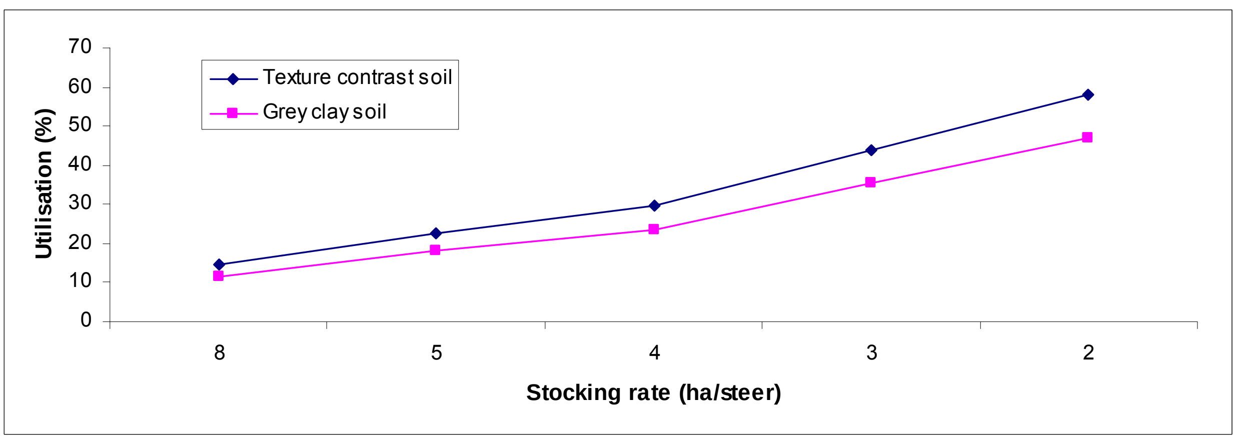


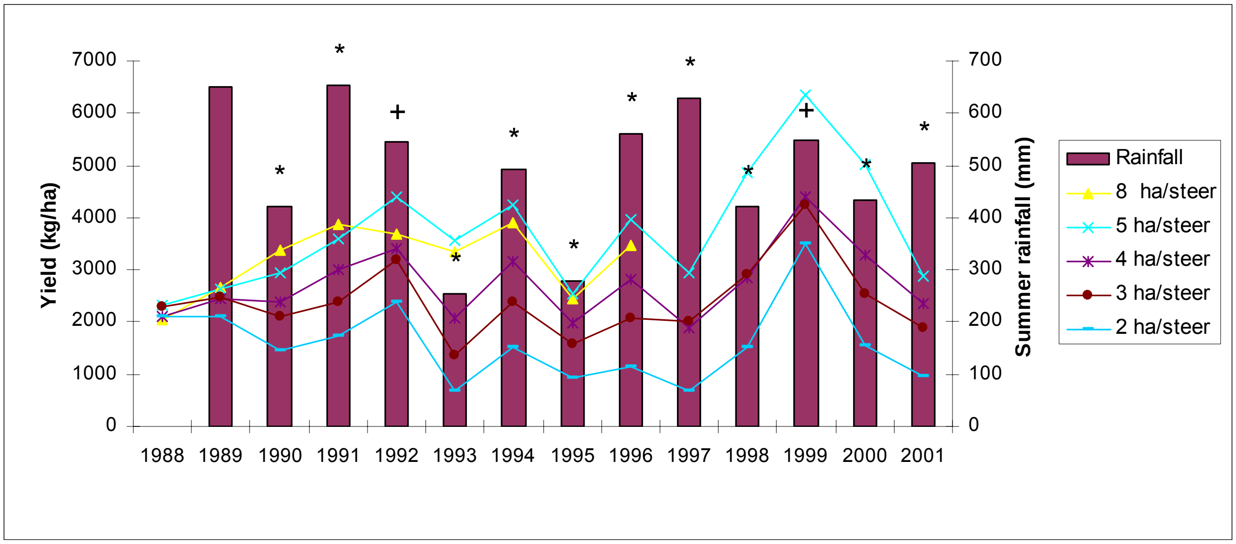
Figure 4.1.2 Mean pasture utilisation (%) achieved at 5 native pasture stocking rates between 1988 and 2001 at Galloway Plains.

4.1.3.3 Total pasture yield

Total pasture yields in autumn varied among years from 6350 kg/ha in native pasture at 5 ha/steer in 1999 to 635 kg/ha in the supplement / burning treatments in 1993. In the native pasture treatments, increasing stocking rate from 8 ha/steer to 2 ha/steer reduced ($P<0.05$) total yields by 1990 (Figure

4.1.3a). Stocking rate influenced total yields more (Figure 4.1.3b) than pasture type (native pasture, legume or supplement / burning) and there was no interaction between stocking rate and pasture type. Pasture type influenced (P<0.05) total yields only in autumn 1993 and 2000 following burning in spring 1992 and 1999.

(a)



(b)

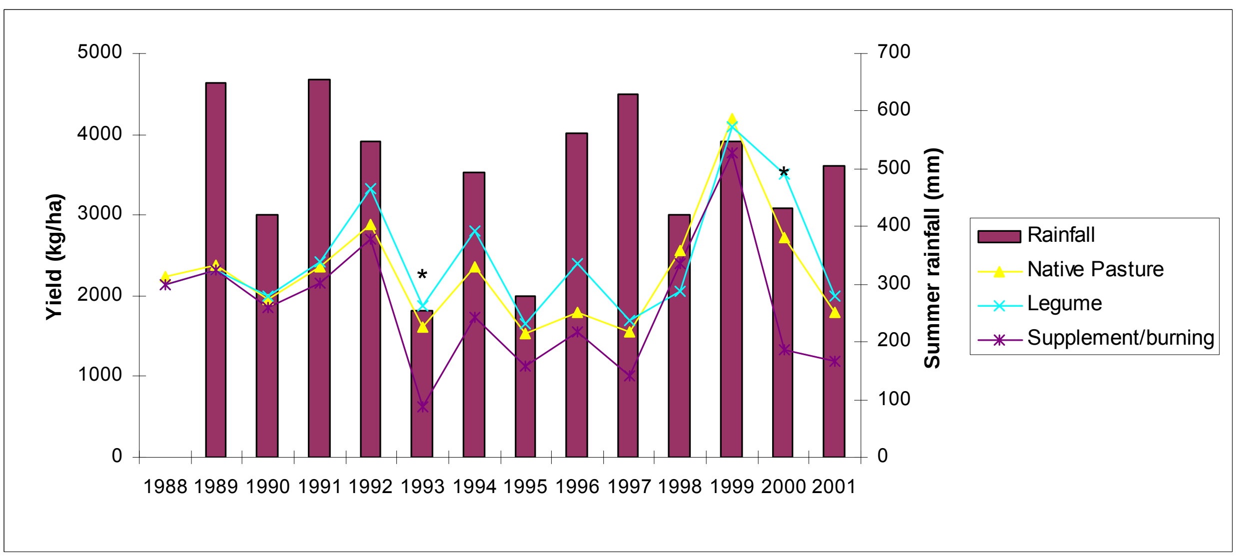


Figure 4.1.3 Changes in yield (kg/ha) of (a) total pasture yield at 5 stocking rates (1988–1996) and 4 stocking rates (1997-2001), (b) total pasture at 3 pasture types in relation to summer rainfall at Galloway Plains (data averaged over 3 stocking rates (1988-1996) and 4 stocking rates (1997-2001) in autumn between 1988 and 2001. (Within years, asterisks indicate significant (P<0.05) and positive indicates significant (P<0.1) differences between treatments).

4.1.3.4 Species content

A large number of species with a diverse range of occurrences were encountered at Galloway Plains. To understand changes in species content, we found it necessary to classify these species into three broad groups to assess their response to grazing. These groups were major, intermediate and minor components and the maximum and minimum values recorded for each of these species are presented in Table 4.1.2. To assess their response to grazing we used both pasture yield and plant frequency for the major species, species content and some plant frequency data for the intermediate species and plant frequency for the minor species groups.

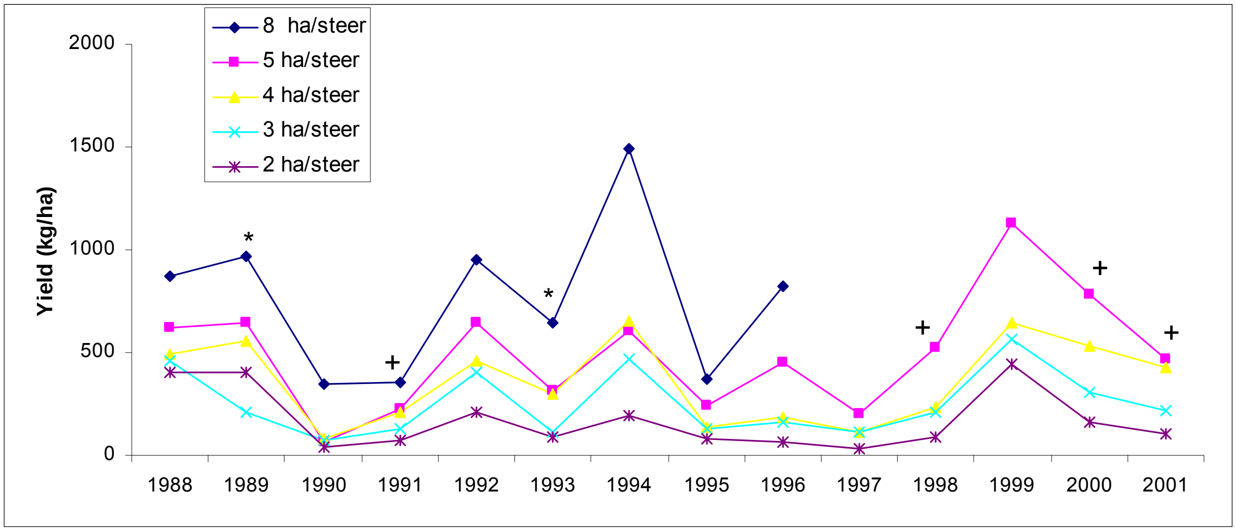
Table 4.1.2 Classification of plant species into groups.

Group	Species	Parameter	Data range
Major	*Aristida* spp. (Wiregrass)	Yield, Frequency	0-1499 kg/ha, 0-46.0%
	Bothriochloa bladhii (Forest bluegrass)	Yield, Frequency	8-4483 kg/ha, 17.1-83.3%
	Heteropogon contortus (Black speargrass)	Yield, Frequency	0-3103 kg/ha, 3.9-87.5%
Intermediate	*Bothriochloa decipiens* (Pitted bluegrass)	Content, Frequency	0-18.3%, 0-72.0%
	Chloris divaricata (Slender chloris)	Content, Frequency	0-36.4%, 0-84.4%
	Chrysopogon fallax (Golden beard)	Content	0-9.2%
	Cymbopogon spp. (Barb wiregrass)	Content	0-20.6%
	Eragrostis spp.(Woodland lovegrass)	Content, Frequency	0-15.6%, 0-51.7%
	Eriochloa spp. (Early spring grass)	Content	0-22.6%
	Stylosanthes scabra (Seca stylo)	Content	0.1-61.2%
Minor	*Panicum* spp. (Panic)	Frequency	0-26.7%
	Sporobolus spp. (Sporobolus)	Frequency	0-40.1%
	Chloris inflata (Purpletop Rhodes grass)	Frequency	0-30.7%
	Tragus australianus (Small burr grass)	Frequency	0-31.3%
	Other grasses	Frequency	2.6-55.6%
	Sedge	Frequency	1.9-76.3%
	Native legumes	Frequency	2.6-69.3%
	Malvaceae	Frequency	0-59.4%
	Other forbs	Frequency	7.2-80.9%

4.1.3.4.1 Stocking rate effects

Of the major species, heavy stocking rates reduced the yield of *H. contortus* but this reduction was significant ($P<0.05$) only in 1989 and 1993 (Figure 4.1.4a). Despite this, there was a consistent trend ($P<0.1$) in 3 of the last 4 years for the yield of *H. contortus* to be reduced by heavy stocking rates. After 1991, there was a clear trend for the yield of *B. bladhii* to be reduced ($P<0.05$) by heavy stocking rates (Figure 4.1.4b) and this was apparent in seven of the ten years to 2001. Despite these reductions in yield of both *H. contortus* and *B. bladhii,* there was no ($P>0.05$) reduction in the frequency of either species (Figure 4.1.5).

(a)



(b)

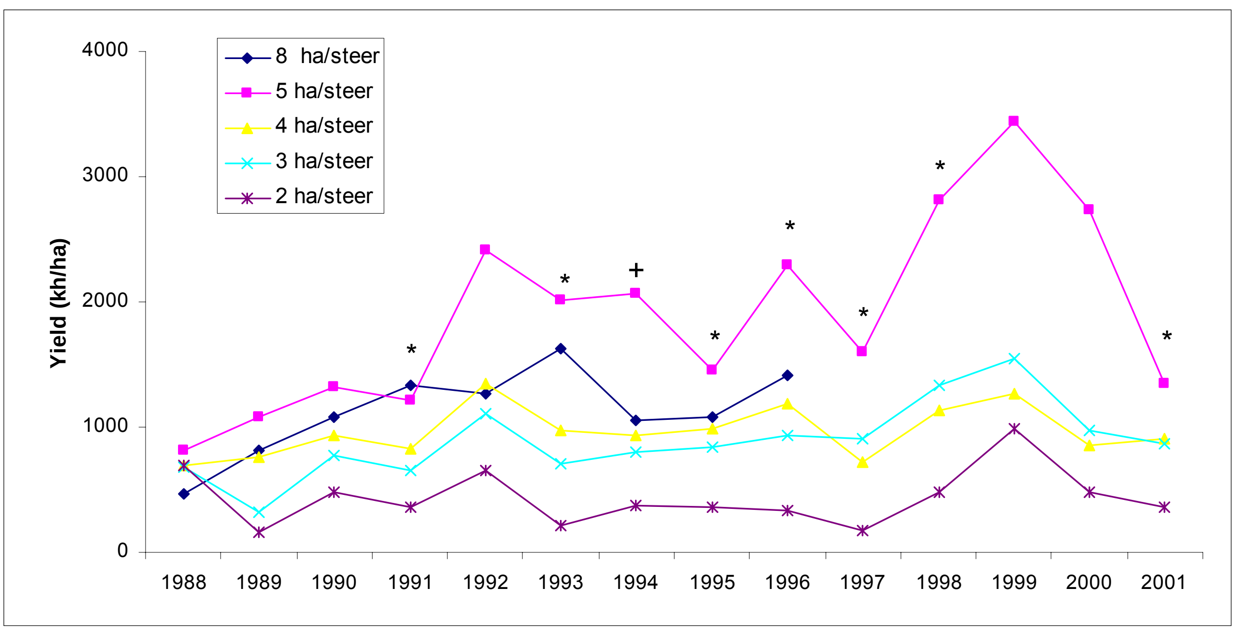
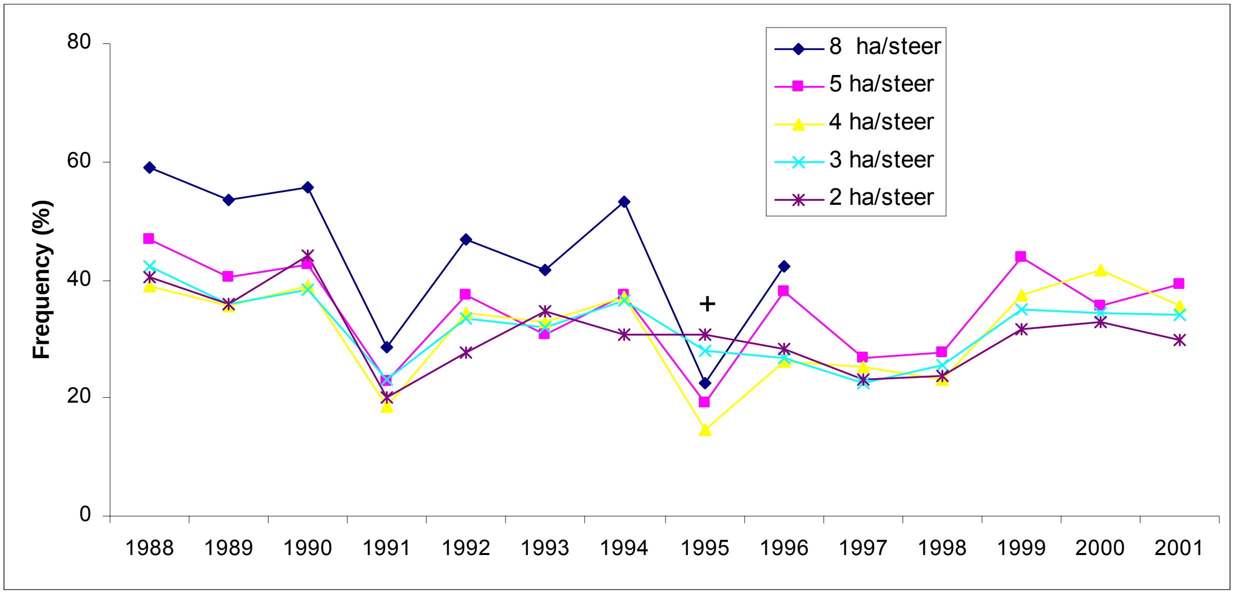


Figure 4.1.4 Changes in yield (kg/ha) of (a) *H. contortus* and (b) *B bladhii* in relation to 5 stocking rates (1989-1996) and 4 stocking rates (1997-2001) in native pasture in autumn between 1988 and 2001. (Within years, asterisks indicate significant (P<0.05) and positive indicates significant (P<0.1) differences between treatments).

(a)



(b)

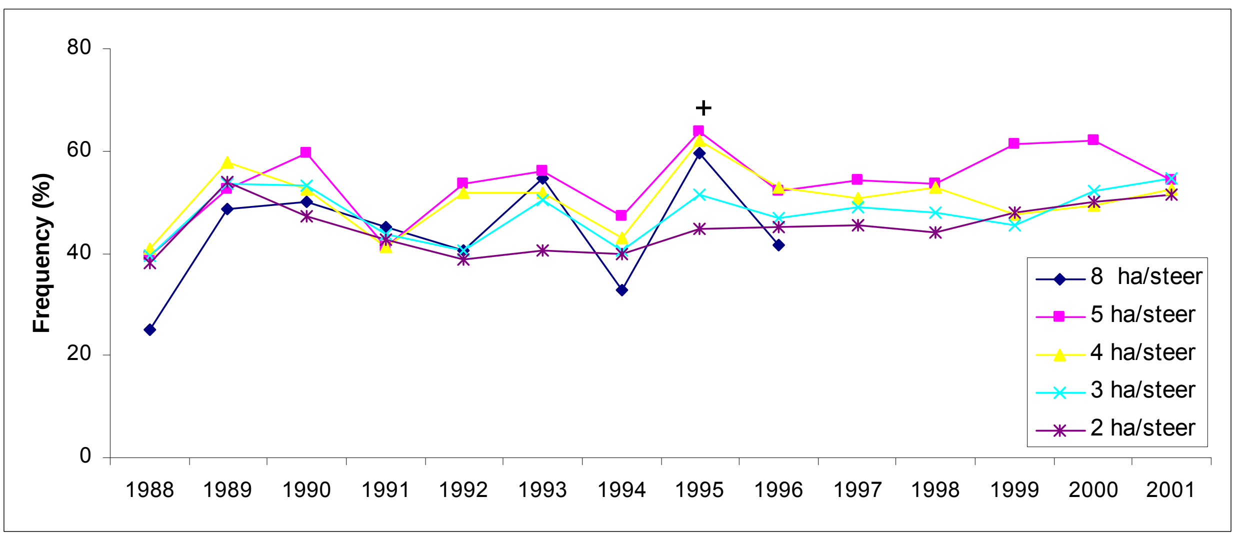
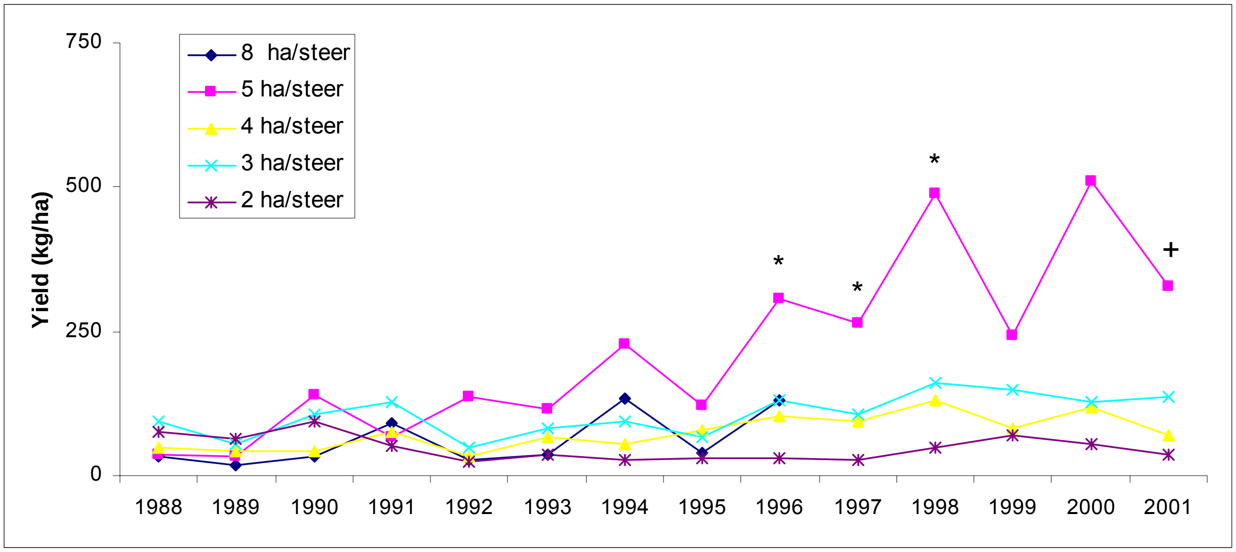


Figure 4.1.5 Changes in frequency (%) of (a) *H. contortus* and (b) *B bladhii* in relation to 5 stocking rates (1989-1996) and 4 stocking rates (1997-2001) in native pasture in autumn between 1988 and 2001. (Within years, asterisks indicate significant ($P<0.05$) and positive indicates significant ($P<0.1$) differences between treatments). (Analyses performed on logarithmic transformed data).

The yield of *Aristida* spp. was unaffected by stocking rate between 1988 and 1995 (Figure 4.1.6a). After 1995, *Aristida* spp. yield at 5 ha/steer increased ($P<0.05$) relative to the other three stocking rates in 1996, 1997 and 1998 while there was a similar trend ($P<0.1$) in 2001. The frequency of *Aristida* spp. was unaffected by stocking rate between 1988 and 1994 (Figure 4.1.6b). However, *Aristida* spp. frequency increased in 1995 to be consistently higher at 5 ha/steer than at the other three stocking rates although this increase was significant ($P<0.05$) only in 1995.

(a)



(b)

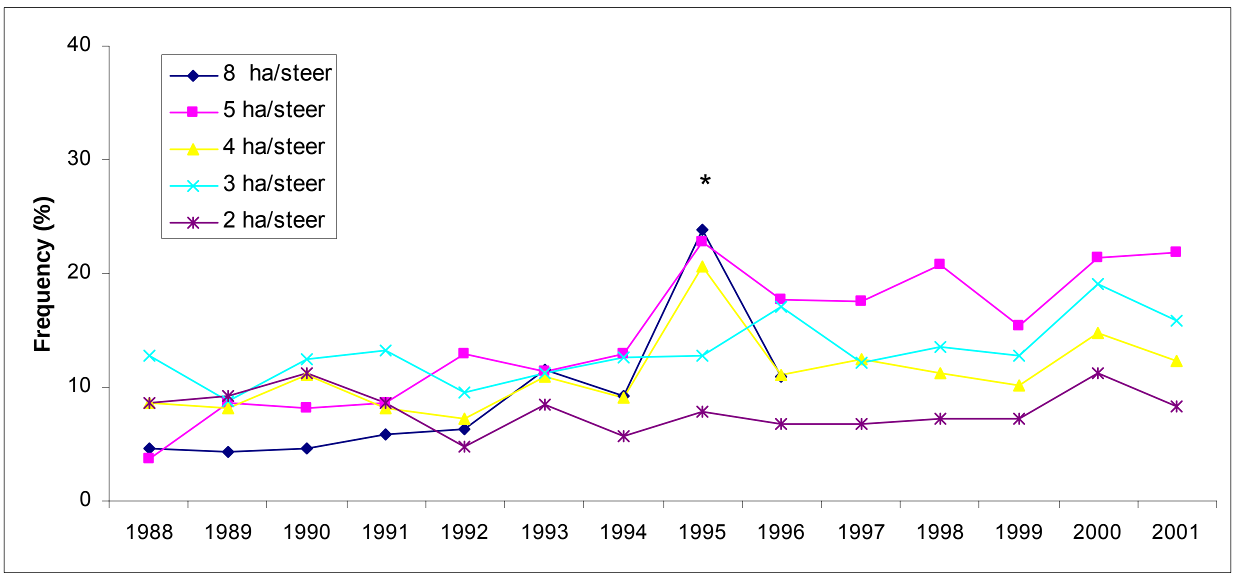
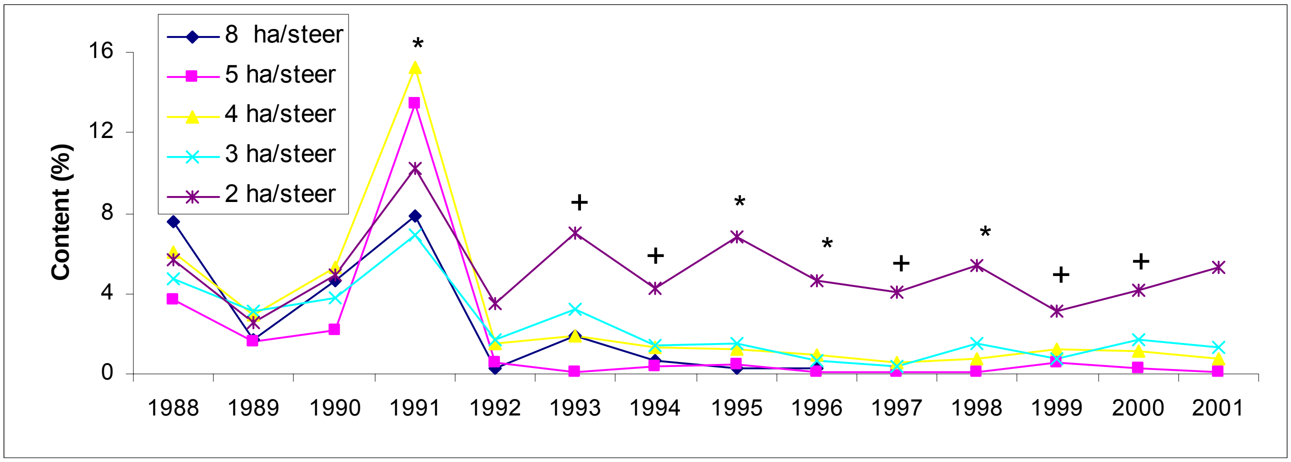


Figure 4.1.6 Changes in (a) yield (kg/ha) and (b) frequency (%) of *Aristida* spp. in relation to 5 stocking rates (1989-1996) and 4 stocking rates (1997-2001) in native pasture in autumn between 1988 and 2001. (Within years, asterisks indicate significant ($P<0.05$) and positive indicates significant ($P<0.1$) differences between treatments). (Analyses of frequency performed on logarithmic transformed data).

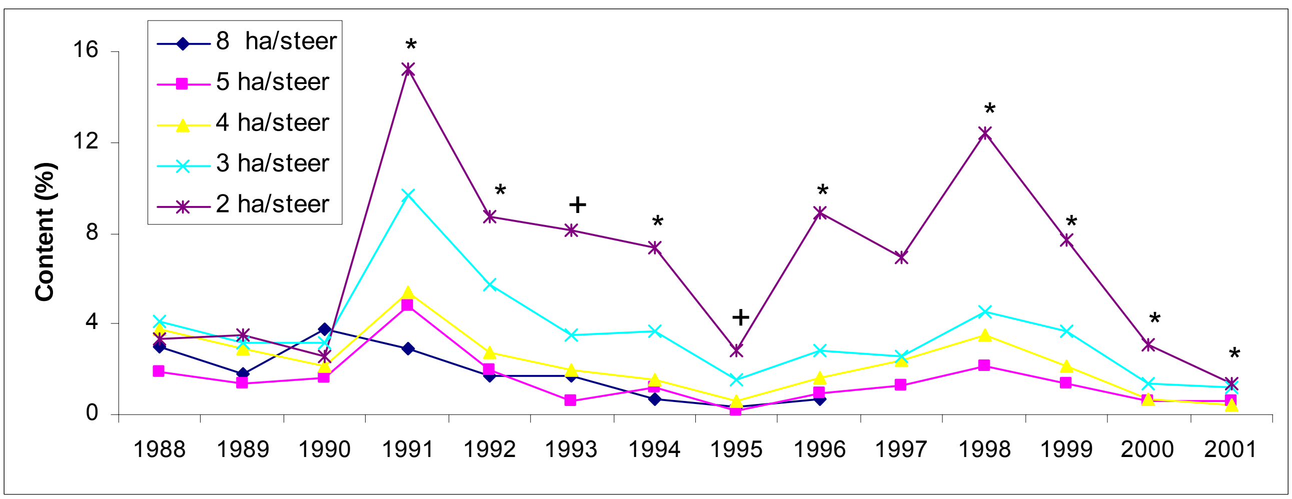
Stocking rate also impacted on the content of the intermediate species *Bothriochloa decipiens, Chloris divaricata and Eragrostis* spp. The pasture content of *B. decipiens* differed ($P<0.05$) between stocking rates in 1991 being highest at 15% at 4 ha/steer and lowest at 7% at 8 ha/steer although these differences appeared to show little consistent impact of stocking rate (Figure 4.1.7a). However, by 1995, the pasture content of *B. decipiens* had increased ($P<0.05$) with increasing stocking rate and this pattern was repeated in 1996 and 1998. Although statistical evidence of this trend was not as strong, this trend ($P<0.1$) was also apparent in 1993-1994, 1997 and 1999-2000.

By 1991, the pasture content of *C. divaricata* had increased ($P<0.05$) to be highest at 2 ha/steer and this effect was repeated in seven of the subsequent ten years to 2001 (Figure 4.1.7b). The pasture content of *Eragrostis* spp. increased ($P<0.05$) with stocking rate in 1995 and, although further statistical evidence of this trend was not strong, this trend ($P<0.1$) was also apparent in 1993 and 1998 (Figure 4.1.7c).

(a)



(b)



(c)

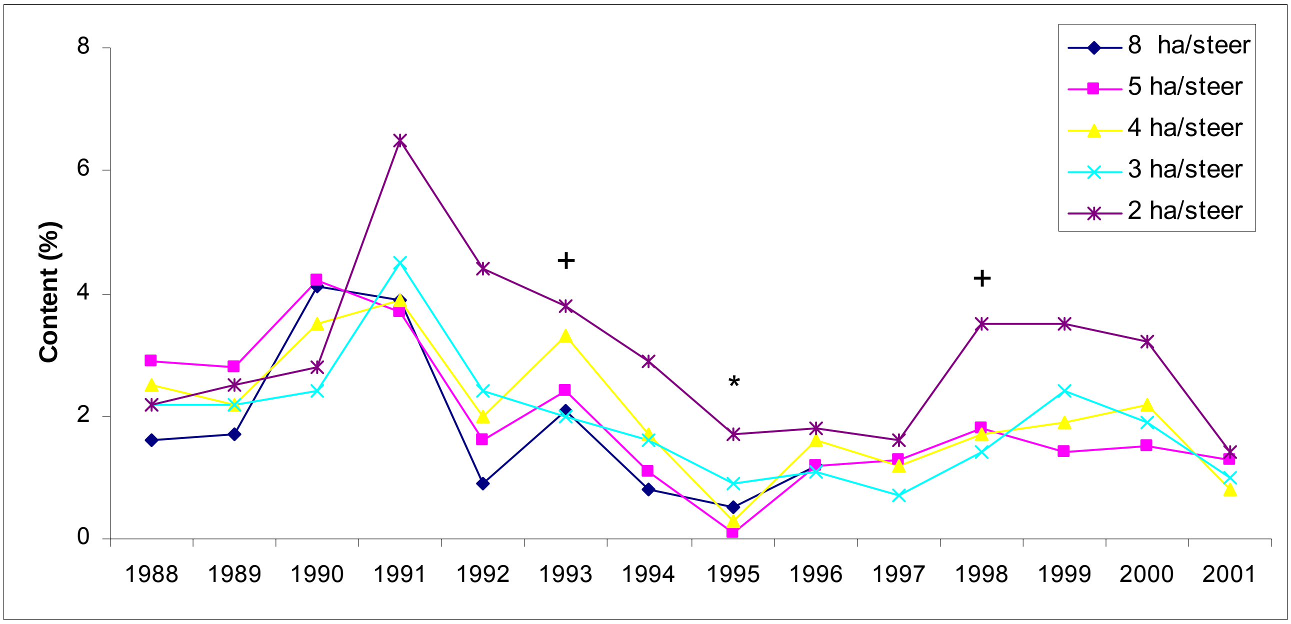
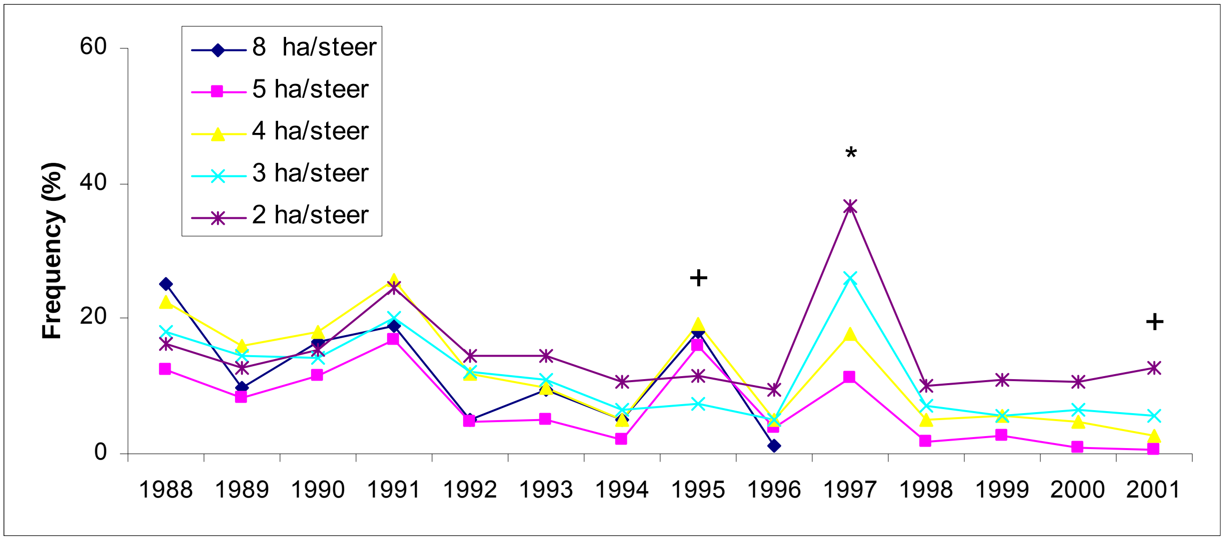


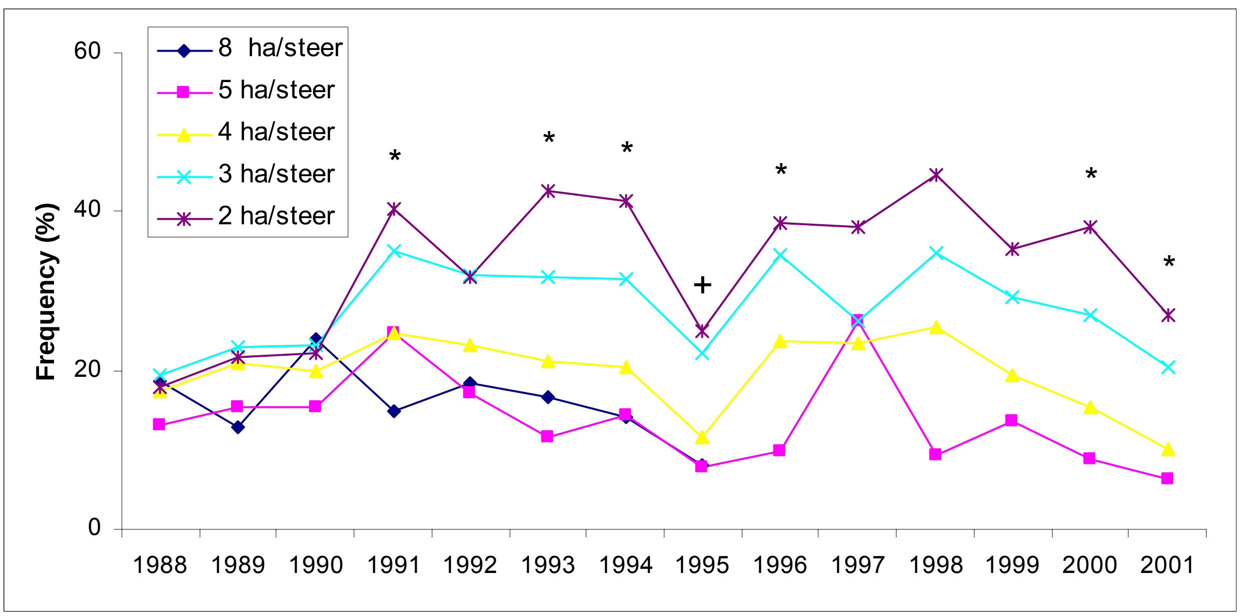
Figure 4.1.7 Changes in the content (%) of (a) *B. decipiens* (b) *C. divaricata* and (c) *Eragrostis* spp. in relation to 5 stocking rates (1989-1996) and 4 stocking rates (1997-2001) in native pasture in autumn between 1988 and 2001. (Within years, asterisks indicate significant (P<0.05) and positive indicates significant (P<0.1) differences between treatments). (Analyses performed on angular transformed data).

Changes in the pasture content of *B. decipiens, C. divaricata and Eragrostis* spp. resulting from the impacts of stocking rate were consistent with changes in the frequencies of these species. The frequency of *B. decipiens* was consistently, but not significantly (P>0.05), higher at heavy stocking rates after 1991 although the difference in 1997 was significant (P<0.05) and this trend (P<0.1) was also apparent in 1995 and 2001 (Figure 4.1.8a). The frequency of *C. divaricata* was higher (P<0.05) at heavy stocking rates in 1991, 1993-1994, 1996 and 2000-2001 and this trend (P<0.1) was also apparent in 1995 (Figure 4.1.8b). Similarly, the frequency of E*ragrostis spp.* was higher (P<0.05) at heavy stocking rates in 1995 and 2001 and this trend (P<0.1) was also apparent in 1993-1994 and 1997 (Figure 4.1.8c).

(a)


Frequency (%)
60
40
20
0
8 ha/steer
5 ha/steer
4 ha/steer
3 ha/steer
2 ha/steer
*
+
+
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

(b)


Frequency (%)
60
40
20
0
8 ha/steer
5 ha/steer
4 ha/steer
3 ha/steer
2 ha/steer
*
*
*
*
*
*
+
1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001

(c)

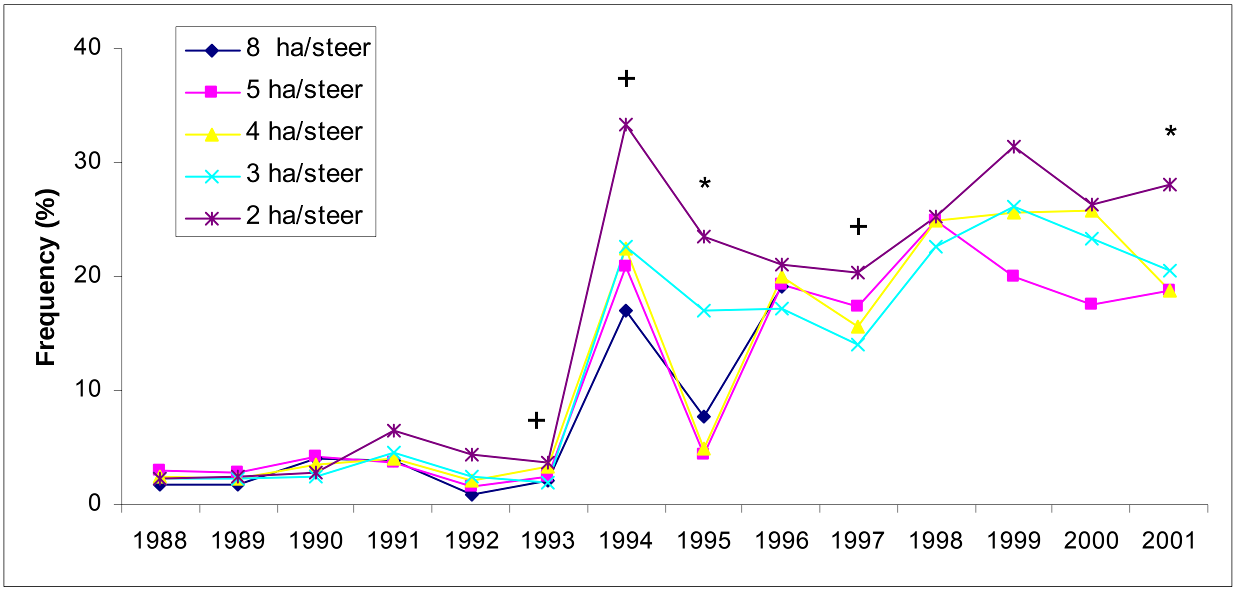
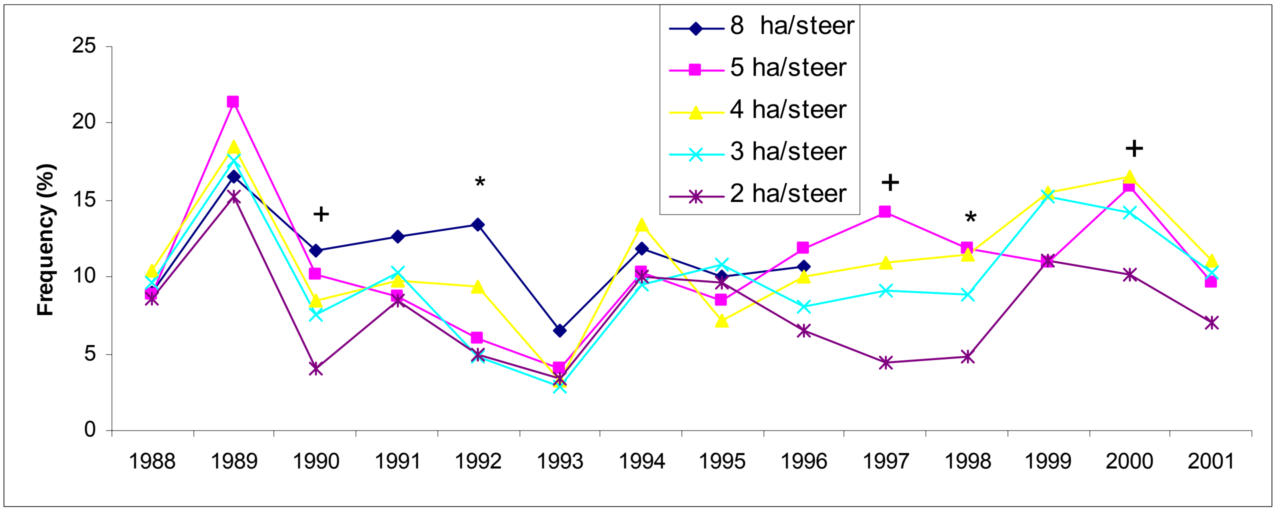


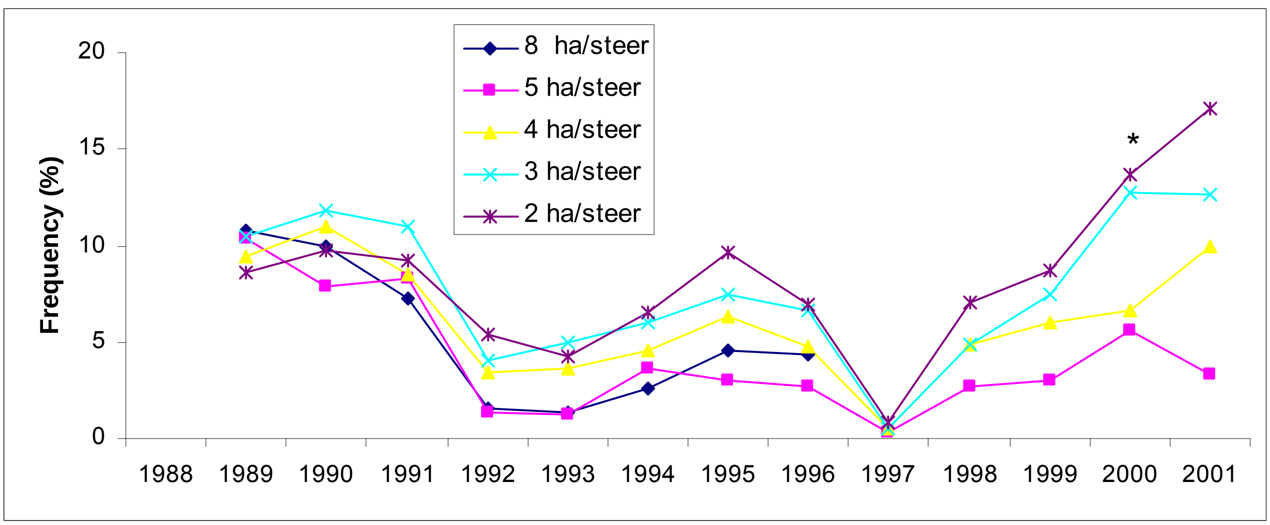
Figure 4.1.8 Changes in the frequency (%) of (a) *B. decipiens* (b) *C. divaricata* and (c) *Eragrostis* spp. in relation to 5 stocking rates (1989-1996) and 4 stocking rates (1997-2001) in native pasture in autumn between 1988 and 2001. (Within years, asterisks indicate significant (P<0.05) and positive indicates significant (P<0.1) differences between treatments). (Analyses performed on angular transformed data).

Stocking rate also impacted on the frequency of four minor species. The frequency of *Panicum* spp. was reduced (P<0.05) with increasing stocking rate in 1992 and 1998 with this trend (P<0.1) also apparent in 1990, 1997 and 2000 (Figure 4.1.9a). The frequency of *Sporobolus* spp. was unaffected by stocking rate between 1988 and 1997 (Figure 4.1.9b) although, after 1997, *Sporobolus* spp. increased with increasing stocking to be higher (P<0.05) at heavier stocking rates in 2000. By 1994, increasing stocking rate had increased (P<0.05) the frequency of *Tragus australianus* and this difference was also apparent in 1995, 2000 and 2001 while this trend was also apparent (P<0.1) in 1996 and 1998 (Figure 4.1.9c). The frequency of the Malvaceae group increased (P<0.05) with heavy stocking rate in 1995 and 2000 with this trend also apparent (P<0.1) in 1997 (Figure 4.1.9d).

(a)


8 ha/steer
5 ha/steer
4 ha/steer
3 ha/steer
2 ha/steer
Frequency (%)
0
5
10
15
20
25
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
+
*
+
*
+

(b)


8 ha/steer
5 ha/steer
4 ha/steer
3 ha/steer
2 ha/steer
Frequency (%)
0
5
10
15
20
1988
1989
1990
1991
1992
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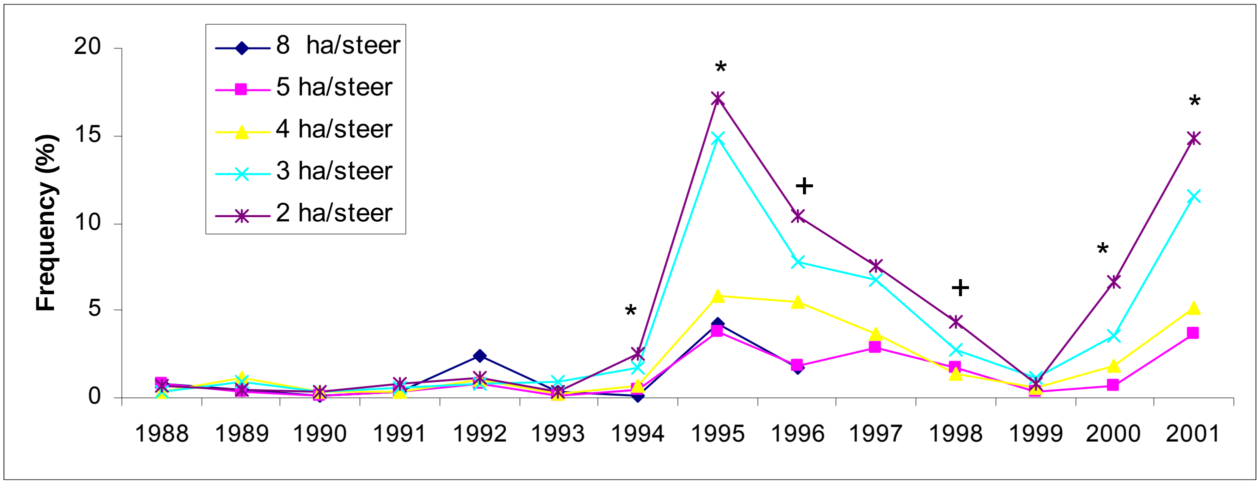
1996
1997
1998
1999
2000
2001
*

(c)



(d)

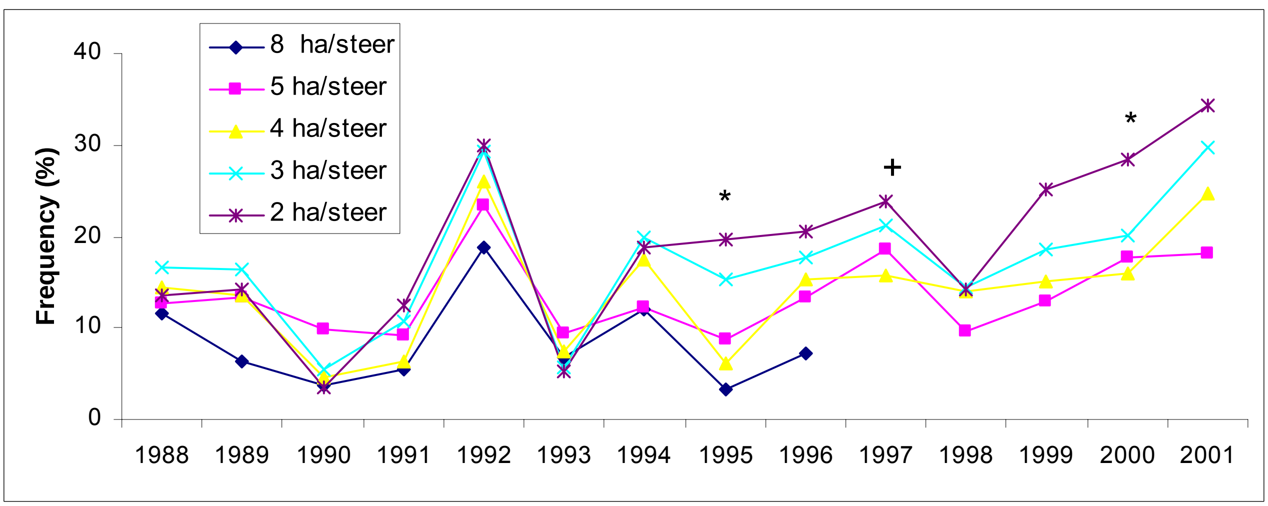


Figure 4.1.9 Changes in the frequency (%) of (a) *Panicum* spp., (b) *Sporobolus* spp., (c) *Tragus australianus* and (d) Malvaceae in relation to 5 stocking rates (1989-1996) and 4 stocking rates (1997-2001) in native pasture autumn between 1988 and 2001. (Within years, asterisks indicate significant (P<0.05) and positive indicates significant (P<0.1) differences between treatments). (Analyses performed on angular transformed data). (Note differences in scale).

4.1.3.4.2 Legume effects

Stylosanthes scabra cv. Seca stylo was the major legume present in the oversown treatments. Some *S. hamata* cv. Verano persisted in small amounts while *Chamaecrista rotoundifolia* cv. Wynn failed to make a meaningful contribution to the pasture. In 1988, Seca contributed less than 1% of total pasture content but increased progressively to be approximately 50% in 2000 (Figure 4.1.10). Stocking rate had little impact on this increasing contribution of Seca stylo to the pasture. The lower (P<0.05) Seca content in 1995 and 1997 at 3 ha/steer was due to paddock effect where the Seca build up was limited on the blue gum flat which traversed the western replicate paddock. The content of Seca stylo declined markedly between 2000 and 2001 due to a large decline in the yield of Seca stylo.

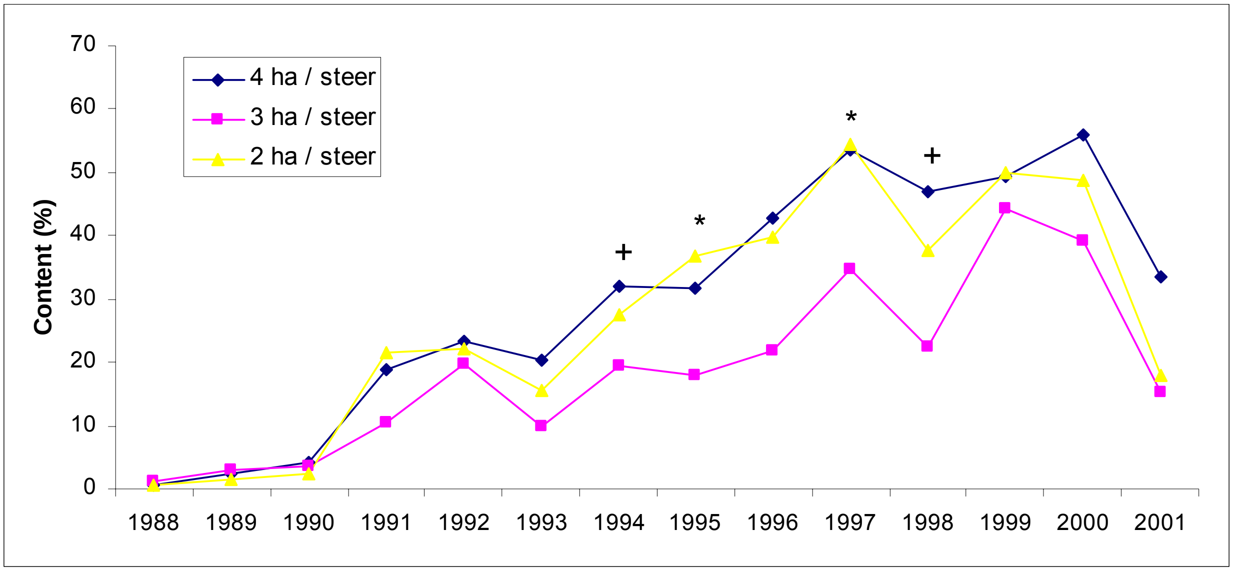


Figure 4.1.10 Changes in the content (%) of Seca stylo at 3 stocking rates in legume oversown native pasture between 1988 and 2001. (Within years, asterisks indicate significant (P<0.05) and positive indicates significant (P<0.1) differences between treatments). (Analyses performed on angular transformed data).

The decline in the Seca content between 2000 and 2001 was not reflected in a decline in Seca stylo plant density (Figure 4.1.11). The initial Seca stylo plant density was 1-2 plants/m^2 and this increased gradually to around 15 plants/m^2 in 1996. After 1996, this rate of increase in density accelerated so that, by 2001, Seca plants densities were 60 plants/m^2 at 2 and 3 ha/steer and 90 plants/m^2 at 4 ha/steer. The very high densities in 1997 were due to the presence of large numbers of seedlings (80 seedlings/m^2) but many of these failed to survive until the autumn 1998 sampling. This accelerated rate of Seca build up after 1996 was related to the increased amount of germinable seed present in the soil seed bank (Figure 4.1.12). (Note that this germinable seed bank represents about 70% of the total Seca seed bank; the remaining 30% is “hard” seed and remains in the soil until it is “softened”).

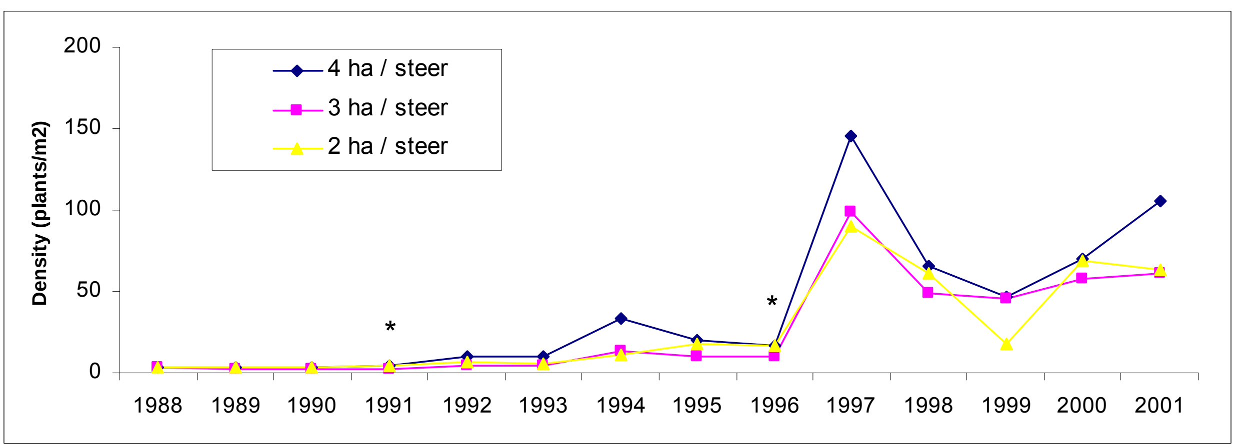


Figure 4.1.11 Changes in the density of Seca stylo (plants/m^2) at 3 stocking rates in legume oversown native pasture between 1988 and 2001. (Within years, asterisks indicate significant (P<0.05) differences between treatments).

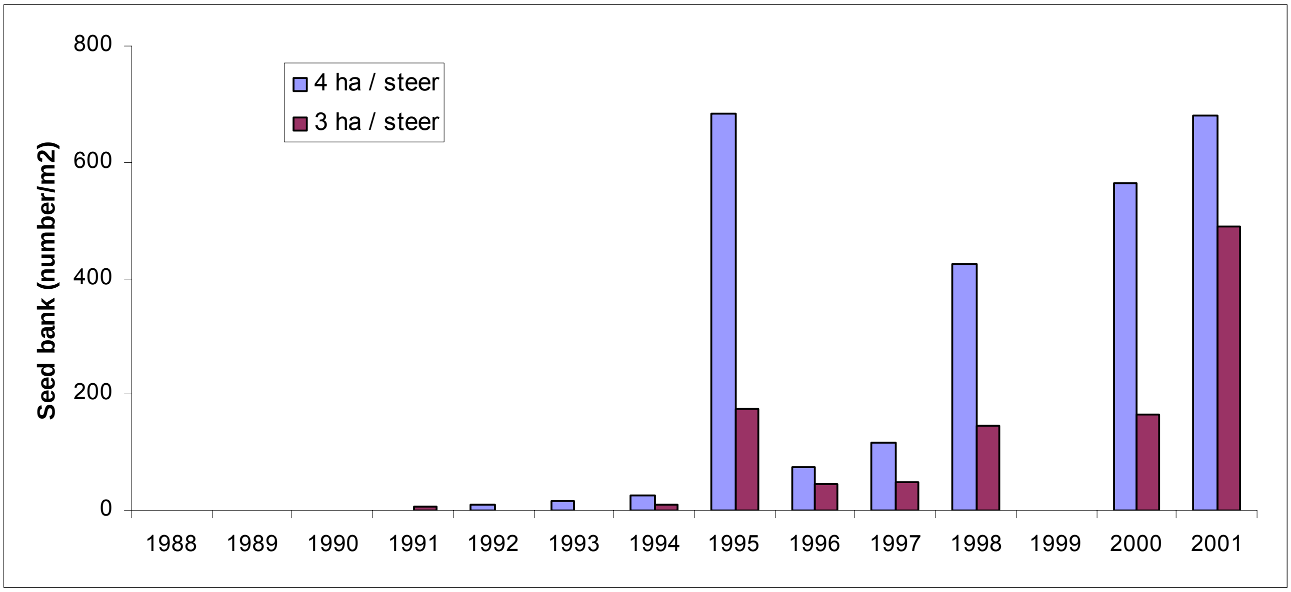
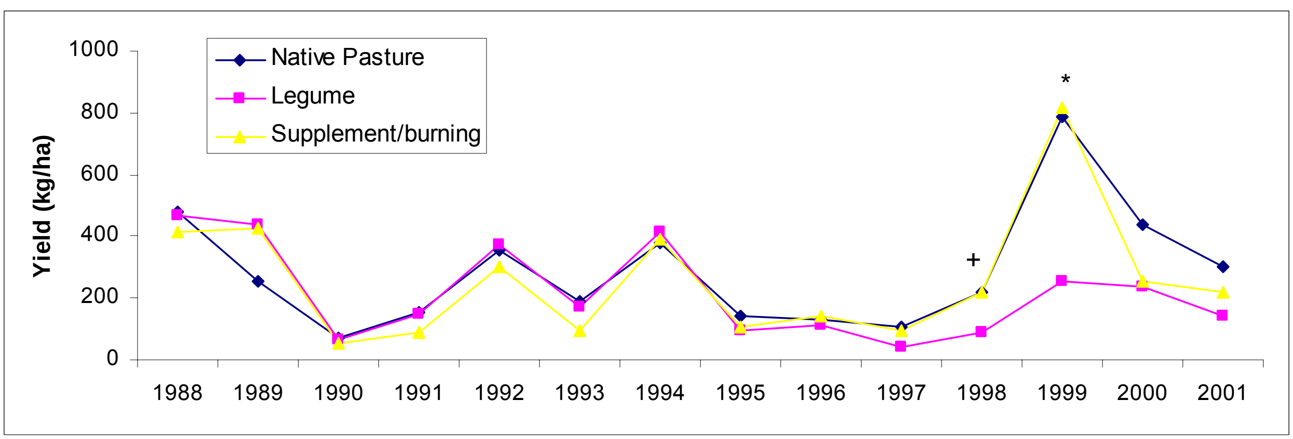


Figure 4.1.12 Changes in the germinable seed bank (seeds/m^2) of Seca stylo at 2 stocking rates in legume oversown native pasture between 1988 and 2001.

Oversowing Seca had little overall impact on the yield of the major species (Figure 4.1.13a,b). Nevertheless, the yield of *H. contortus* was reduced (P<0.05) by legume oversowing in 1999 and this trend was also apparent (P<0.1) in 1998 while the yield of *B. bladhii* remained unaffected by legume oversowing except in 1993.

(a)



(b)

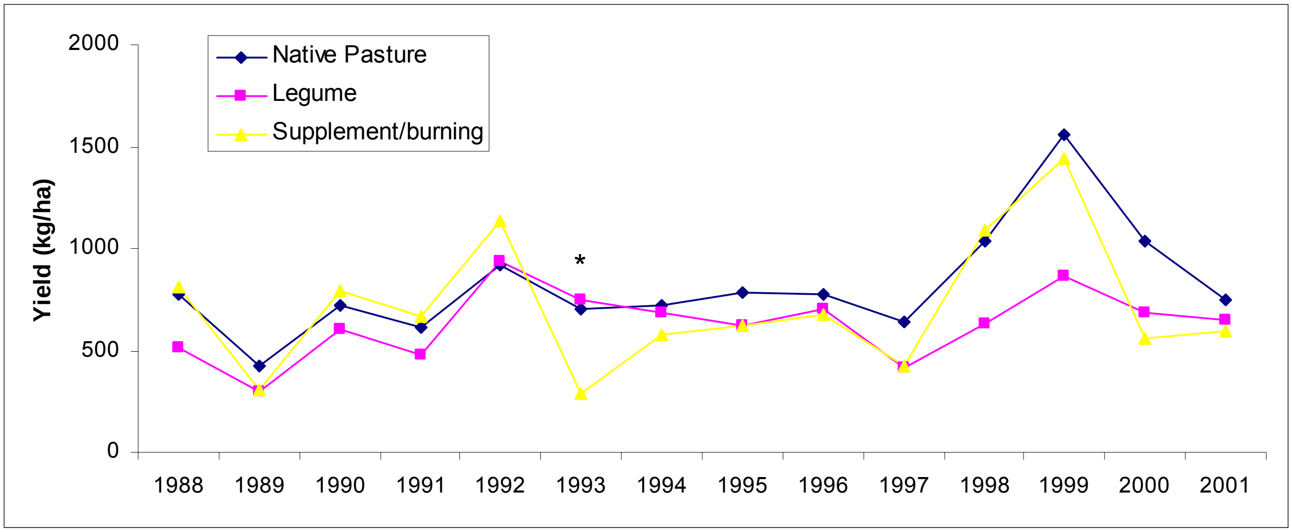
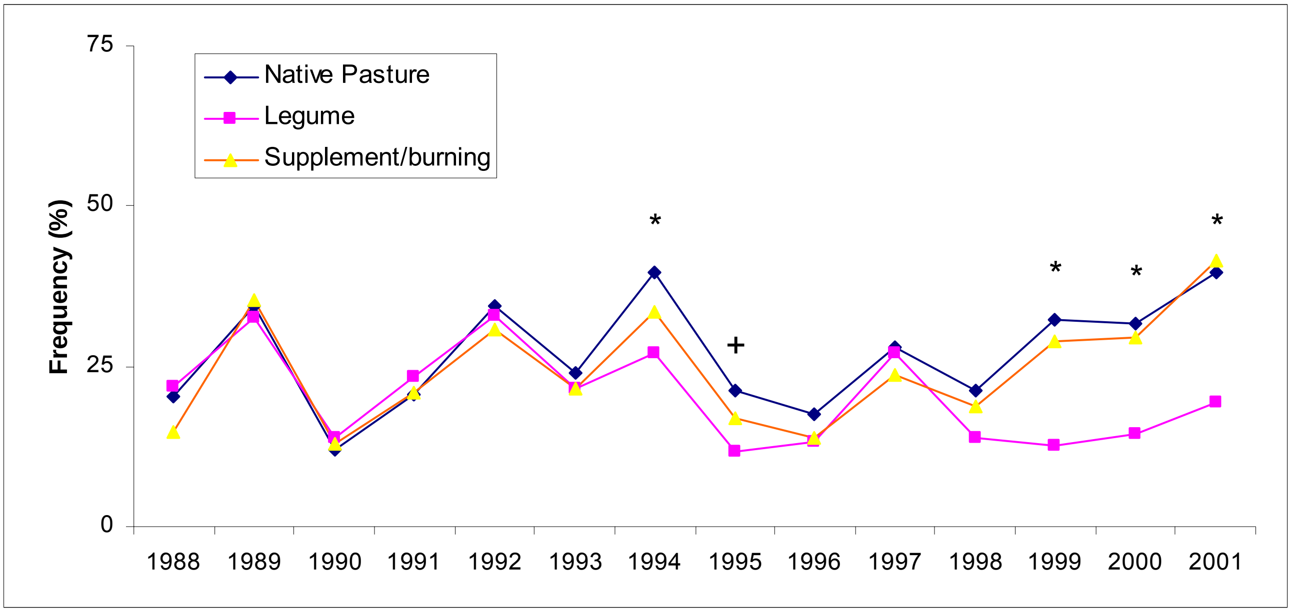


Figure 4.1.13 Changes in the yield (kg/ha) of (a) *H. contortus* and (b) *B. bladhii* at 3 pasture types (averaged over 3 stocking rates (1987-1996) and 4 stocking rates (1997-2001) between 1988 and 2001. (Within years, asterisks indicate significant ($P<0.05$) and positive indicates significant ($P<0.1$) differences between treatments).

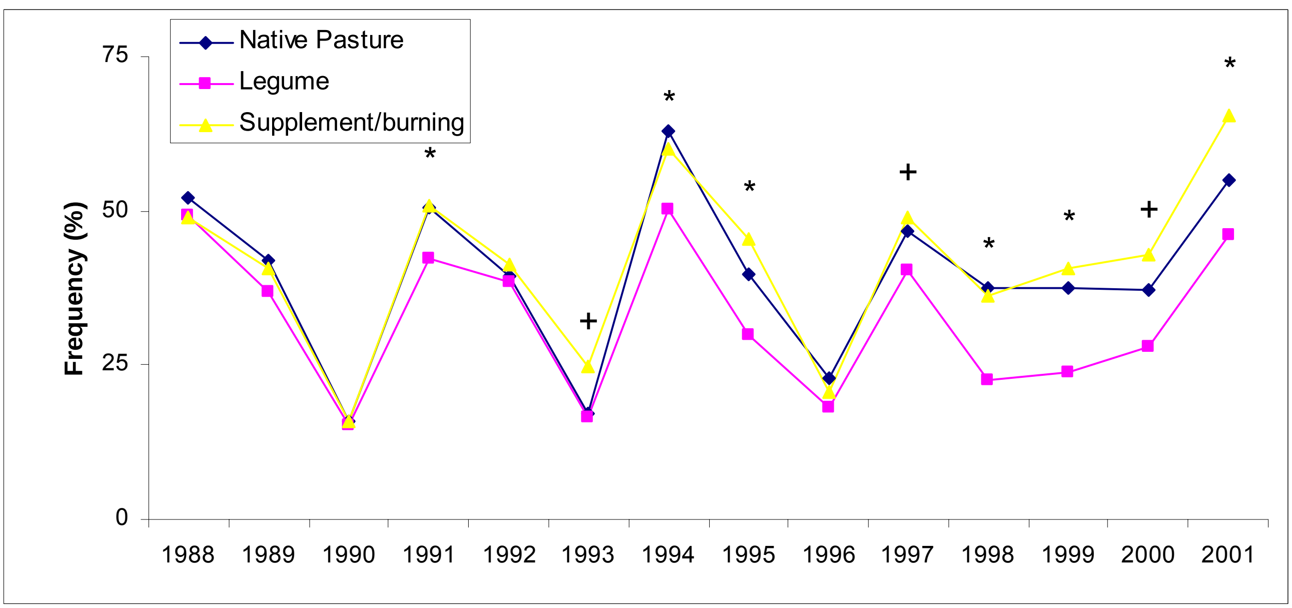
Legume oversowing also impacted on the frequency of 3 minor species. By 1994, the frequency of Native legumes had been reduced ($P<0.05$) by legume oversowing and this reduction also occurred in 1999, 2000 and 2001 with this trend also apparent ($P<0.1$) in 1995 (Figure 4.1.14a). The frequency of Other forbs was reduced ($P<0.05$) in 1991 1994-1995, 1998-1999 and 2001 with this trend also apparent ($P<0.1$) in 1993, 1997 and 2000 (Figure 4.1.14b). Legume oversowing increased ($P<0.05$) the frequency of *Chloris inflata* in 1995, 1998, 2000 and 2001 with this trend also apparent ($P<0.1$) in 1999 (Figure 4.1.14c).

(a)



Native Pasture
Legume
Supplement/burning
Frequency (%)
75
50
25
0
*
+
*
*
*
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

(b)



Native Pasture
Legume
Supplement/burning
Frequency (%)
75
50
25
0
*
+
*
*
+
*
*
+
*
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

(c)

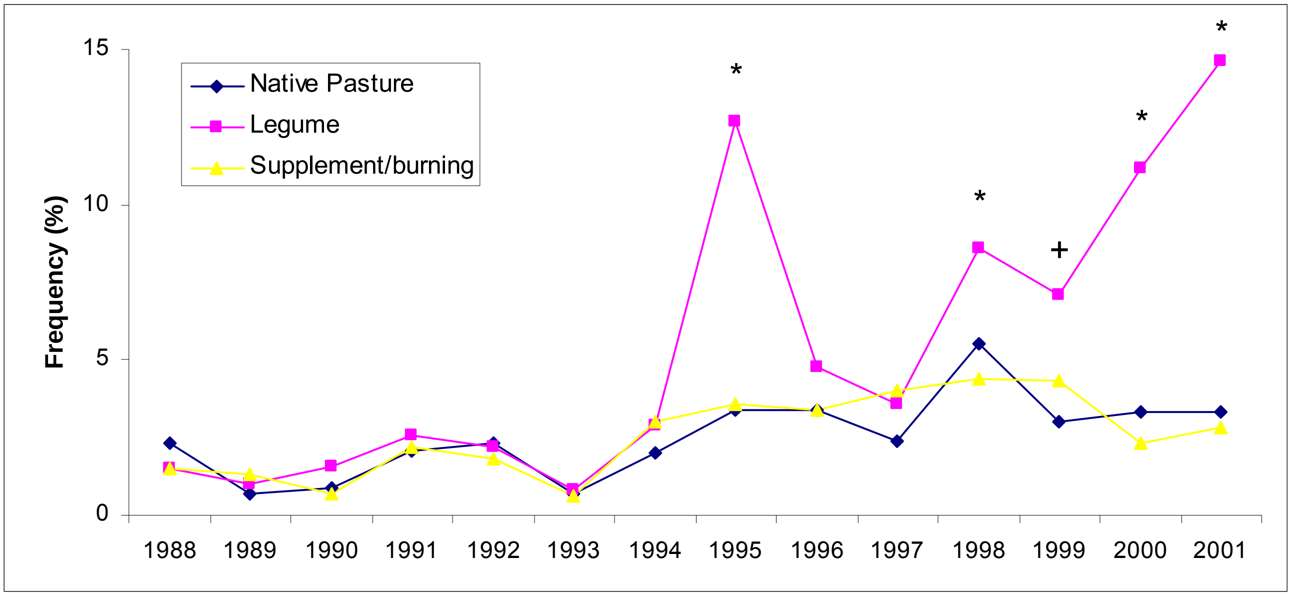
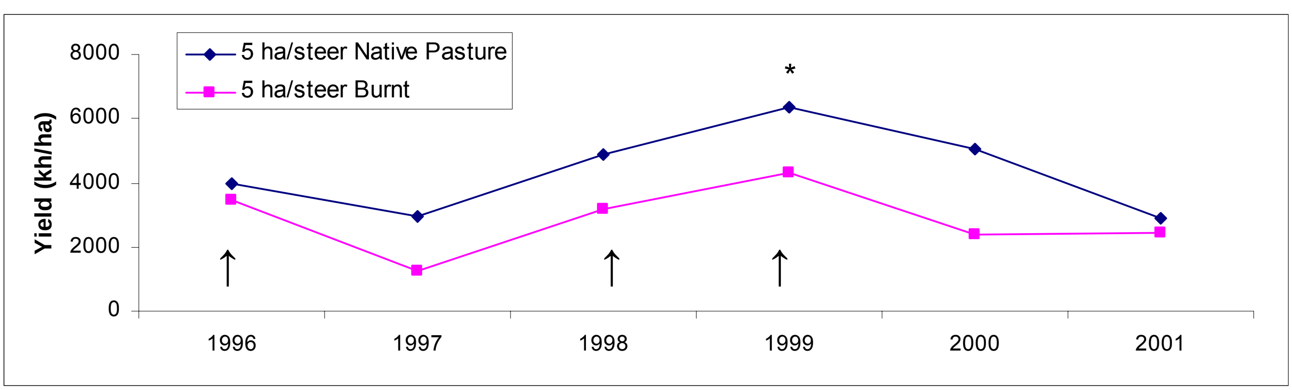


Figure 4.1.14 Changes in the frequency (%) of (a) Native legumes, (b) Other forbs and (c) *Chloris inflata* at 3 pasture technologies (averaged over 3 stocking rates) between 1988 and 2001. (Within years, asterisks indicate significant ($P<0.05$) and positive indicates significant ($P<0.1$) differences between treatments). (Analyses performed on angular transformed data).

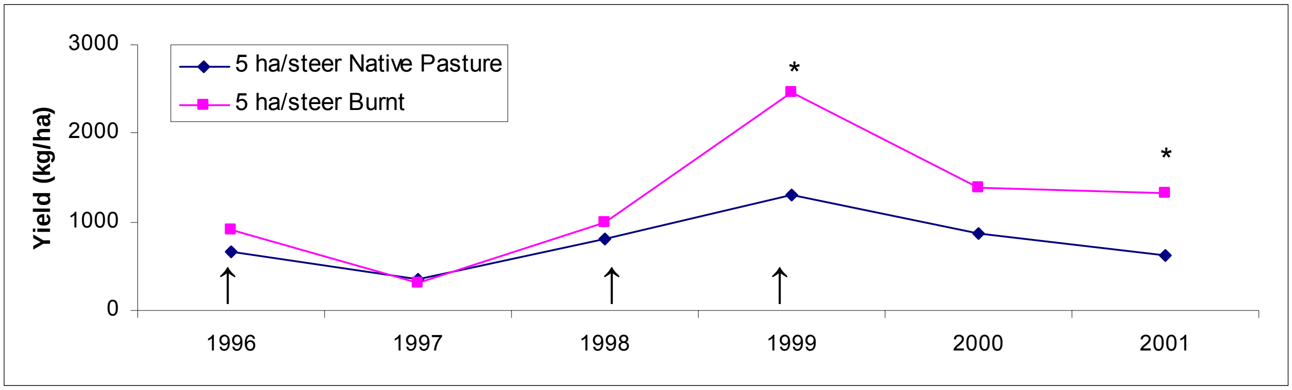
4.1.3.4.3 Supplement / burning effects

Spring burning in 1992 failed to increase the yield of *H. contortus* compared with native pasture (Figure 4.1.13a) but did reduce ($P<0.05$) the yield of *B. bladhii* in autumn 1993 (Figure 4.1.13b). However, spring burning at 5 ha/steer between 1996 and 2000 did alter total yield and individual species yields compared with unburnt native pasture (Figure 4.1.15). Burning in 1996, 1998 and 1999 reduced ($P<0.05$) total pasture yield in 1999 (Figure 4.1.15a), increased ($P<0.05$) *H. contortus* yield in 1999 and 2001 (Figure 4.1.15b) and reduced ($P<0.05$) *B. bladhii* yield in 2000 (Figure 4.1.15c). Clearly, stocking rate and its interaction with pasture yield - and hence fuel to carry a fire - is an important factor in using spring burning to change pasture content.

(a)



(b)



(c)

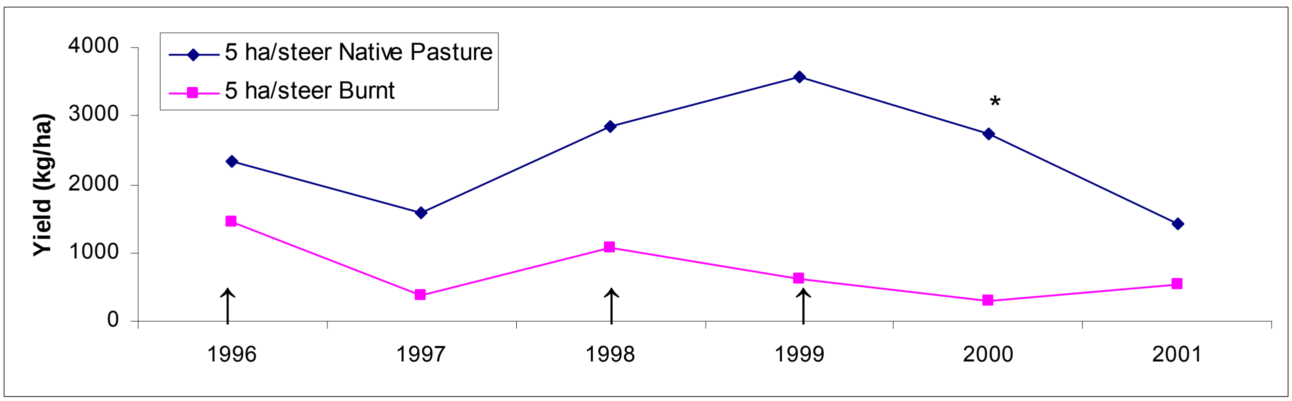


Figure 4.1.15 Changes in the yield (kg/ha) of (a) total pasture, (b) *H. contortus* and (c) *B. bladhii* with and without burning at a stocking rate of 5 ha/steer between 1996 and 2001. (Within years, asterisks indicate significant (P<0.05) differences between treatments). Arrows indicate date of burning.

The yield of *Aristida* spp. was unaffected by the supplement / burning treatments between 1988 and 1992 (Figure 4.1.16a). After the first spring burn in 1992 there was a trend (P>0.01) for the *Aristida* spp. yield to be lower following burning than in native pasture and legume oversown treatments. By 1995, this trend became significant (P<0.05) in five of the next seven years. The frequency of *Aristida* spp. was consistently lower following burning than either the native pasture or legume oversown treatments but these differences were not significant (P>0.05)(Figure 4.1.16b).

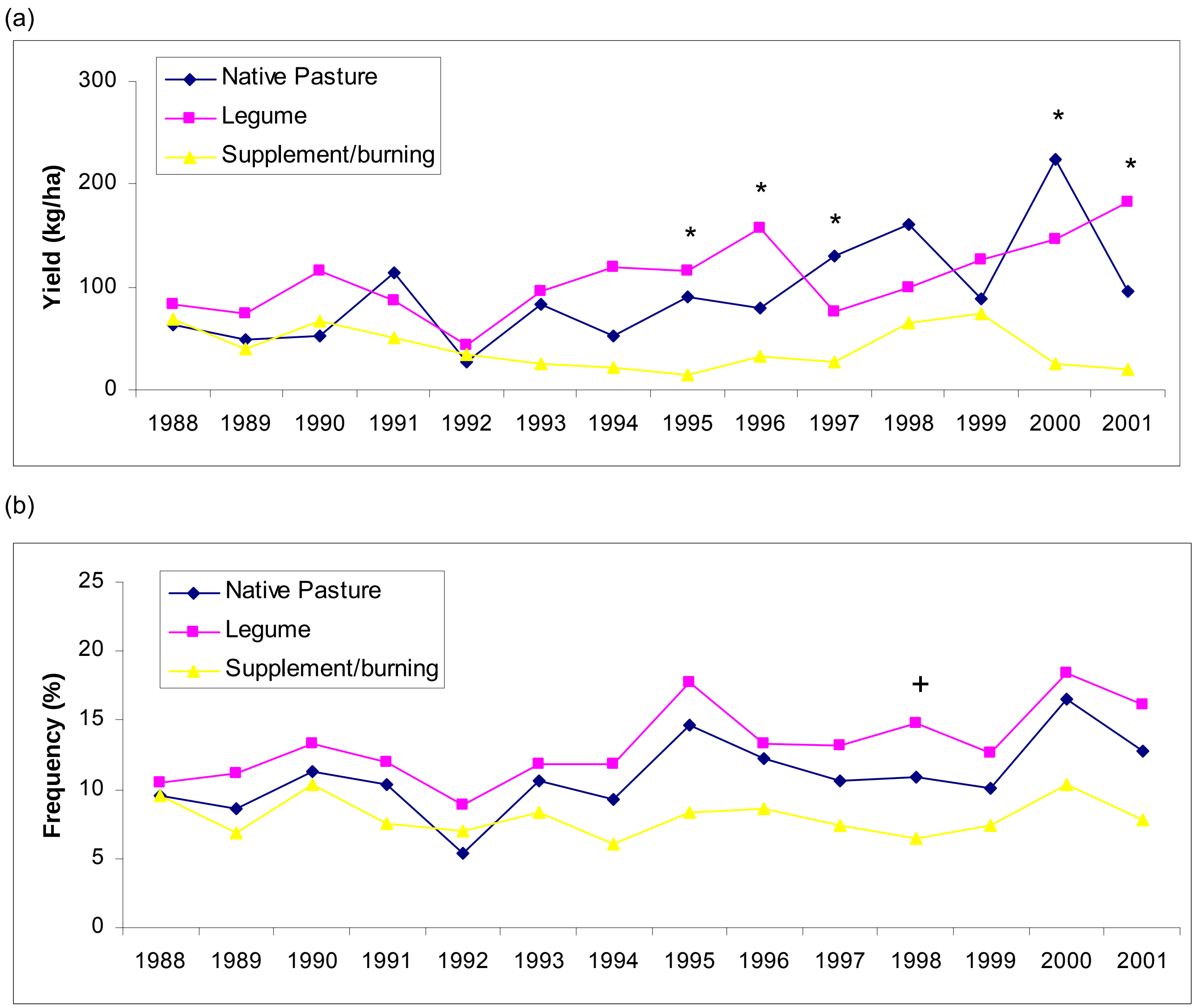
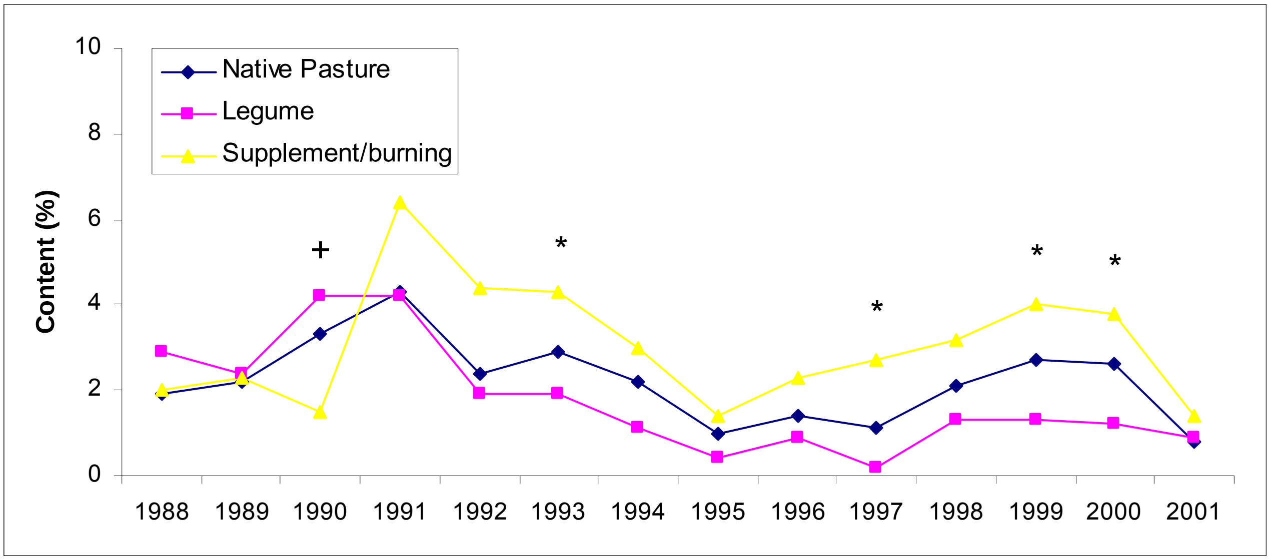


Figure 4.1.16 Changes in (a) yield (kg/ha) and (b) frequency (%) of *Aristida* spp. at 3 pasture types (averaged over 3 stocking rates (1987-1996) and 4 stocking rates (1997-2001) between 1988 and 2001. (Within years, asterisks indicate significant ($P<0.05$) and positive indicates significant ($P<0.1$) differences between treatments). (Analyses of frequency performed on angular transformed data).

The supplement / burning treatments also impacted on the content of two intermediate species. By 1993, the content of *Eragrostis* spp. had increased ($P<0.05$) in the supplement / burning treatments and this increase was also apparent in 1997 and 1999-2000 with a similar trend ($P<0.1$) evident in 1990 (Figure 4.1.17a). The content of *Chrysopogon fallax* remained unaffected by stocking rate between 1988 and 1998 but increased ($P<0.05$) in the supplement / burning treatment in 1999 and 2000 (Figure 4.1.17b).

(a)



(b)

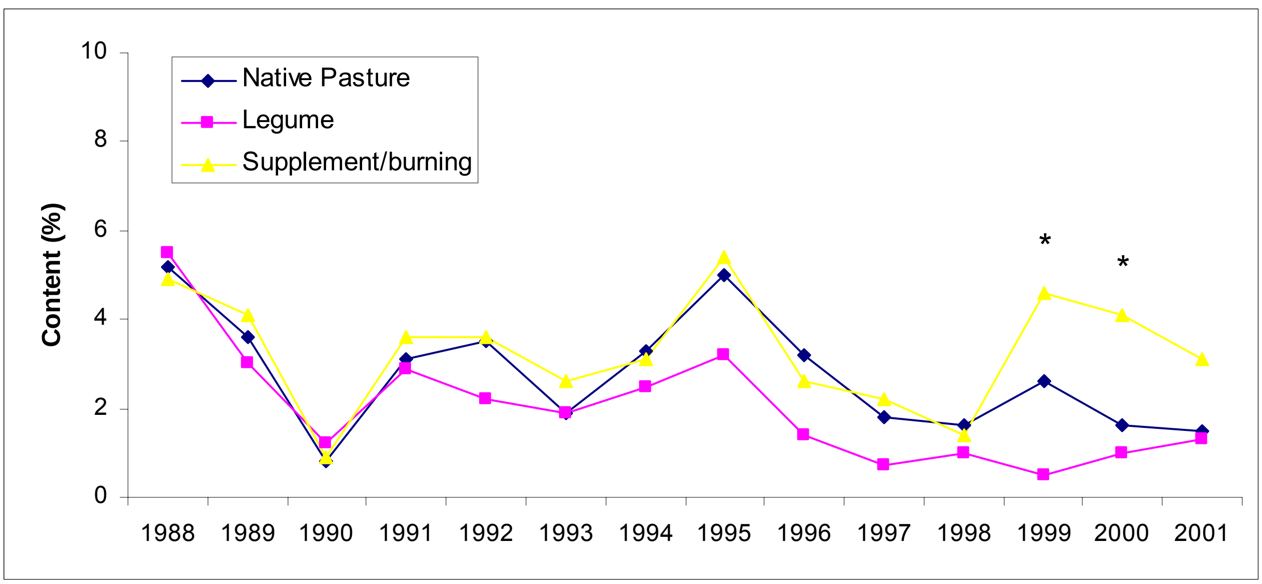
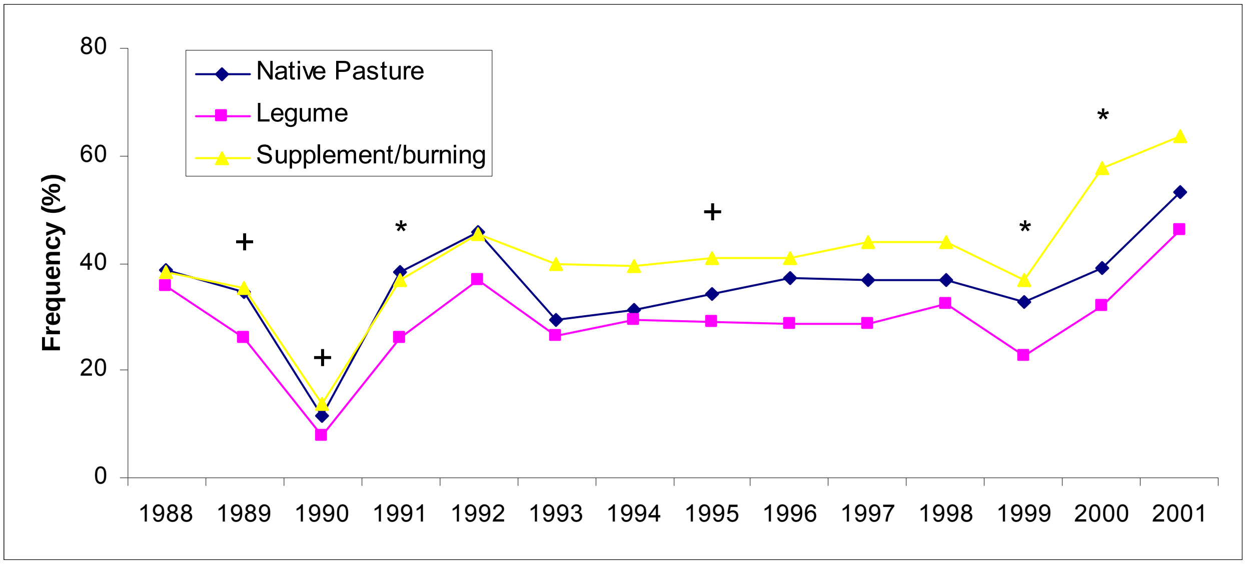


Figure 4.1.17 Changes in the content (%) of (a) *Eragrostis* spp. and (b) *Chrysopogon fallax* at 3 pasture types (averaged over 3 stocking rates (1987-1996) and 4 stocking rates (1997-2001) between 1988 and 2001. (Within years, asterisks indicate significant ($P<0.05$) and positive indicates significant ($P<0.1$) differences between treatments). (Analyses performed on angular transformed data).

The supplement / burning treatments also impacted on the frequency of two minor species. By 1991, the frequency of Sedges was reduced ($P<0.05$) by legume oversowing although, by 1999 and 2000, the frequency of these Sedges had been increased by the supplement / burning treatment (Figure 4.1.18a). This trend ($P<0.1$) was also apparent in 1995. The frequency of Other grasses was reduced ($P<0.05$) in native pasture in 1993 but by 1997 the frequency of the Other grasses was increased ($P<0.05$) by the supplement / burning treatment (Figure 4.1.18b). This impact was also apparent in 1999 and 2000.

(a)



(b)

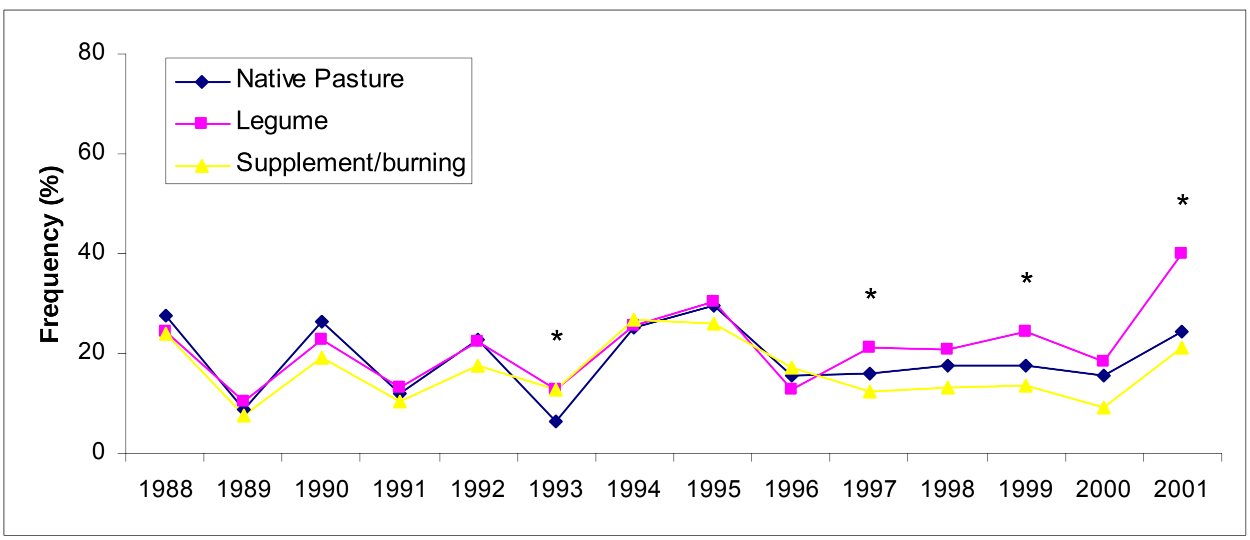
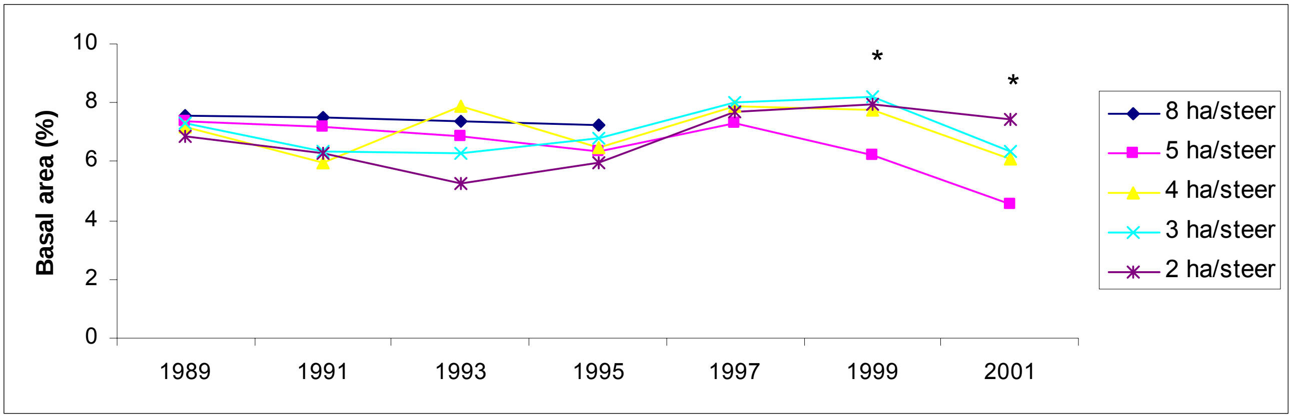


Figure 4.1.18 Changes in the frequency (%) of (a) Sedges and (b) Other grasses at 3 pasture types (averaged over 3 stocking rates (1987-1996) and 4 stocking rates (1997-2001) between 1988 and 2001 (Within years, asterisks indicate significant ($P<0.05$) and positive indicates significant ($P<0.1$) differences between treatments). (Analyses performed on angular transformed data).

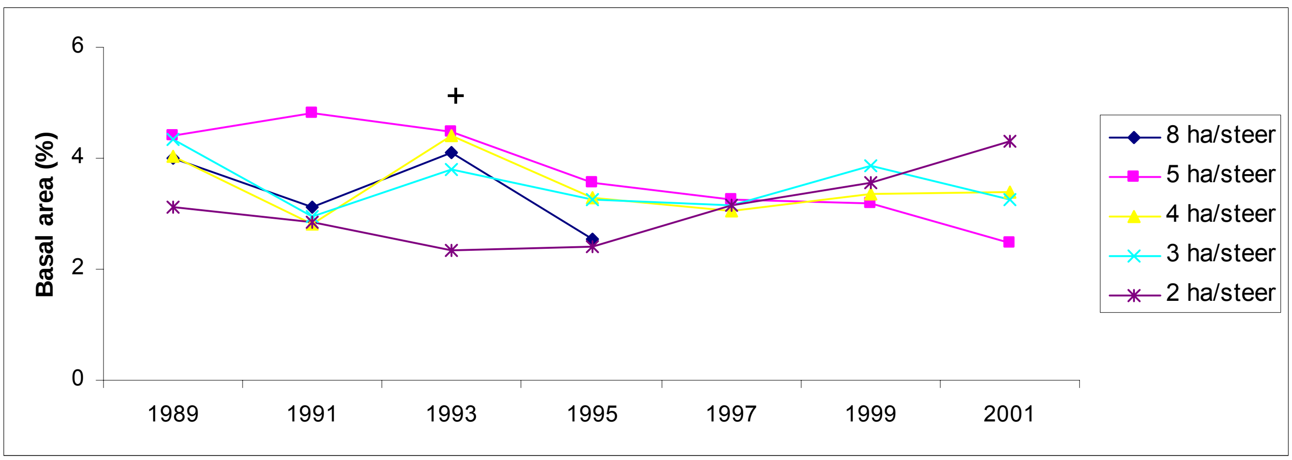
4.1.3.5 Perennial grass basal area

Grazing at different stocking rates had no impact on total basal area between 1989 and 1997 (Figure 4.1.19a) although, in 1999 and 2001, grazing at 5 ha/steer did reduce ($P<0.05$) total basal area. There were no differences ($P>0.05$) in the basal area of the decreaser species (*H. contortus* and *B. bladhii*) as a result of stocking rate although there was a trend ($P<0.1$) in 1993 for the heavy stocking rate to reduce the basal area of these species (Figure 4.1.19b). After 1991, the basal area of increaser species (*B. decipiens, C. divaricata and Eragrostis* spp.) was consistently higher at the 2 ha/steer but these differences were significant (P<0.05) only in 2001 (Figure 4.1.19c). There was no impact of stocking rate apparent on any of the individual increaser species *B. decipiens, C. divaricata* or *Eragrostis* spp.

(a)



(b)



(c)

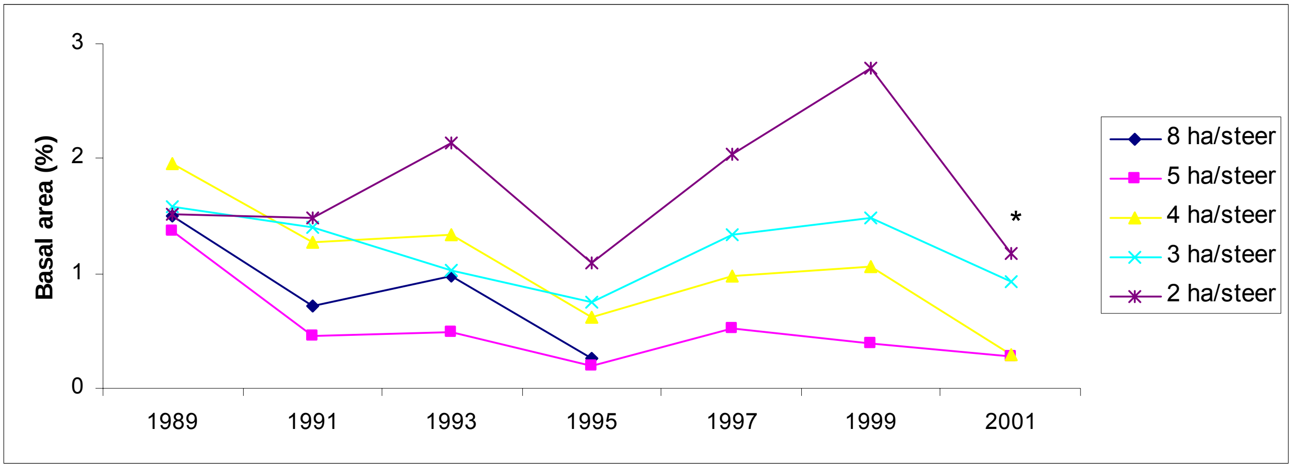


Figure 4.1.19 Changes in the basal area (%) of (a) total perennial grasses, (b) Decreaser perennial grasses and (c) Increaser perennial grasses at 5 stocking rates (1988 and 1995) and 4 stocking rates (1997 and 2001. (Within years, asterisks indicate significant ($P<0.05$) and positive indicates significant ($P<0.1$) differences between treatments).

Analyses of basal area in 1995 indicated no clear impact of either stocking rate or pasture type on this variable. Nevertheless, there was a trend ($P<0.1$) for the basal area of decreaser species to be higher at 4 ha/steer compared with that at 2 ha/steer while the reverse situation occurred for the basal area of increaser species (Figure 4.1.20).

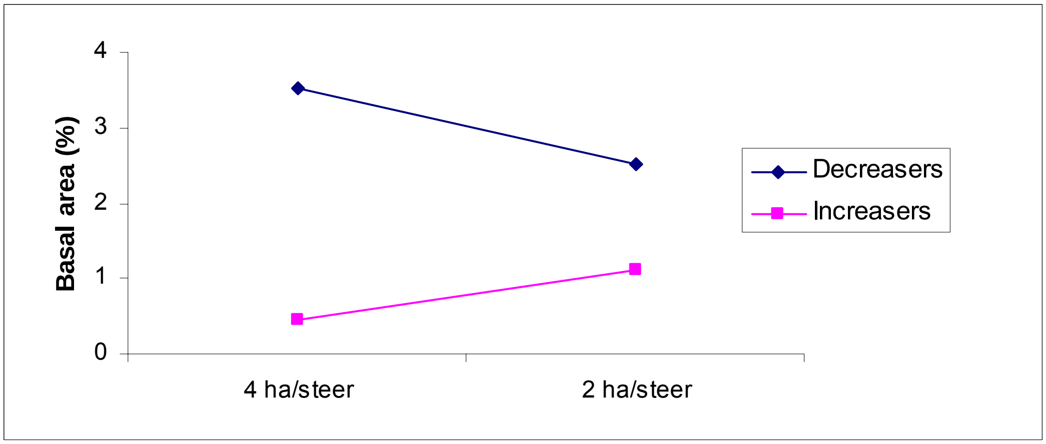


Figure 4.1.20 Basal area (%) of Decreaser and Increaser perennial grasses at 2 stocking rates (ha/steer) in 1995 at Galloway Plains.

By 2001, the basal areas of total, decreaser and increaser species were all higher ($P<0.05$) at 2 ha/steer than at 5 ha/steer (Figure 4.1.21a). Of the individual perennial grass species, the basal area of both *B. bladhii* and *B. decipiens* were also both higher ($P<0.05$) at 2 ha/steer than at 5 ha/steer and there was a similar trend ($P<0.1$) for *C. divaricata* (Figure 4.1.21b). Therefore, the high total basal area evident in 1999 and 2001 at 2 ha/steer compared with that at 5 ha/steer (Figure 4.1.19a) reflected the high contribution of increaser species rather than a lesser contribution of decreaser grasses.

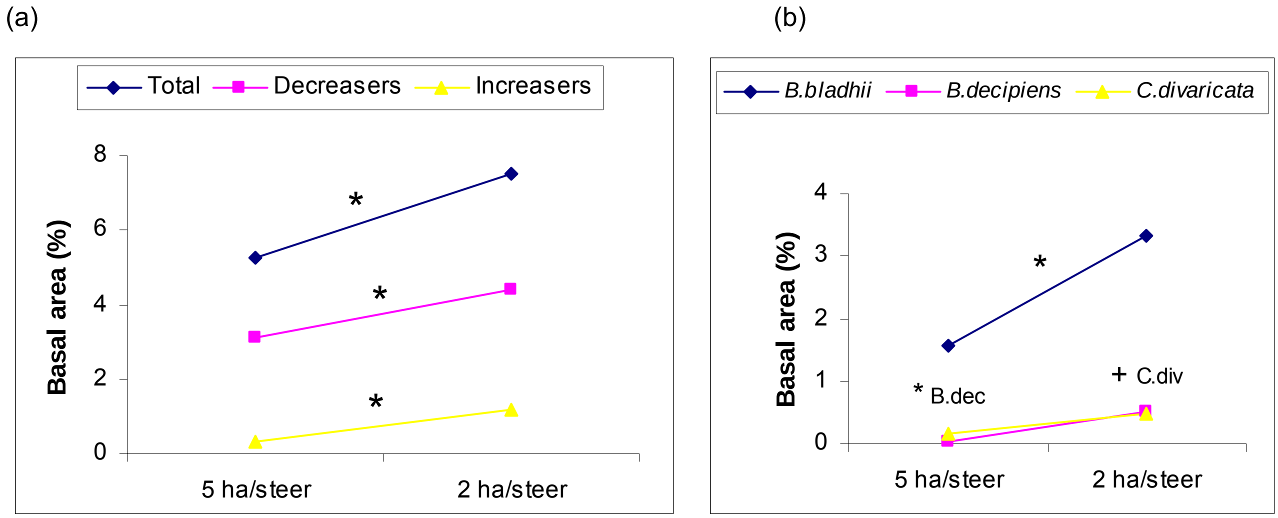


Figure 4.1.21 Basal area (%) of (a) Total, Decreaser and Increaser and (b), *B. bladhii, C. divaricata* and *Eragrostis* spp. perennial grasses at 2 stocking rates (ha/steer) in 2001 at Galloway Plains. (Asterisks indicate significant (P<0.05) and positive indicates significant (P<0.1) differences between treatments).

4.1.3.6 Population dynamics of *H. contortus*

4.1.3.6.1 Plant turnover

For the 13 years of recording the original 8 treatments, a total of 6235 *H. contortus* plants were recorded — 946 original plants in 1988 and 5289 seedlings recruited between 1989 and 2001. An additional 2416 plants — 222 original plants and 2194 seedlings — were recorded between 1996 and 2001 in the additional, burnt at 5 ha/steer treatment. Between 1988 and 2001, mean turnover rate for plant number was 94.7% while the mean turnover rate for basal area was 95.9%. There were no differences (P>0.05) in plant turnover due to either stocking rate or pasture type (Table 4.1.3).

Table 4.1.3 Turnover[1] of plant number and basal area of *H. contortus* between 1988 and 2001 in relation to four native pasture stocking rates and three pasture types.

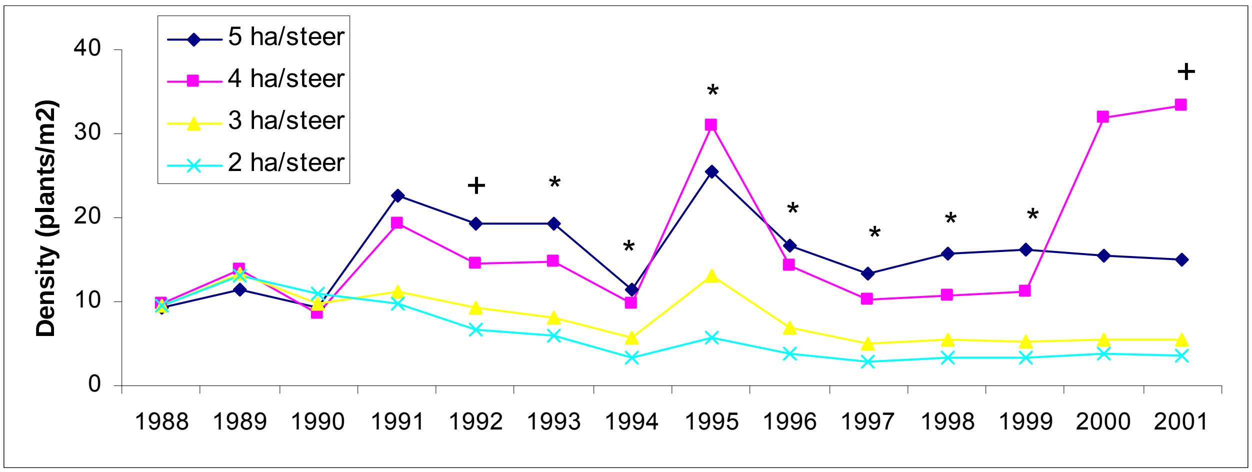
Variable	Treatment	Plant number	Basal area
Stocking rate	5 ha/steer	89.0	89.0
	4 ha/steer	100.0	100.0
	3 ha/steer	94.5	94.5
	2 ha/steer	95.9	95.9
Pasture type	Native pasture	95.7	97.2
	Legume	96.7	96.4
	Supplement / burning	95.7	97.5

[1] Plant turnover for plant number and basal area was calculated as 1 minus the fraction of the population not turning over during the period of the study expressed as a percentage (after O'Connor 1994). The fraction not turning over was the number of individual plants or basal area present in 1988 and still present in 2001.

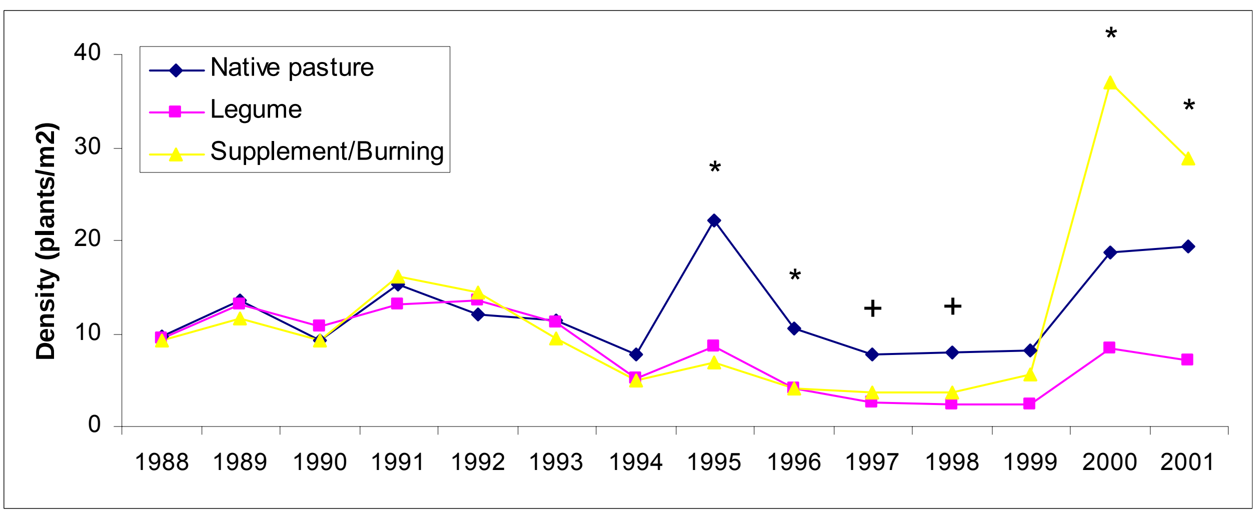
4.1.3.6.2 Changes in plant density and frequency

Between 1988 and 2001, the density of *H. contortus* showed an increase at 5 and 4 ha/steer and a decline at 3 and 2 ha/steer (Figure 4.1.22a). Grazing at the four native pasture stocking rates resulted in differences ($P<0.05$) in density between 1993 and 1999 and this trend ($P<0.1$) was also apparent in 1992 and 2001. In 1995 and 1996, *H. contortus* density was higher ($P<0.05$) in native pasture compared with legume oversown and supplement / burning treatments and this trend ($P<0.1$) was also apparent in 1997 and 1998. There was a substantial increase in density in 2000 in the supplement / burning treatment following the 1999 spring burning (Figure 4.1.22b). A pasture type x stocking rate interaction was significant ($P<0.05$) in 2000 and 2001 when density was highest in the 4 ha/steer, supplement / burning treatment (Figure 4.1.22c). These differences in density resulted from changes in both seedling recruitment and plant survival (see below).

(a)



(b)



(c)

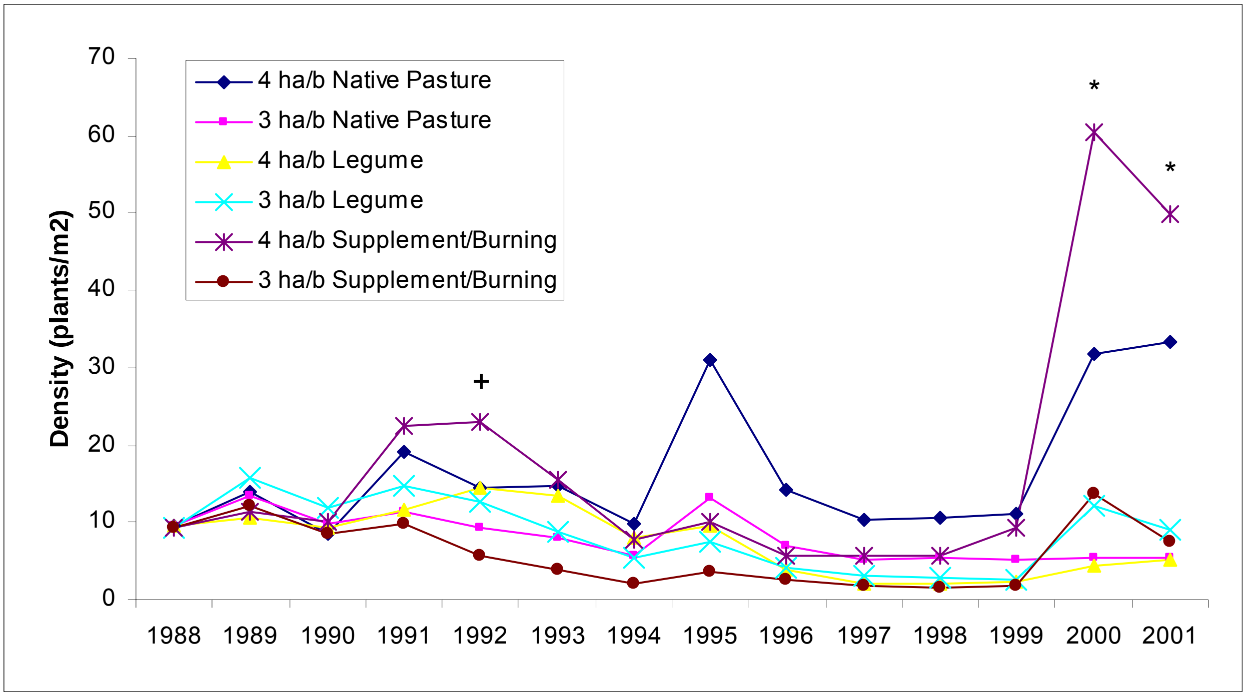
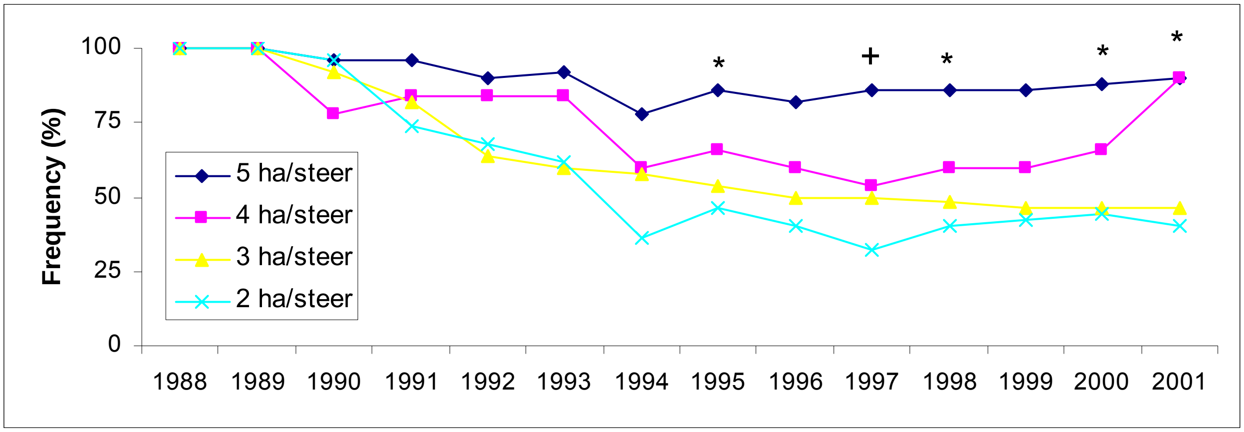


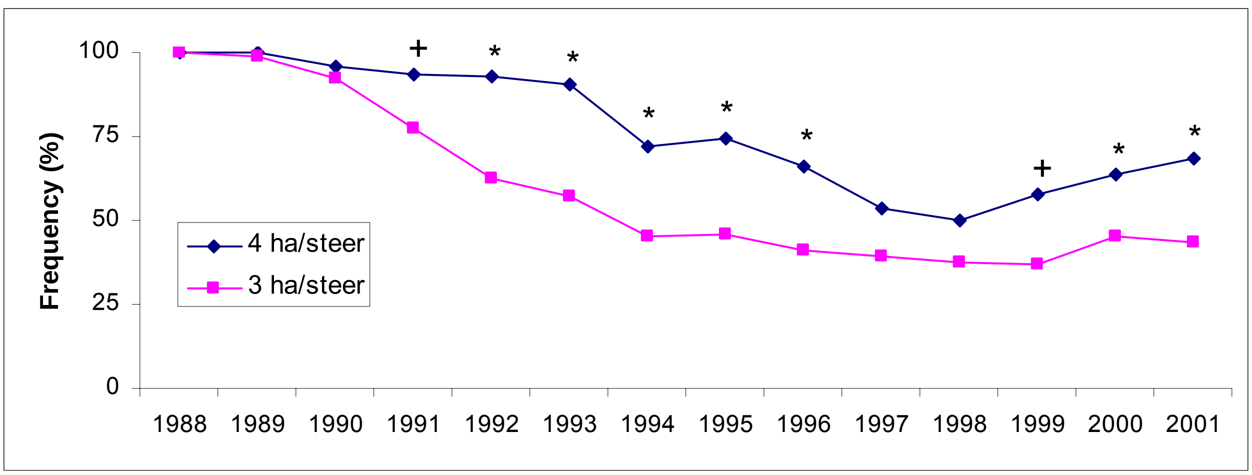
Figure 4.1.22 Changes in the density (plants/m^{-2}) of *H. contortus* at (a) 4 native pasture stocking rates, (b) 3 pasture types (data averaged over 2 stocking rates) and (c) 3 pasture types x 2 stocking rates interaction in autumn between 1988 and 2001. (Within years, asterisks indicate significant (P<0.05) and positive indicates significant (P<0.1) differences between treatments).

The frequency of *H. contortus* in the permanent quadrats declined in all treatments between 1988 and 2001. This decline was greater (P<0.05) in 1995 at the two heavy compared with the two light stocking rates in native pasture. These differences occurred also in 1998 and 2000-2001 while this trend (P<0.1) was also apparent in 1998 (Figure 4.1.23a). The stocking rate x pasture type interaction on *H. contortus* frequency was significant (P<0.05) only in 2001 although the stocking rate impact was significant (P<0.05) from 1991 until 1996 and again in 2000 and 2001 (Figure 4.1.23b) while the pasture type impact was significant (P<0.05) in 2000 and 2001 (Figure 4.1.23c).

(a)


100
75
50
25
0
Frequency (%)
5 ha/steer
4 ha/steer
3 ha/steer
2 ha/steer
*
+
*
*
*
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

(b)


100
75
50
25
0
Frequency (%)
4 ha/steer
3 ha/steer
+
*
*
*
*
*
+
*
*
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

(c)

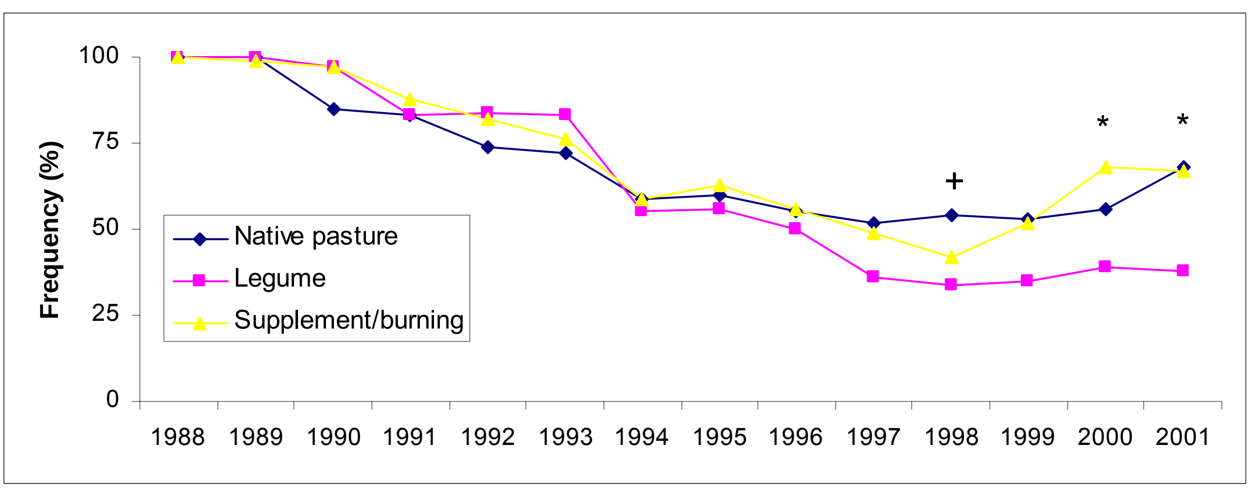
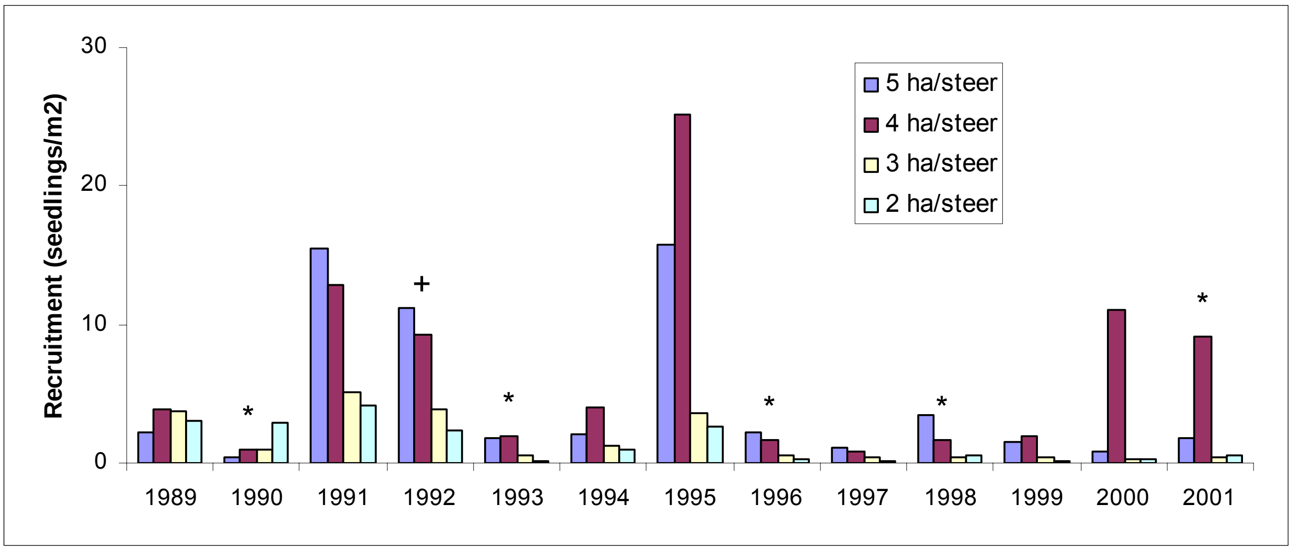

100
75
50
25
0
Frequency (%)
Native pasture
Legume
Supplement/burning
+
*
*
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

Figure 4.1.23 Changes in the frequency (%) of *H. contortus* in permanent quadrats in autumn between 1989 and 2001 in relation to (a) four stocking rates in native pasture and (b) two stocking rates (averaged across pasture types) and (c) three pasture types (averaged across two stocking rates). (Within years, asterisks indicate significant (P<0.05) and positive indicates significant (P<0.1differences between treatments).

Seedling recruitment of *H. contortus* in 1990 was highest (P<0.05) at 2 ha/steer but this situation was reversed in 1993, 1996, 1998 and 2001 when recruitment was higher (P<0.05) at 5 and 4 ha/steer than at 3 and 2 ha/steer (Figure 4.1.24a). Few differences in seedling recruitment occurred in response to pasture type although recruitment was higher (P<0.05) in the supplement / burning treatment in 2000 (Figure 4.1.24b).

(a)



(b)

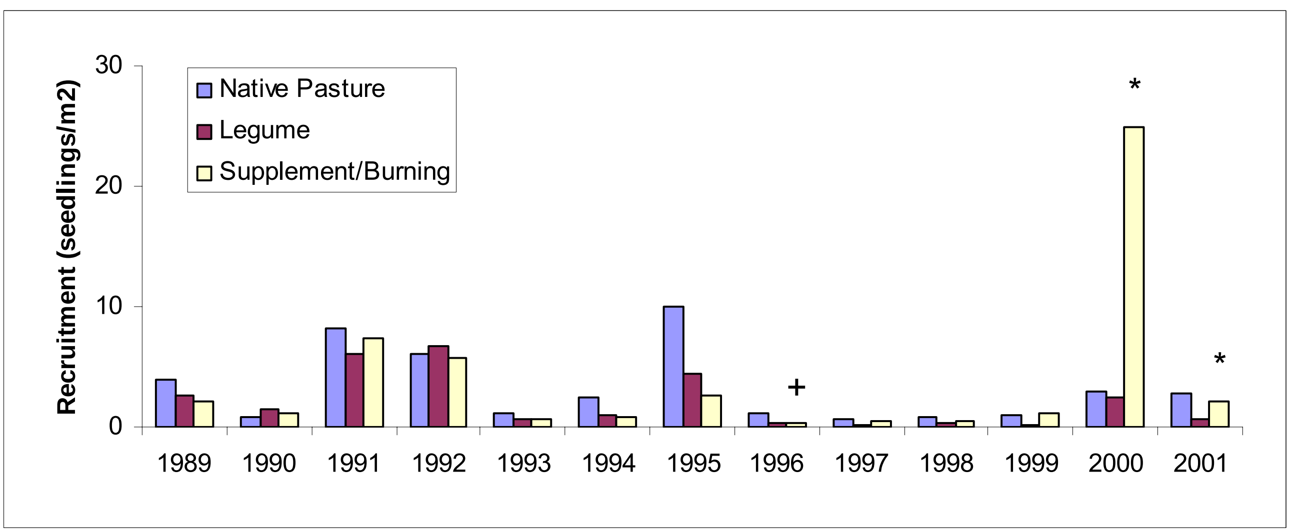
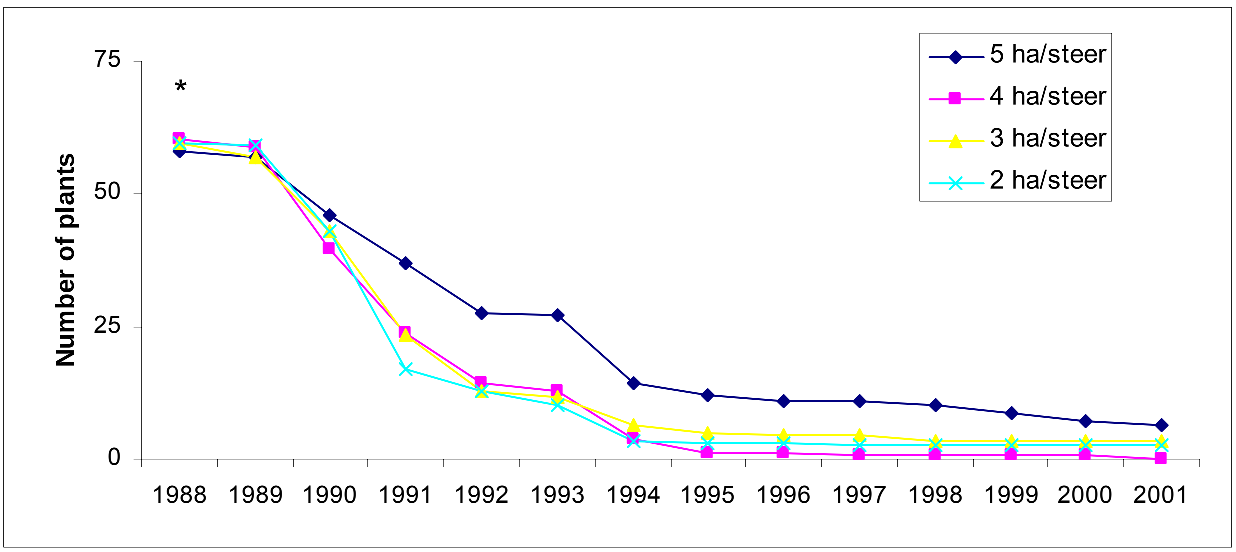


Figure 4.1.24 Changes in seedling recruitment (seedlings/m^2) of *H. contortus* at (a) four stocking rates in native pasture and (b) three pasture types (averaged across two stocking rates) in autumn between 1989 and

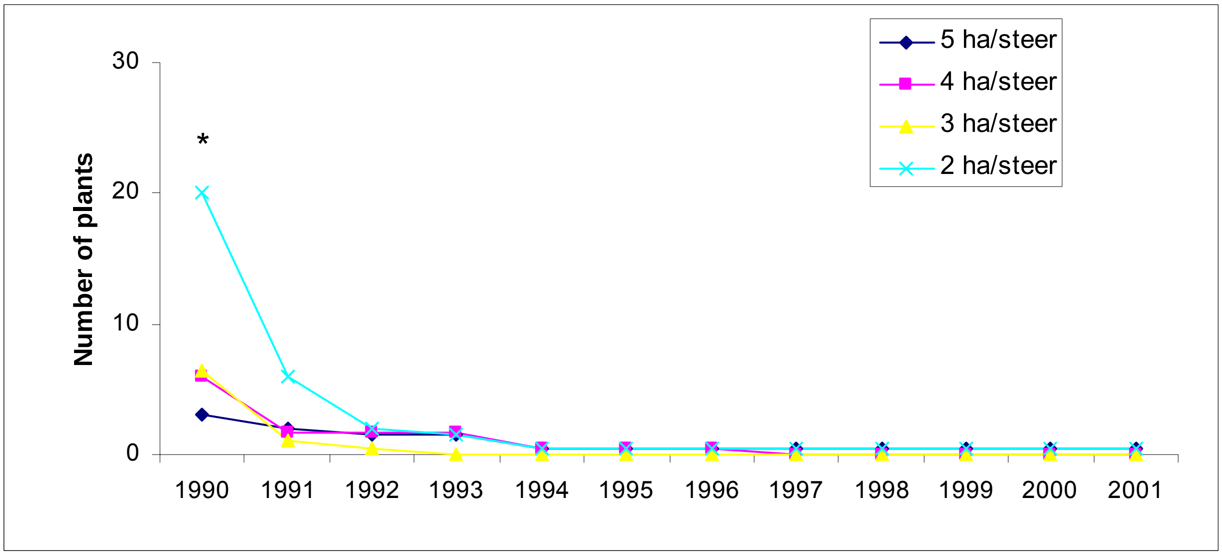
2001. (Within years, asterisks indicate significant (P<0.05) and positive indicates significant (P<0.1) differences between treatments). (Analyses performed on logarithmic transformed data).

The survival of the original *H. contortus* plants was influenced (P<0.05) by a stocking rate x pasture interaction with survival highest at 5 ha/steer in native pasture and lowest at 2 and 4 ha/steer both in native pasture (Figure 4.1.25a). Survival of seedling cohorts for the years 1990, 1991 and 1992 were influenced (P<0.05) by stocking rate (Figure 4.1.25b, c, d). For the 1990 cohort, more seedlings were recruited at 2 ha/steer but these seedlings had lower survival than those at the other three stocking rates. Commencing in 1991, seedling recruitment was consistently higher at 4 and 3 ha/steer but these 1991 seedlings had lower survival than those at the heavier two stocking rates. A similar situation occurred with the 1992 seedling cohort where differences (P<0.05) in survival reflected the higher seedling recruitment at the 5 and 4 ha/steer than at the 3 and 2 ha/steer treatments.

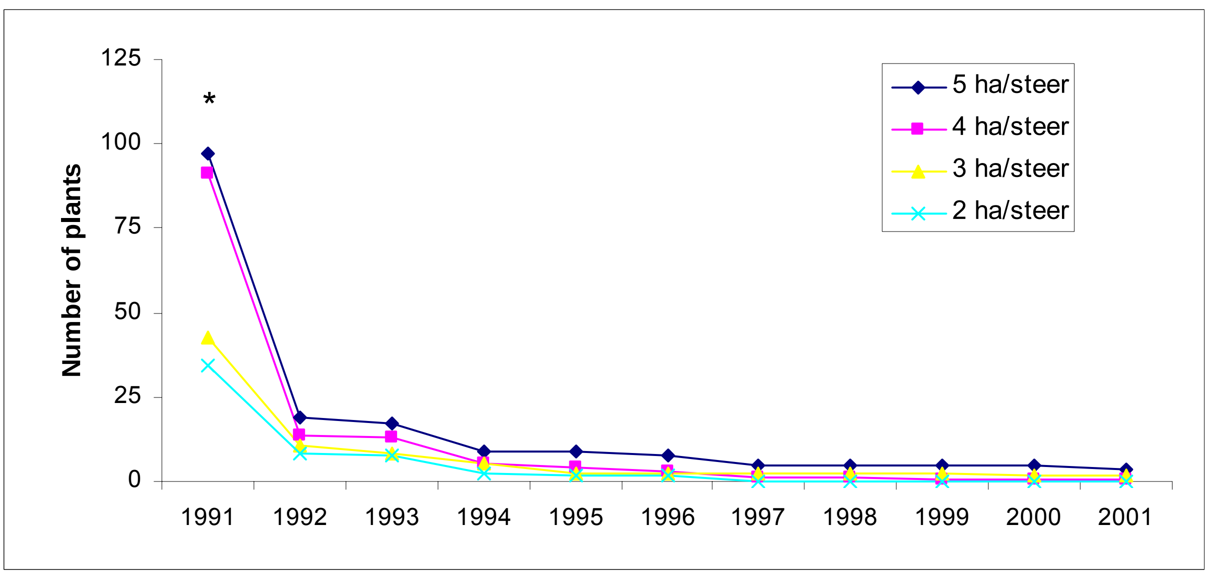
(a)



(b)


Number of plants
30
20
10
0
*
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
5 ha/steer
4 ha/steer
3 ha/steer
2 ha/steer

(c)


Number of plants
125
100
75
50
25
0
*
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
5 ha/steer
4 ha/steer
3 ha/steer
2 ha/steer

(d)

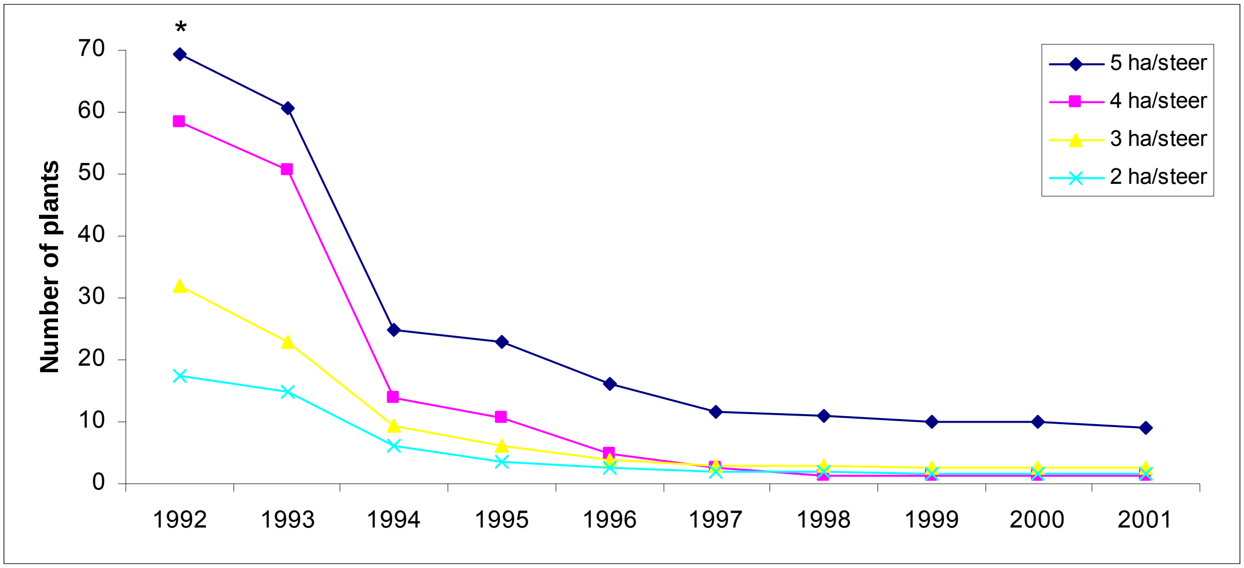
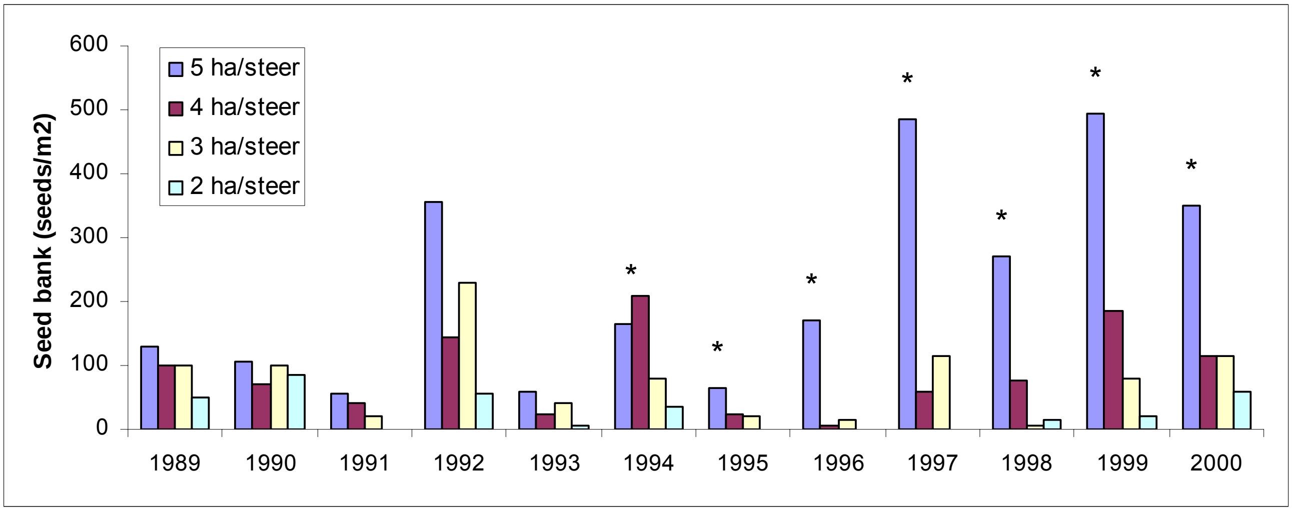


Figure 4.1.25 Changes in the survival (number of plants) of *H. contortus* plants between 1988 and 2001 for (a) original plants, (b) 1990 seedlings, (c) 1991 seedlings and (d) 1992 seedlings. (Asterisks indicate, significant (P<0.05) differences in survival overtime between treatments).

The large differences in *H. contortus* seedling recruitment mirrored differences in the level of seed present in the soil seed bank (Figure 4.1.26). Clearly, heavy grazing pressure reduces *H. contortus* seed production which, in turn, reduces the size of the soil seed bank and this results in reduced seedling recruitment. Eventually this reduced recruitment results in lower plant density as the existing mature plants die and are not replaced by seedlings plants. Pasture type did not affect soil seed bank.

(a)



(b)

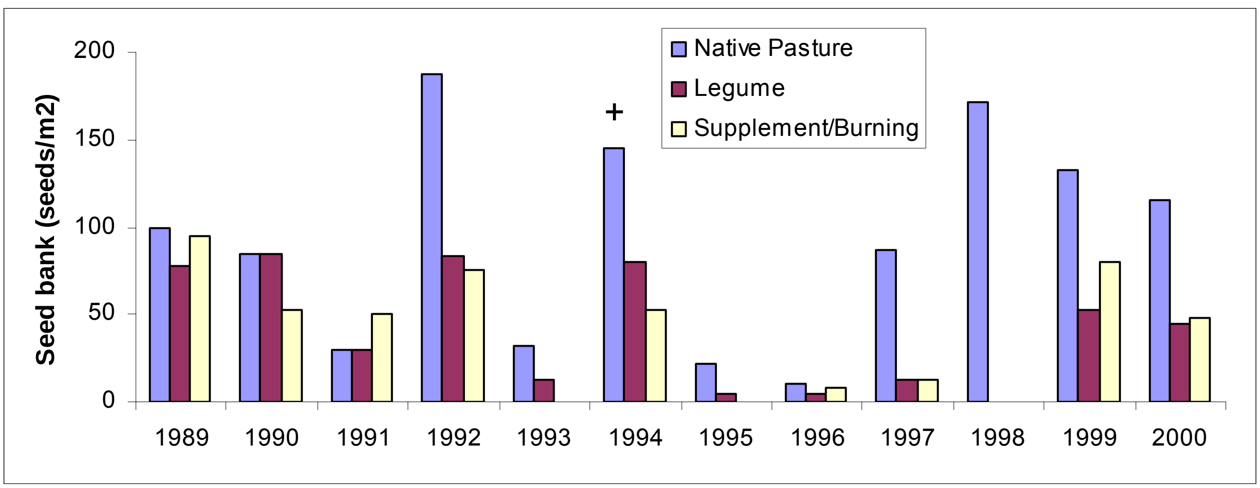


Figure 4.1.26 Changes in the soil seed bank (seeds/m^2) of *H. contortus* in autumn between 1989 and 2001 in relation to (a) four stocking rates in native pasture and (b) three pasture types (averaged across two stocking rates). (Within years, asterisks indicate significant ($P<0.05$) and positive indicates significant ($P<0.1$differences between treatments).

The mechanism by which burning promotes *H. contortus* density is clearly demonstrated by comparing the soil seed bank in spring 1999 prior to burning (Figure 4.1.27a) and seedling recruitment in the subsequent autumn (Figure 41.27b). Soil seed banks in spring 1999 were 500 seeds/m^2 in both the native pasture and burning treatments at 5 ha/steer treatments and were reduced progressively with increasing stocking rate to be 50 seeds/m^2 at 2 ha/steer. Spring burning directly stimulates *H. contortus* seed germination and this is demonstrated by the substantially greater seedling recruitment at 5 ha/steer in the burnt compared with the unburned, native pasture treatments.

(a) (b)

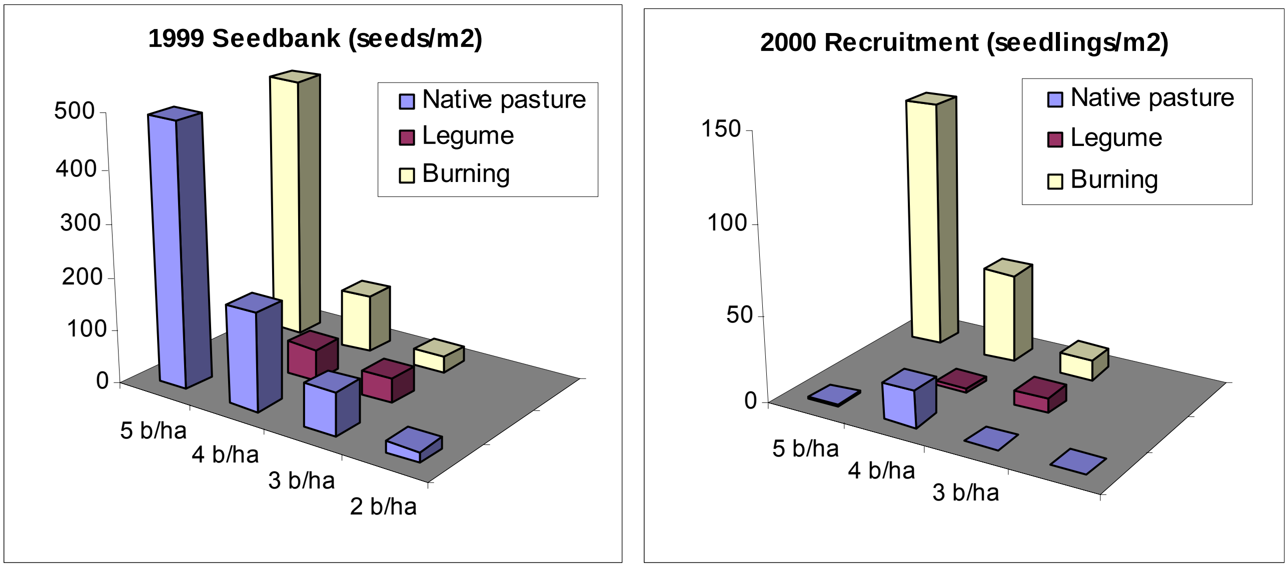
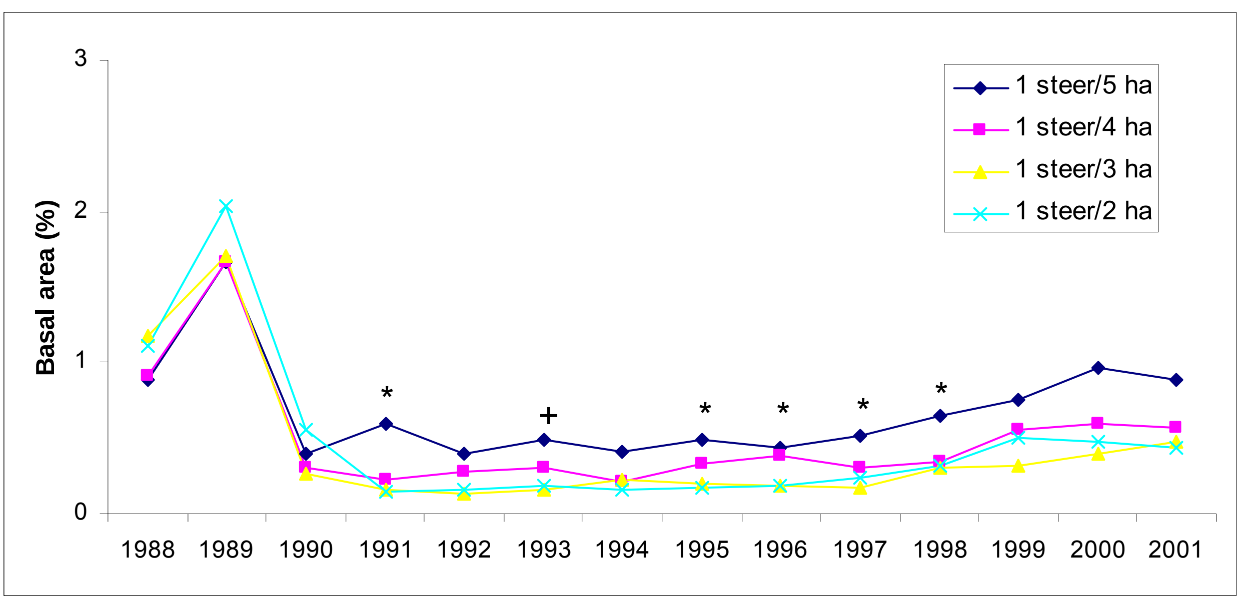


Figure 4.1.27 Impacts of fire on (a) seed bank (seeds/m^2) and (b) recruitment (seedlings/m^2) in native pasture, legume oversown and supplement / burnt pasture between 1999 and 2000.

4.1.3.6.3 Basal area of *H. contortus*

In native pasture, the basal area of *H. contortus* was reduced ($P<0.05$) by heavy stocking rates in 1991 and during the period 1995 to 1999 (Figure 4.1.28a) There was a stocking x pasture type interaction ($P<0.05$) in 1996 when basal area was highest at 4 ha/steer in native pasture and also in 2001 when basal area was highest at 4 ha/steer in the supplement / burning treatment (Figure 4.1.28b).

(a)



(b)

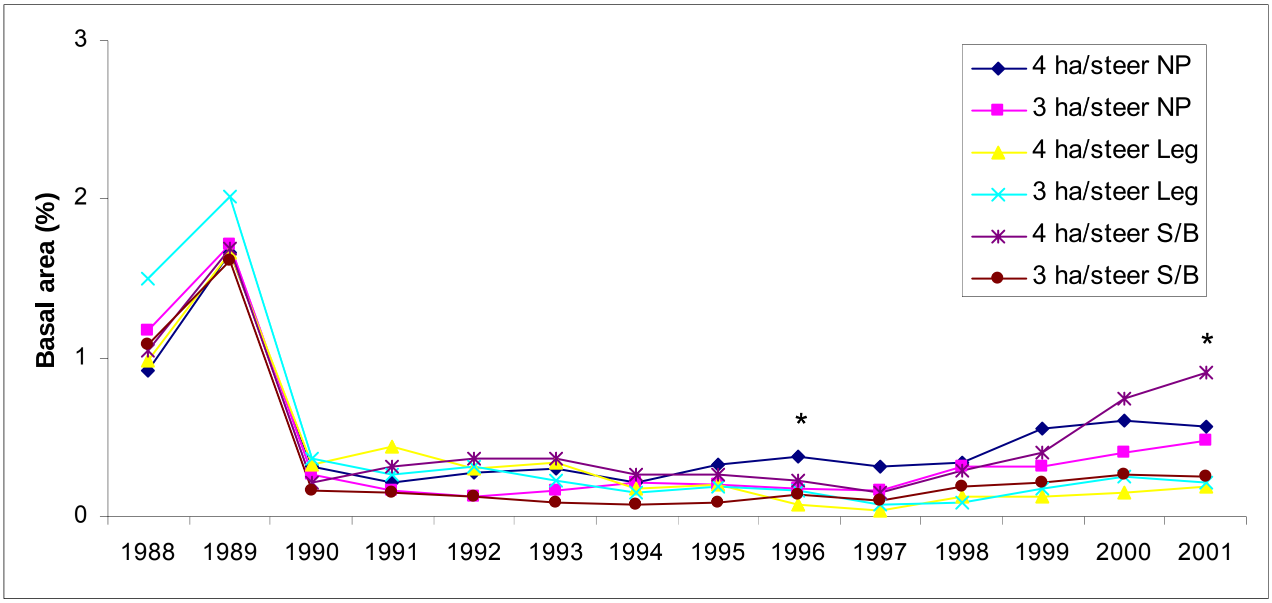
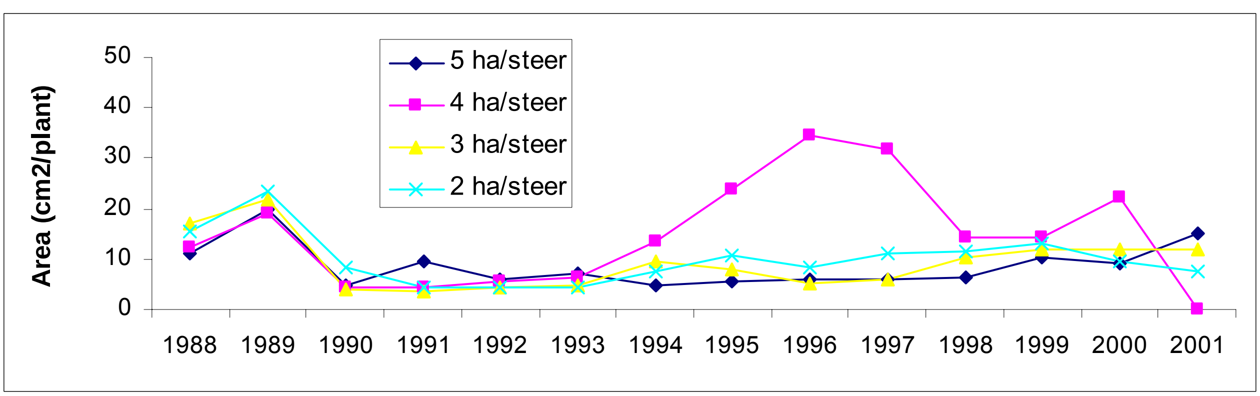


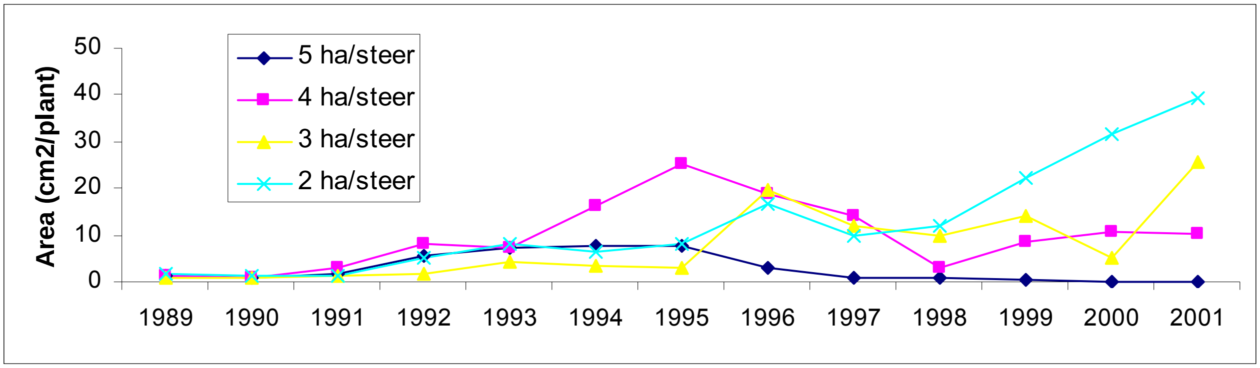
Figure 4.1.28 Changes in the basal area (%[2]) of *H. contortus* at (a) 4 native pasture stocking rates, (b) and 2 stocking rates at 3 pasture types in autumn between 1988 and 2001. (Within years, asterisks indicate significant (P<0.05) and positive indicates significant (P<0.1) differences between treatments).

Changes in basal area of *H. contortus* in the permanent quadrats (Figure 4.1.28) resulted from changes in plant density because there were few differences in plant size (Figure 4.1.29). For the original 1988 plants there was no major changes in size between 1988 and 2001 and there were no differences (P>0.05) between the four stocking rates (Figure 4.1.29a). Plants from the 1989 (Figure 4.1.29b), 1991 (Figure 4.1.29c) and 1992 (Figure 4.1.29d) seedling cohorts all increased in area with time and stocking rate influenced (P<0.05) size only once in 1996 for the 1991 plants. Plants from the 1994 seedling cohorts were larger (P<0.05) in 1994 and 1999 at 2 ha/steer than at the other three stocking rates (Figure 4.1.29e). Similarly, plants from the 1995 seedling cohort were larger (P<0.05) in 1996 at 2 ha/steer than at the other three stocking rates (Figure 4.1.29f).

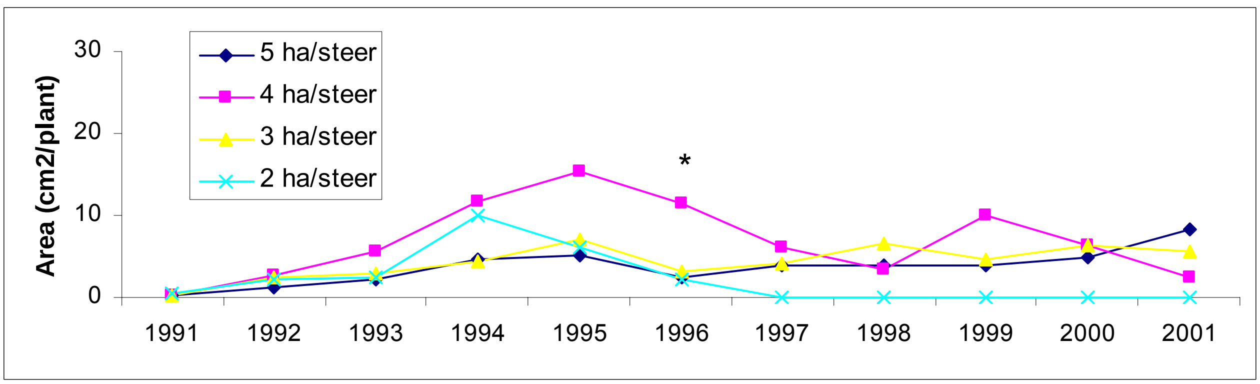
(a)



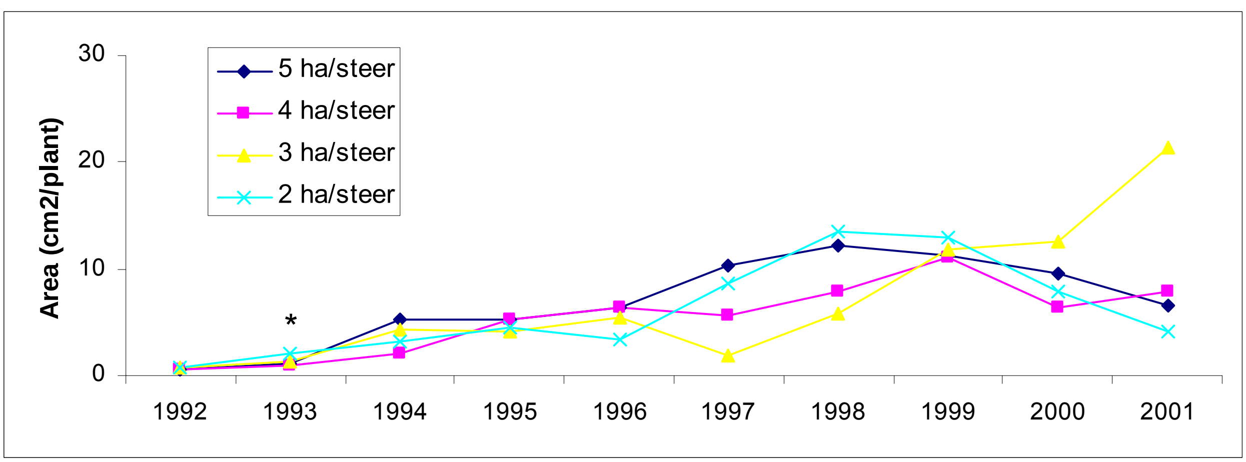
(b)


Area (cm2/plant)
50
40
30
20
10
0
5 ha/steer
4 ha/steer
3 ha/steer
2 ha/steer
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

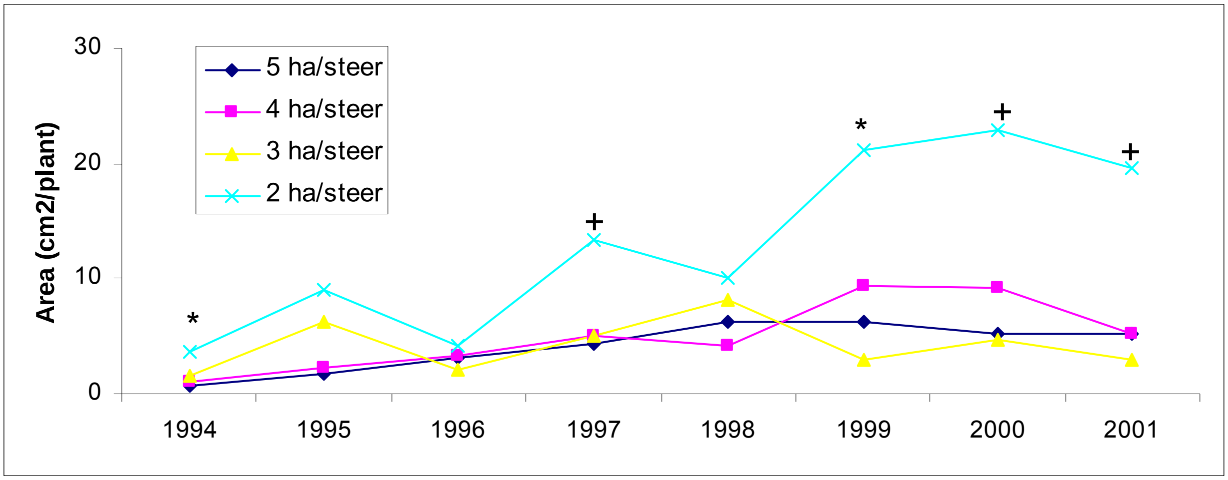
(c)


Area (cm2/plant)
30
20
10
0
5 ha/steer
4 ha/steer
3 ha/steer
2 ha/steer
*
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

(d)


Area (cm2/plant)
30
20
10
0
5 ha/steer
4 ha/steer
3 ha/steer
2 ha/steer
*
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

(e)



(f)

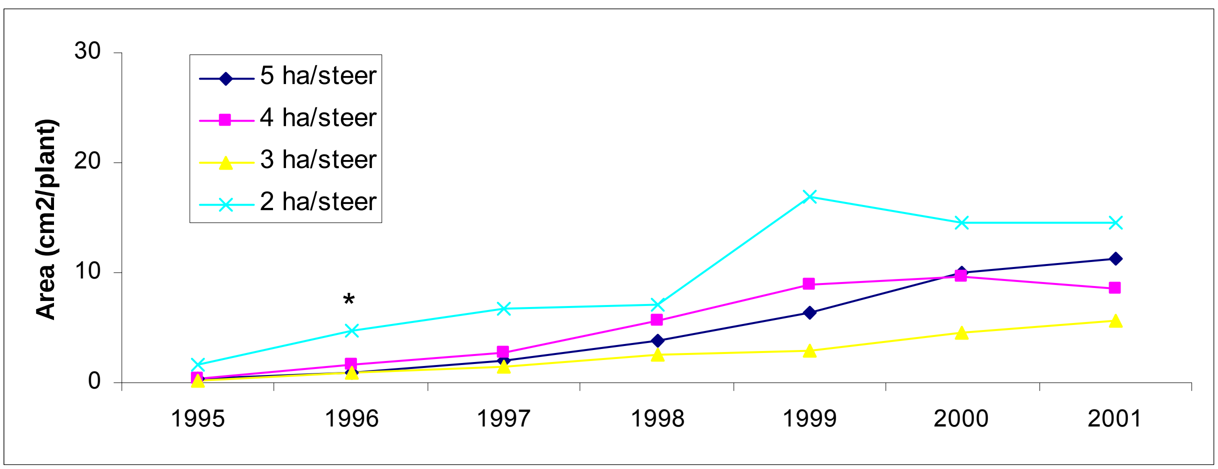
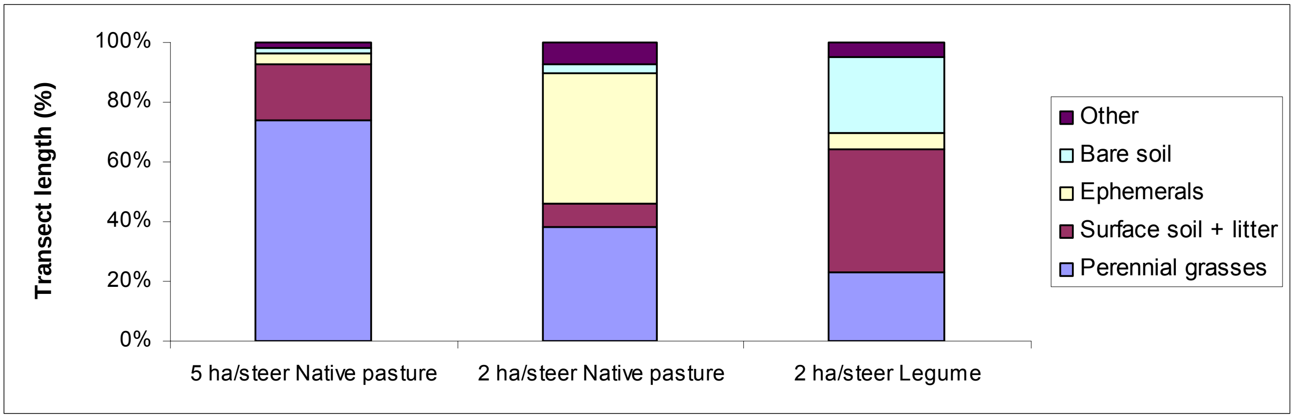


Figure 4.1.29 Changes in plant size (cm^2/plant) of *H. contortus* plants in relation to four stocking rates in native pasture for (a) the original plants, (b) the 1989 seedling cohort, (c) the 1991 seedling cohort, (d) the 1992 seedling cohort, (e) the 1994 seedling cohort and (f) the 1995 seedling cohort between 1988 and 2001. (Asterisks indicate significant ($P<0.05$) differences in survival overtime between treatments).

4.1.3.7 Landscape function analysis

The proportion of transect length occupied by perennial grasses was highest at 5 ha/steer in native pasture and decreased ($P<0.1$) to be intermediate at 2 ha/steer in native pasture and was lowest at 2 ha/steer in legume oversown pasture (Figure 4.1.30a). The proportion of transect length occupied by ephemerals was higher ($P<0.01$) at 2 ha/steer in native pasture than at the 2 other treatments while proportion of transect length occupied by bare soil was higher ($P<0.01$) in the legume oversown than in the other 2 treatments. Indices for landscape stability and landscape nutrient cycling tended to be higher at 5 ha/steer in native pasture than in the other 2 treatments but these differences were not significant ($P>0.05$). Indices for landscape infiltration were higher ($P<0.05$) at 5 ha/steer in native pasture than at either 2 ha/steer in native pasture or at 2 ha/steer in oversown legume (Figure 4.1.30b). The landscape infiltration index for the eastern replicate was also higher ($P<0.05$) than that for the western replicate.

(a)



(b)

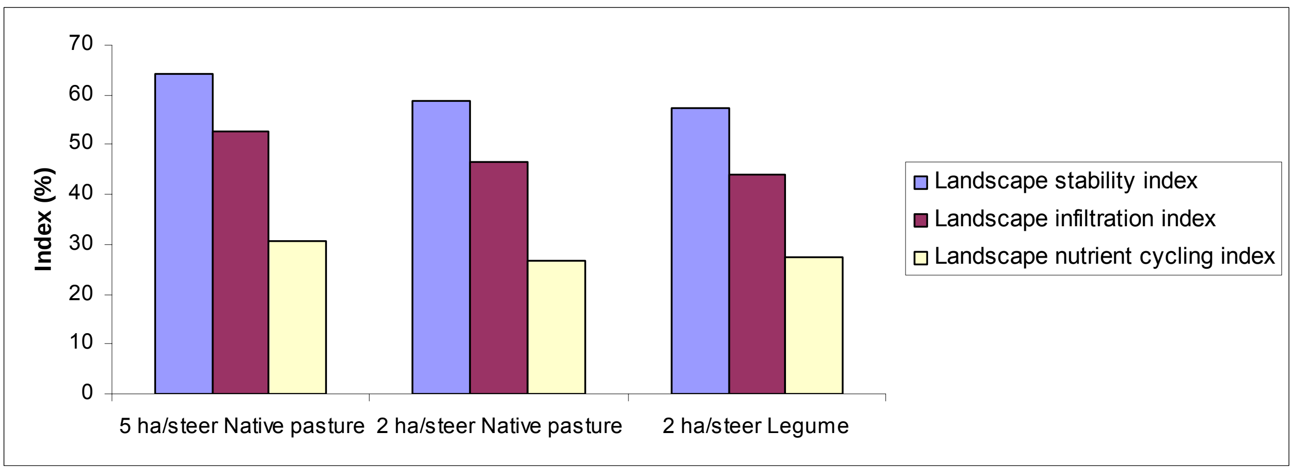


Figure 4.1.30 Mean values for (a) transect length (%) and (b) indices (%) of landscape stability, landscape infiltration landscape nutrient cycling for 3 treatments in December.

4.1.4 Discussion

4.1.4.1 Impacts of stocking rates and pasture types

Increasing stocking rate from 8 ha/steer to 2 ha/steer reduced total pasture yield and changed pasture content. Compared with stocking rate, pasture type had little impact on total pasture yield but did impact on pasture content. Increasing stocking rate in native pasture was associated with a reduction in the occurrence of *H. contortus* and an increase in the occurrence of *B. decipiens*, *C. divaricata* and *Eragrostis* spp. Oversowing legumes and supplement / burning caused changes in the occurrence of a range of species. Three important features of these results were:

- There was a lag time before the impacts of grazing treatments were reflected in changes in pasture species content. For example, differences ($P<0.05$) in the density of *H. contortus* were not apparent before 1993 and there were no differences ($P<0.05$) in the frequency of *H. contortus* after 13 years of treatment.

- Treatment impacts on *H. contortus* differed substantially when measured by the three different sampling methods (Botanal, Wheel point and Permanent quadrats). These differences probably reflect the fact that these different methods measure the pasture at two different scales – individual plant versus the community scale.
- This study was conducted throughout the driest period in recorded rainfall history and the results need to be interpreted in relation to this rainfall trend.

Despite the sequence of very dry years, grazing at stocking rates of 8, 5 and 4 ha/steer resulted in pasture utilisation of 30% or less while stocking rates of 3 and 2 ha/steer exceeded this 30% figure. From studies of a range of stocking rate and other data sources across a diverse range of land systems, McKeon *et al.* (1990) indicated that 30 % represented a long term “safe” utilisation rate. The Galloway Plains study supports this 30% utilisation figure as representing a threshold for sustainable grazing practices - all the deleterious changes in pasture content recorded occurred at stocking rates of 3 and 2 ha/steer which exceeded 30% utilisation.

Data from the landscape function analysis study support the argument that increasing stocking rate from 5 to 2 ha/steer, either with or without an oversown legume, results in reduced landscape stability. This is evidenced by:

- The replacement of perennial grass zones with bare soil or bare soil with a sparse cover of ephemeral plants.
- A decrease in the proportion of downhill slope occupied by run-on zones.
- A decrease in the infiltration index of the landscape as derived from soil surface indicators.

4.1.4.2 Measuring change in *H. contortus* using three different sampling methods

The major differences measured in the impact of the treatments on *H. contortus* probably reflect the scale at which each technique measured the pasture. At the community scale, the wheel point measured perennial grass basal area based on the number of “hits” on live perennial grass tussocks and these wheel point points were spaced at approximately 1 metre intervals across paddocks. Also at the community scale, Botanal measured species yields and occurrences in quadrats spaced approximately 40-50 meter apart. At the individual plant scale, permanent quadrats measured individually identified plants located in subjectively located permanent quadrats. These permanent quadrats were located in the “interzone” between patches where *H. contortus* plant density was high and those patches were *H. contortus* was low or absent (Wandera *et al.* 1993). At Galloway Plains, these “interzones” expanded at 5 and 4 ha/steer as *H. contortus* density increased but they contracted at 3 and 2 ha/steer as *H. contortus* density decreased. Under these circumstances, these “interzone” patches more accurately reflect changes in both plant density and frequency of *H. contortus* than if the permanent quadrats had been randomly distributed across the paddock. Similarly, the wheel point and Botanal methods assessed *H. contortus* independently of these “interzones”. Therefore, compared with the permanent quadrat method, the relative failure of the wheel point and Botanal methods to measure changes in *H. contortus* probably reflects the failure of these two community scale measurements to account for the distribution of *H. contortus* throughout the pasture.

4.1.4.3 Changes in species content in native pasture

4.1.4.3.1 Major species

At the community scale, increasing stocking rates failed to reduce the frequency of either *H. contortus* or *B. bladhii,* despite some reduction in yield of both species. This suggests that there has been little change in pasture content and indicates some degree of resilience within this *H. contortus* community. This suggestion is supported by the basal area data which indicated no change in *H. contortus* basal area. However, by 2001, the basal area of *B. bladhii* was higher at 2 ha/steer than at 5 ha/steer. In contrast, individual plant scale data provided strong evidence of a grazing impact on *H. contortus* with plant density, plant frequency and basal area all declining with increasing stocking rate.

Differences in the occurrence of *H. contortus* between the two replicates, which were located on different soil types, probably further explains why treatment differences in *H. contortus* were not statistically significant. The yield and frequency of *H. contortus* were consistently higher on the eastern replicate (duplex soil) which is more suitable for its growth than on the western replicate (infertile clay soil). At the community scale, increasing stocking rate in native pasture reduced the yield of *H. contortus* with no impact on frequency although there was some evidence of an overall decline in frequency of this species from 1988 until 2001. The reduction in *H. contortus* yield with increasing stocking rate is consistent with the diet selection studies which indicated that steers consistently selected *H. contortus* when it was available in the pasture (Section 4.3 Diet selection).

For the other decreaser perennial grass *B. bladhii*, increasing stocking rate reduced yield but not frequency at the community scale as occurred with *H. contortus*. The frequency of *B. bladhii* tended to increase between 1988 and 1989 but remained relatively constant after 1989. However, the basal area of *B. bladhii* at 2 ha/steer in 2001 was higher that at 5 ha/steer indicating that this species increased with increasing stocking rate rather than decreased as would be expected for a "decreaser" perennial grass. This anomaly is consistent with other data (Orr *et al.* 1999) suggesting that *B. bladhii* has progressively replaced *H. contortus* and indicates that *B. bladhii* is in fact an increaser in these native pastures rather than, as we originally classified, a decreaser species. An alternative suggestion is that this replacement of *H. contortus* by *B. bladhii* may merely reflect the absence of burning which is important in maintaining *H. contortus*. This failure of increasing stocking rate to reduce the frequency of *B. bladhii* is consistent with the diet selection studies which indicated that this species was selected only when more preferred species were not available in the pasture (Section 4.3 Diet selection).

The highest yields of *Aristida* spp. at Galloway Plains occurred at the lightest stocking rate. This finding is consistent with results from Glenwood in southern Queensland *H. contortus* pastures indicating that these species have their highest plant density and basal area under the lightest stocking rate (Orr *et al.* 2004c). Diet selection studies (Section 4.3 Diet selection) indicated that *Aristida* spp. was not preferred by steers and reached a maximum value of only 2% of the diet in 1994 and there was no effect of stocking rate on the *Aristida* spp. content of the diet. The reduction in the occurrence of *Aristida* spp. with increasing stocking rate indicates that this species is a decreaser species at Galloway Plains and also at Glenwood.

4.1.4.3.2 Intermediate and minor species

Increasing stocking rates in native pasture increased the occurrence of the intermediate species *B. decipiens*, *C. divaricata* and *Eragrostis* spp. and these increases are consistent with other reports of increased occurrence with increasing stocking rates (Anderson 1993). The increased occurrence of both *C. divaricata* and *Eragrostis* spp. in the pasture with increasing stocking rate was also reflected in an increase in the occurrence of these species in the diets selected by steers (Section 4.3 Diet selection). Of the minor species, the occurrence of *Panicum* spp. was reduced with increasing stocking rate whereas the occurrences of *Sporobolus* spp. and *Tragus australianus* as well as the Malvaceae group were all increased with increasing stocking rate. Little data are available on the impact of stocking rate on these minor species although *T. australianus* is known to be an indicator of overgrazing (Anderson 1993).

4.1.4.4 Changes in pasture content in legume oversown native pasture

Oversowing legumes into these *H. contortus* pastures failed to influence total pasture yield compared with that in the other two pasture types at the same stocking rate. In contrast, using a band seeder to oversow legumes at Glenwood in southern Queensland *H. contortus* pastures generally reduced total pasture yield compared with unsown native pasture although this reduction was attributed partly to the removal of 33% of the native pasture which is an inherent feature of the band seeder technology (MacLeod and Cook 2004). The major impact of oversowing legumes at Galloway Plains was the gradual increase in Stylo plant densities from 3 plants/m^2 in 1988 to 75 plants/m^2 in 2001 and this increase was associated with a similar increase in pasture content from <1% in 1988 to 50% in 2000. This increasing contribution of Stylo to pasture content was associated with increased steer liveweight gain, particularly in autumn (Section 4.2 Animal production). This increased liveweight gain is consistent with the pattern of diet selection by oesophageal fistulated steers (Section 4.3 Diet selection) which indicated that steer diets contained a high proportion of Stylo in autumn.

Oversowing legumes failed to reduce the occurrence of *H. contortus* or *B. bladhii* in the first 10 years of this study. However, by 1998 the yield of *H. contortus* had been reduced by legume oversowing - this reduction was associated with declining plant density and frequency relative to the two other pasture types. This suggests that the occurrence of *H. contortus* in legume oversown pastures may decline with longer time periods than covered by this study and management may need to consider the use of, for example, spring burning as a management tool to maintain the occurrence of *H. contortus*. Noble *et al.* (2000) discussed the potential role of fire in manipulating the balance of Stylo and native perennial grasses.

Oversowing legumes also resulted in a decline in the occurrences of both Native legumes and Other forbs components of the pasture. Unfortunately, when this study commenced in 1988, little attention was focused on individual species and how they contribute to measures of plant species diversity so that no attempt was made to record individual native legume or forb species. Nevertheless, the native legumes *Rhynchosia minima* and *Glycine tabacina* were common in native pasture (particularly under light grazing) whereas these species had lower occurrences in the legume oversown treatments. This trend was consistent with the reduced occurrence of Other forbs in the legume oversown treatments, Other forbs comprised a lower proportion of steer diets compared with that in the two other pasture types (See Section 4.3 Diet selection). The annual / short lived perennial grass *Chloris inflata* was the only species to increase in the legume oversown treatments. This species is generally regarded as relatively unpalatable and its occurrence is regarded as an indicator of soil disturbance (Anderson 1993).

The gradual increase in Stylo contribution to overall pasture content and associated changes in species occurrences over the 13 years of this study indicates the need to understand the long term consequences of sowing legumes into native pastures. In particular, we need to understand how legume content changes and how these changes might be managed in the long term. McIvor *et al.* (1996) have highlighted the problems associated with the long term maintenance of stylo based pastures.

4.1.4.5 Changes in pasture content with supplement / burning

Spring burning reduced total pasture yields in autumn 1993 and 2000 following burning in spring 1992 and 1999 (burning was possible only in those two springs at the 3 and 2 ha/steer stocking rate treatments). In general terms, total yield measured in autumn following spring burning differs from that in unburnt pasture. Total yield in the burnt pasture comprises only that summer seasons pasture growth whereas total yield in unburnt pasture comprises that summer seasons pasture growth in addition to carry over pasture growth from previous growing seasons. Thus, the differences in total pasture yield between burnt an unburnt pasture probably represent the carry over growth from previous growing seasons.

Spring burning substantially increased the contribution of *H. contortus* to overall pasture yield but only where stocking rate was light enough to ensure an effective burn. This increased *H. contortus* content at light stocking rates occurred for two reasons; firstly, the light stocking rate enabled *H. contortus* plants to produce substantial amounts of seed in the previous autumn prior to burning and secondly, spring burning promoted the germination of this seed much beyond that obtained in the absence of fire. The 2 and 3 ha/steer stocking rates were too heavy for these processes to occur while the 4 ha/steer treatment was marginal during our study although it may be sufficient during a sequence of years with above average rainfall.

Spring burning had no clear impact on *B. bladhii* at 2, 3 and 4 ha/steer. However, the yield of this species was reduced at 5 ha/steer at the same time as *H. contortus* yields increased, suggesting that *B. bladhii* may be reduced by spring burning under light stocking rate. Given the overall importance of *B. bladhii* in these *H. contortus* pastures together with the conflicting changes measured in this grazing study, it is suggested that more research should be focused on the role of this species. Furthermore, other members of the *Bothriochloa* genus are major species in other pasture communities in northern Australia, e.g. *B. ewartiana*, however the role of these species in these communities is not well understood.

Spring burning reduced the yield of *Aristida* spp. compared with that in both native pasture and legume oversowing treatments. This result is consistent with the result from Gayndah (Orr *et al.* 1997) but differ from the result from Glenwood where spring burning failed to reduce *Aristida* spp. (Orr 2004). Both Gayndah and Glenwood are located in the southern *H. contortus* region and these conflicting results reflect differences in the individual species of *Aristida* spp. present in these pastures. McIntyre (1996) classified the *Aristida* spp. in this region as belonging to different Section - referred to as “fine” taxa (Sections *Arthratherum* and *Streptachne*) and “coarse” taxa (Sections *Calycinae* and *Aristida*). The *Aristida* spp. at Galloway Plains belong to the “coarse” taxa and the reduction in these species with spring burning at Galloway Plains is consistent with similar reductions in “coarse” taxa at Gayndah (Orr *et al.* 1997). By contrast, “fine” taxa dominate the pasture at Glenwood and this taxa is not reduced by spring burning (Orr 2004).

Of the intermediate species, both *Eragrostis* spp. and *Chrysopogon fallax* increased with burning compared with unburnt native pasture. Anderson (1993) indicated that increased abundances of both these species indicate the pasture is being overgrazed. Of the minor species, the occurrences of Sedges and Other grasses increased with burning. Anderson (1993) also indicated that Sedges increase as perennial grasses disappear from the pasture. Thus, increases in these species suggest that burning “opens up” the pasture and allows space for less desirable species to increase.

4.1.4.6 Perennial grass basal area

The measurement of perennial grass basal area provided little evidence that either stocking rate or pasture type treatments impacted on these *H. contortus* pastures. This finding is counter intuitive as basal area generally declines as stocking rate increases. For example, increasing levels of pasture utilisation between 1978 and 1984 in Mulga (*Acacia aneura*) woodlands at Charleville markedly reduced the total perennial grass basal area as well as the basal area of desirable perennial grasses (Orr *et al.* 1993). At Galloway Plains, the 1995 data suggested that trends in basal area were moving in the anticipated direction – that is, basal area of decreaser species were higher at 4 ha/steer than at 2 ha/steer whereas basal area of increaser species was higher that at 4 ha/steer. However, the anticipated trends failed to be apparent in 2001 when, in fact, total, decreaser species, increaser species and *B. bladhii* basal area were highest at the heaviest stocking rate.

The spatial distribution of individual plants and differences between the two replicates have already been suggested as two reasons for the lack of significant treatment impacts on *H. contortus*. However, these reasons fail to explain the general lack of significance in the basal area trends reported for the other perennial grasses. Of particular interest here were the increaser grasses which each showed clear differences in both yield and frequency between the four native pasture stocking rates but differences in their basal area failed to be significant until 2001. This rise in increaser species basal area contributed to higher total perennial grass basal area in 1999 and 2001 as there were no treatment differences in the basal area of decreaser species.

4.1.4.7 Population dynamics of *H. contortus*

At the individual plant scale, increasing stocking rate from 5 to 2 ha/steer in native pasture substantially reduced the occurrence of *H. contortus*. Furthermore, the mechanisms involved in these density changes have been elucidated clearly by following the fate of individual plants in permanent quadrats. The major mechanism of these density changes was the reduction in seedling recruitment which was mediated through the soil seed bank and which, in turn, was mediated through seed production. Increasing stocking rate did reduce the survival of the initial plants however this impact was less important than the reduction of seedling recruitment. The failure of seedling recruitment to replace the original plants at 2 and 3 ha/steer resulted in an overall reduction in density and frequency as the initial plants died and were not replaced leaving quadrats that initially contained *H. contortus* devoid of *H. contortus* plants. Reduced *H. contortus* density with increasing stocking rates at Galloway Plains is consistent with a similar trend that was developing in a similar study of *H. contortus* dynamics at Glenwood (Orr *et al.* 2004a). However, the decline in *H. contortus* density with increasing stocking rate at Glenwood failed to be consistent probably because of the relative short time frame of that study (1990-1996) together with a more severe drought than at Galloway Plains. Thus, the 13 year time frame of the Galloway Plains study has clearly indicated the impact of increasing stocking rate on *H. contortus* plant density.

Knowing that seedling recruitment plays a critical role in maintaining *H. contortus* density means that management systems can be devised to allow the maintenance of this species. For example, the 2000 seedling recruitment event demonstrates the role of stocking rate and spring burning in achieving large seedling recruitments to boost plant density. Thus, reduced grazing pressure in autumn to allow seed set (Orr *et al.* 2004b) followed by spring burning in association with a favourable Southern Oscillation Index should increase H. contortus density through enhanced seedling recruitment.

Increasing stocking rate from 5 to 2 ha/steer in native pasture also reduced the basal area of *H. contortus.* This reflected differences in plant density because there were no consistent differences in plant size between the treatments. This reduction of *H. contortus* basal area with increasing stocking rate is consistent with the study at Glenwood (Orr *et al.* 2004a) although basal area values at Galloway Plains were much lower than those at Glenwood. These differences in the values for *H. contortus* basal area reflect the fact that *H. contortus* density was consistently higher at Glenwood than at Galloway Plains and *H. contortus* contributed only 20% of total pasture yield at Galloway Plains compared with 50% at Glenwood.

4.1.5 Conclusions

This study indicates that increasing stocking rate in native pasture results in reduced total pasture yields and less desirable pasture content. Oversowing legumes and supplement / burning treatments did not change total pasture yields at similar stocking rates to that in native pasture but there are indications that these pasture types do have some detrimental impacts on pasture content.

4.2 Animal production

4.2.1 Introduction

The sustainable management of native pastures represents a major challenge to grazing land managers. Although *H. contortus* pastures cover 23 M hectare in Queensland, there have been few studies of animal production from these native pastures because most early studies in Queensland (Hacker *et al.* 1982), focussed on the replacement of native pastures with introduced grasses and legumes. However, the complete replacement of native with exotic species has usually been uneconomic although one option has been to augment these native pastures with low fertility demanding legumes such as *Stylosanthes* species. For example, Middleton *et al.* (1993) demonstrated that such pasture development in central Queensland can result in an additional liveweight gain of 40-70 kg per head per year over native pasture. McLennan *et al.* (1987) reported a mean annual liveweight gain of 102 kg/head across a range of native and sown pastures at a range of sites within the *H. contortus* pasture community while Miller and Stockwell (1991) reported animal liveweight gains of 120 kg/head per year for southern *H. contortus* pastures. This section reports the impacts of stocking rate, legume oversowing and supplement / burning treatments on animal liveweight gains at Galloway Plains.

4.2.2 Methods

4.2.2.1 Animal selection

A total of 13 drafts of *Bos indicus* cross steers were used between 1988 and 2001 (Table 4.2.1). For each draft, five steers were allocated to each paddock based on random stratified initial fasted liveweight. Steers grazed the experimental paddocks for periods that varied between eight to twelve months. Steers were weighed (unfasted) at 4 weekly intervals for drafts 1 to 6 and six weekly for drafts 7 to 13.

In order to accelerate stocking rate effects, 6 steers were included in drafts 5, 8, 12 and 13. For draft 5, the 3 heaviest steers were withdrawn from each paddock in June 1993 because of extremely dry conditions. For draft 8, the steers were of much lower initial liveweight so that 1 steer from the previous draft was retained in each paddock for approximately 6 months. A different arrangement of steers occurred for draft 11 when only four steers grazed each paddock in order to test whether the liveweight advantage to steers grazing legume oversown treatments was cumulative over two consecutive years. To achieve this arrangement, 2 steers from the previous draft (draft 10) with approximately 500 kg/head liveweight were retained while two new, replacement steers of initial liveweight 250 kg/head were added to each paddock. The two large steers retained from draft 10 were selected on the basis of a liveweight close to the mean liveweight for each paddock.

Table 4.2.1 Sources of steers, number of steers per paddock, initial liveweight together with initial and end date of each draft between 1988 and 2000 at Galloway Plains.

Year	Draft	Source	Animals per paddock	Initial liveweight (kg)	Start date	End date
1988	1	"Hanging Rock", Mt. Coolon	5	278	14/9/1988	21/6/1989
1989	2	"Vacquera", Mt. Coolon	5	291	13/7/1989	4/4/1990
1990	3	"Rangeview", Ravenswood	5	324	17/7/1990	19/6/1991
1991	4	"Avoca Vale", Mingela	5	282	9/7/1991	15/7/1992
1992	5	"Rangeview", Ravenswood	6[1]	259	29/7/1992	8/9/1993
1993	6	"Rangeview", Ravenswood	5	277	16/9/1993	12/10/1994
1994	7	Not available	5	276	30/11/1994	2/8/1995
1995	8	"Swans Lagoon", Ayr	6[2]	172	9/8/1995	23/8/1996
1996	9	Not available	5	272	23/10/1996	8/10/1997
1997	10	Theodore	5	329	15/10/1997	2/9/1998
1998	11	"Swans Lagoon", Ayr	4[3]	323	2/9/1998	5/8/1999
1999	12	"Swans Lagoon", Ayr	6[4]	252	29/7/1999	3/8/2000
2000	13	"Swans Lagoon", Ayr	6[4]	297	26/7/2000	6/6/2001

[1] Heaviest 3 animals removed in June 1993 due to dry conditions.
[2] One extra animal per paddock retained until March 1996 due to low initial liveweight of draft 8.
[3] Two animals of 500kg from the previous draft and 2 animals of 250 kg liveweight.
[4] One extra animal per paddock for the entire draft.

4.2.2.2 Animal management

Animals were weighed following an overnight fast at the beginning and end of each draft. In between these fasted liveweight recordings, steers were weighed without over night fasting initially at approximately 4 weekly intervals for drafts 1 to 6 but this period between weighing was extended to 6 weekly weighing for draft 7 and all subsequent weighing occasions.

All drafts were vaccinated with "5 in 1" and for ephemeral fever and blooded for ephemeral fever. Buffalo fly infestations were treated as required.

4.2.2.3 Supplementary feeding

No dry season supplement was fed to animals in draft 1. For drafts 2 and 3, cottonseed meal (CSM) containing approximately 40% crude protein was fed once per week to animals in the supplement treatments as detailed in Table 4.2.2.

Table 4.2.2 Dry season supplement fed to steers in different steer drafts together with start and finish date between 1988 and 1991 at Galloway Plains.

Draft	Amount (g CSM/steer/day)	Start	Finish
2	500	25/8/1989	3/11/1989
3	500	13/8/1990	27/12/1990
4	500	20/9/1991	17/12/1991

Animals grazing the legume oversown treatments were fed Phosphorus as Fermaphos during the wet season as detailed in Table 4.2.3. No phosphorus was fed to steers grazing either the corresponding native pasture or supplement / burning treatments.

Table 4.2.3 Phosphorus supplement fed to steers in different steer drafts together with start and finish date between 1988 and 2000 at Galloway Plains.

Draft	Amount (g/steer/day)	Start	Finish
1	6	13/1/1989	20/6/1989
2	5.9	3/11/1989	3/7/1990
3	6	18/1/1991	10/5/1991
4	5	12/12/1991	26/5/1992
5	5	26/10/1992	15/5/1993
6	9	20/10/1993	23/5/1994
7	Nil		
8	6	13/11/1995	21/6/1996
9	6	25/11/1996	7/4/1997
10	6	15/12/1997	6/7/1998
11	6	25/1/1999	8/6/1999
12	?		
13	4	22/1/2001	28/5/2001

4.2.2.4 Statistical analyses

The grazing experiment was a randomised complete block design consisting of two replicates of 11 treatments. The treatments were set up in a factorial structure made up of 5 stocking rates and 3 pasture types with four treatment combinations missing during 1988–1996 and 4 stocking rates and 3 pasture types with one treatment combination missing during 1997 -2001. Given the lack of balance in the treatment structure, the data was analysed using analysis of variance (ANOVA) with an appropriate nested factorial structure in GenStat (GenStat 4.21, Reference Manual). All measurements were analysed separately for each year.

4.2.3 Results

4.2.3.1 Liveweight gain relationships

Averaged across all years, annual liveweight gain per steer decreased linearly with increasing stocking rate in both native pasture (R^2=0.781; n=5) and legume oversown (R^2=0.999; n=3) treatments (Figure 4.2.1a). Liveweight gain per hectare increased linearly with increasing stocking rate for both native pasture (R^2=0.877; n=5) and legume oversown pasture (R^2=0.950; n=3)(Figure 4.2.1b). For both the liveweight gain per steer and per hectare relationships, both the intercept and slope of the regression lines for legume oversown pasture were higher than that for native pasture.

(a)

(b)

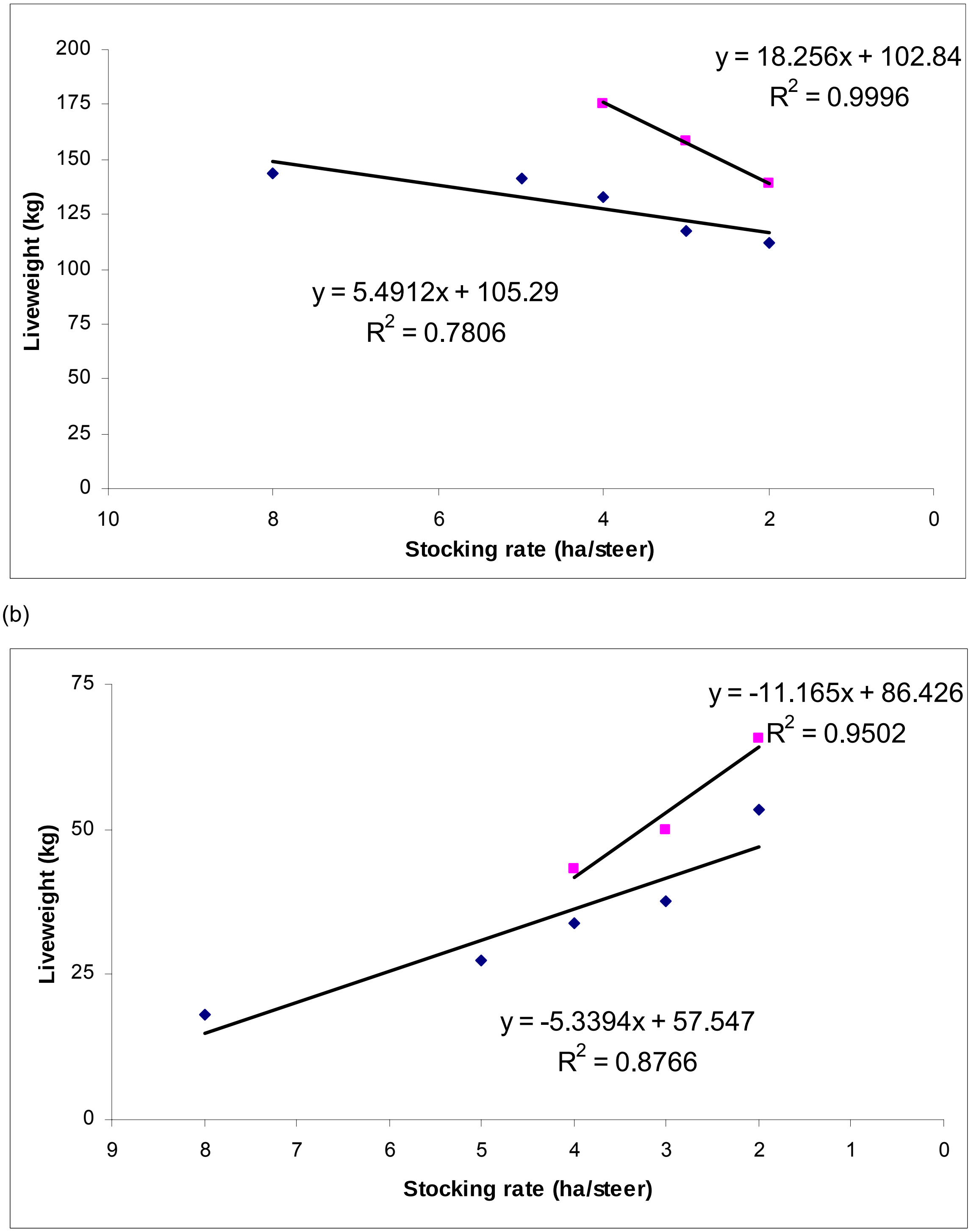


Figure 4.2.1 Relationships between annual liveweight gain for an (a) per animal (kg/steer) and (b) per hectare (kg/ha).

4.2.3.2 Impact of stocking rate in native pasture

Annual liveweight gain (kg/steer) in native pasture varied widely with stocking rate and seasonal rainfall and ranged from a minimum of 43 kg/steer at a stocking rate of 2 ha/steer in 1992-93 (a low rainfall year) to 182 kg/steer at a stocking rate of 8 ha/steer in 1995-96 (a high rainfall year)(Figure 4.2.2). Within each draft, there was a consistent pattern for annual liveweight gain to be highest at the lightest stocking rate and decrease with increasing stocking rate from 8 ha/steer (5 ha/steer after 1995-96) to 2 ha/steer. These differences in annual liveweight gain were significant (P<0.05) for the 1990-91 to 1992-93, 1995-96 and the 1999-2000 and 2000-01 draft of steers while this trend was also apparent (P<0.1) for the 1994-95 and 1998-99 drafts.

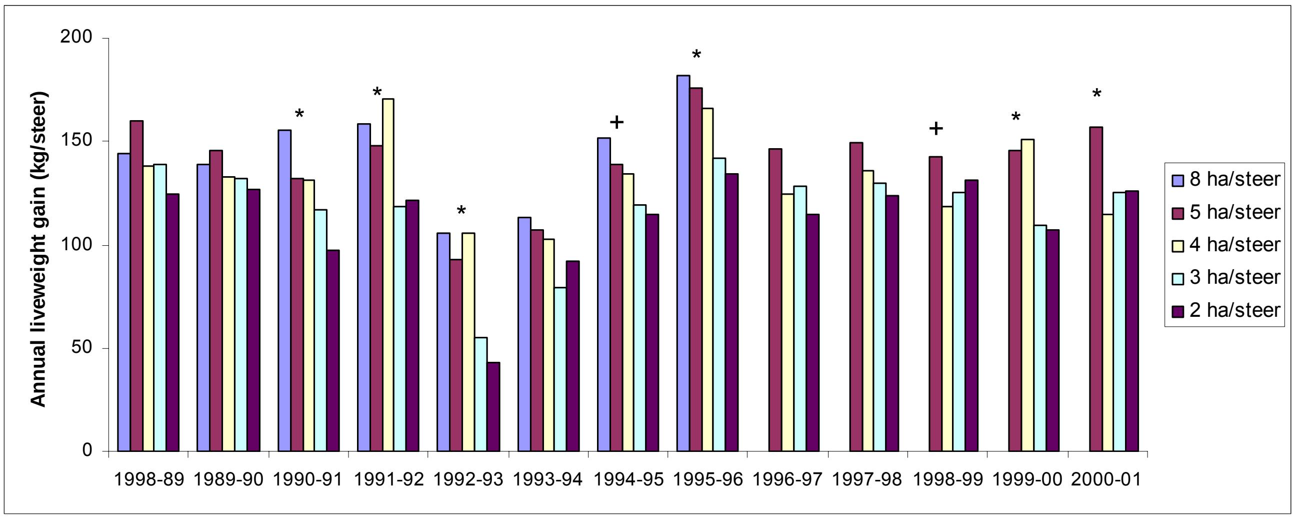


Figure 4.2.2 Liveweight gain (kg/head) of steers grazing native pasture at five stocking rates at Galloway Plains between 1988 and 2001.

4.2.3.3 Impact of legume oversowing

The main effect of pasture type was significant (P<0.05) in all 13 drafts while the main effect of stocking rate was significant (P<0.05) in 8 of the 13 drafts. However, a pasture type x stocking rate interaction on animal liveweight was significant (P<0.05) for only the 1999-2000 draft. Annual liveweight gain was consistently higher (20-60 kg/head) in the legume oversown compared with that in the native pasture and supplement / burning treatments and there were no differences (P>0.05) between these latter two pasture types (Figure 4.2.3). As with native pasture, annual liveweight gain decreased with increasing stocking rate (data not presented).

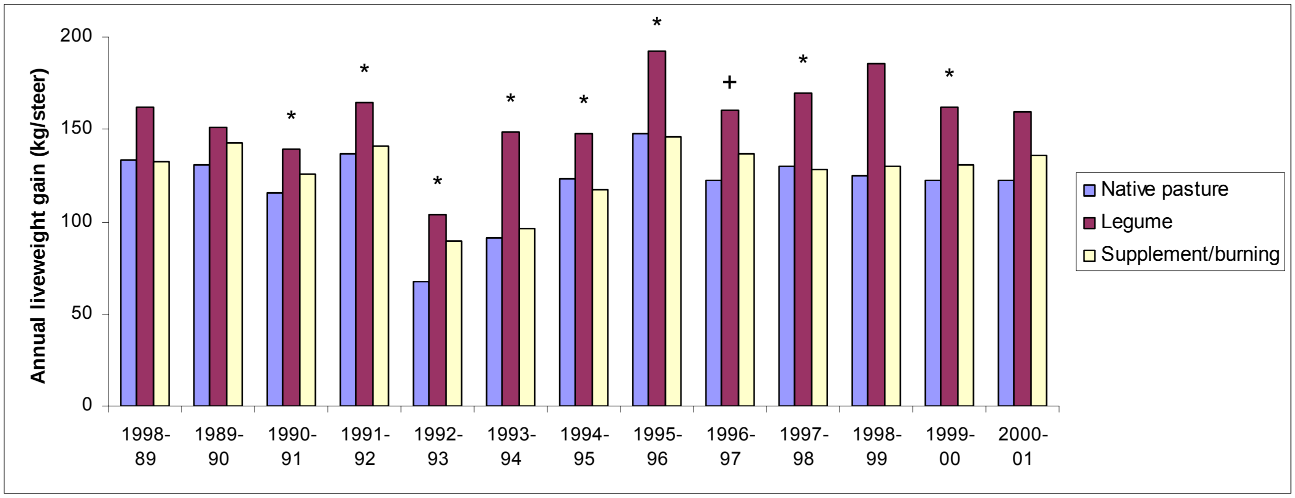


Figure 4.2.3 Liveweight gain (kg/head) of steers grazing three pasture types (data averaged over three stocking rates) at Galloway Plains between 1988 and 2001.

4.2.3.4 Steer age effects

A feature of the draft 11 steers was the large difference in the liveweight change of the young steers compared with the old steers (Figure 4.2.4). The young steers in the legume oversown treatments were heavier (P<0.05) than those in native pasture by the third weighing and this higher liveweight was sustained throughout the remaining period of this draft. In contrast, the liveweight of older steers in legume oversown treatments was similar to that in the native pasture except for the last two weightings. The liveweight advantage over the whole season for young steers in legume oversown treatments was 92 kg/steer over native pasture compared with only 30 kg /steer for the older steers.

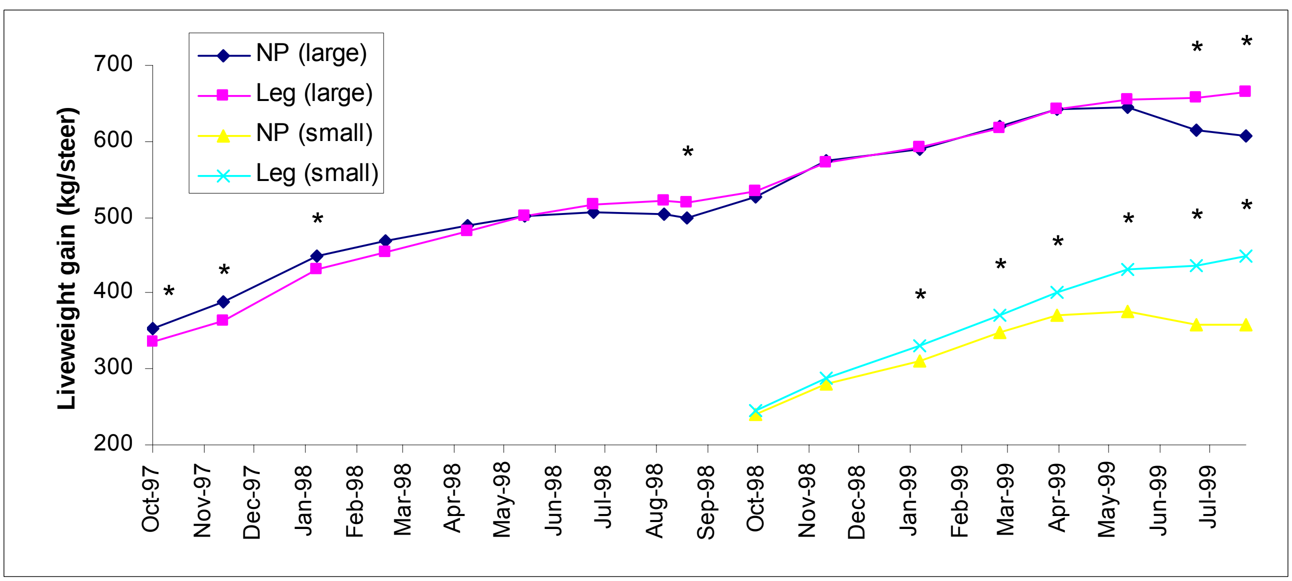


Figure 4.2.4 Unfasted liveweight change (kg/head) of two groups of steers (large and small) steers grazing native pasture and legume oversown pastures (averaged over three stocking rates) for the 1997-99 (large steers) and 1998-99 (small steers) at Galloway Plains between 1997 and 1999.

The extent of the annual liveweight advantage to legume oversown pasture, up to 60 kg/steer in 1998-99, compared with native pasture varied between years although there was an overall trend for this liveweight advantage to increase with increasing legume content in the pasture (Figure 4.2.5). The major liveweight benefit of legume oversowing occurred during the autumn and early winter period. During the relative drought year of 1993-94, steers grazing legume oversown pastures managed to largely maintain liveweight during the winter – spring period whereas steers grazing native pastures and supplement / burning pastures lost weight (Figure 4.2.6a). During the generally favourable rainfall year of 1995-96, all steers continued to gain weight throughout the year although the liveweight advantage to steers grazing legume oversown pastures was evident in spring and this advantage continued to increase during the autumn and winter period (Figure 4.2.6b).

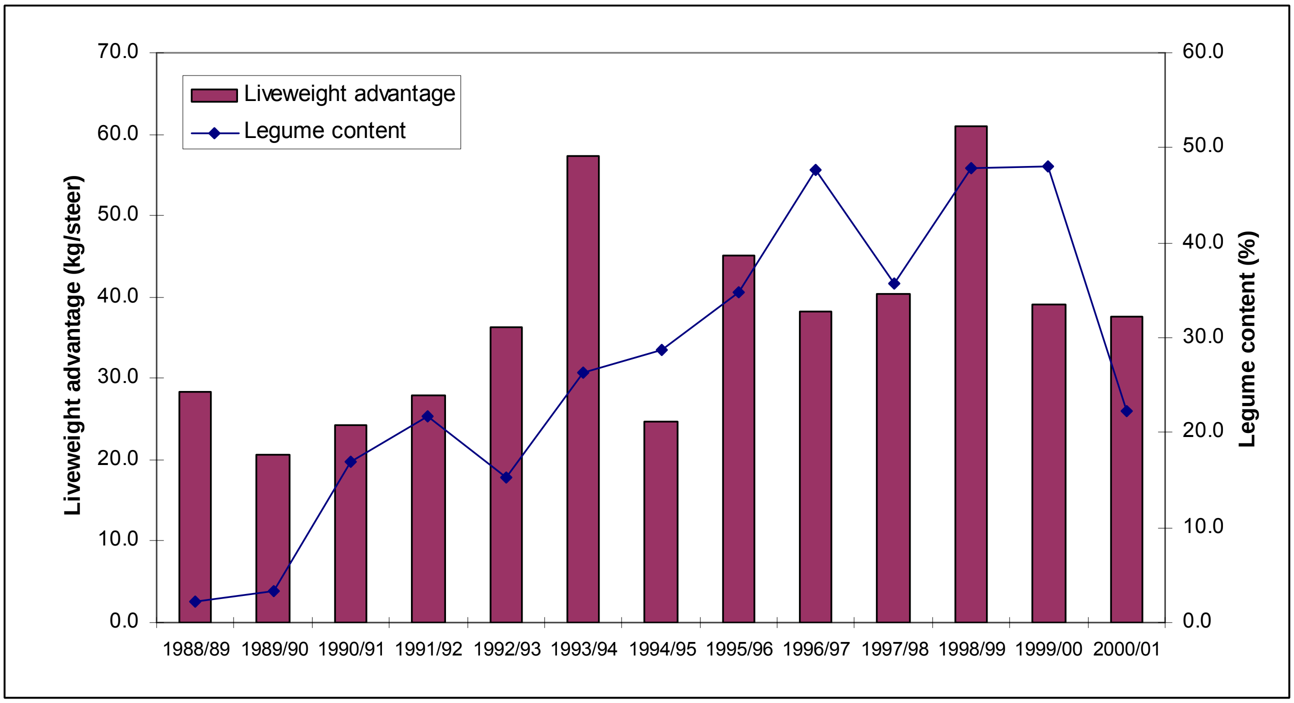


Figure 4.2.5 Liveweight advantage to steers grazing legume oversown native pasture in relation to the legume content (%) in the pasture at Galloway Plains between 1989 and 2001.

(a)

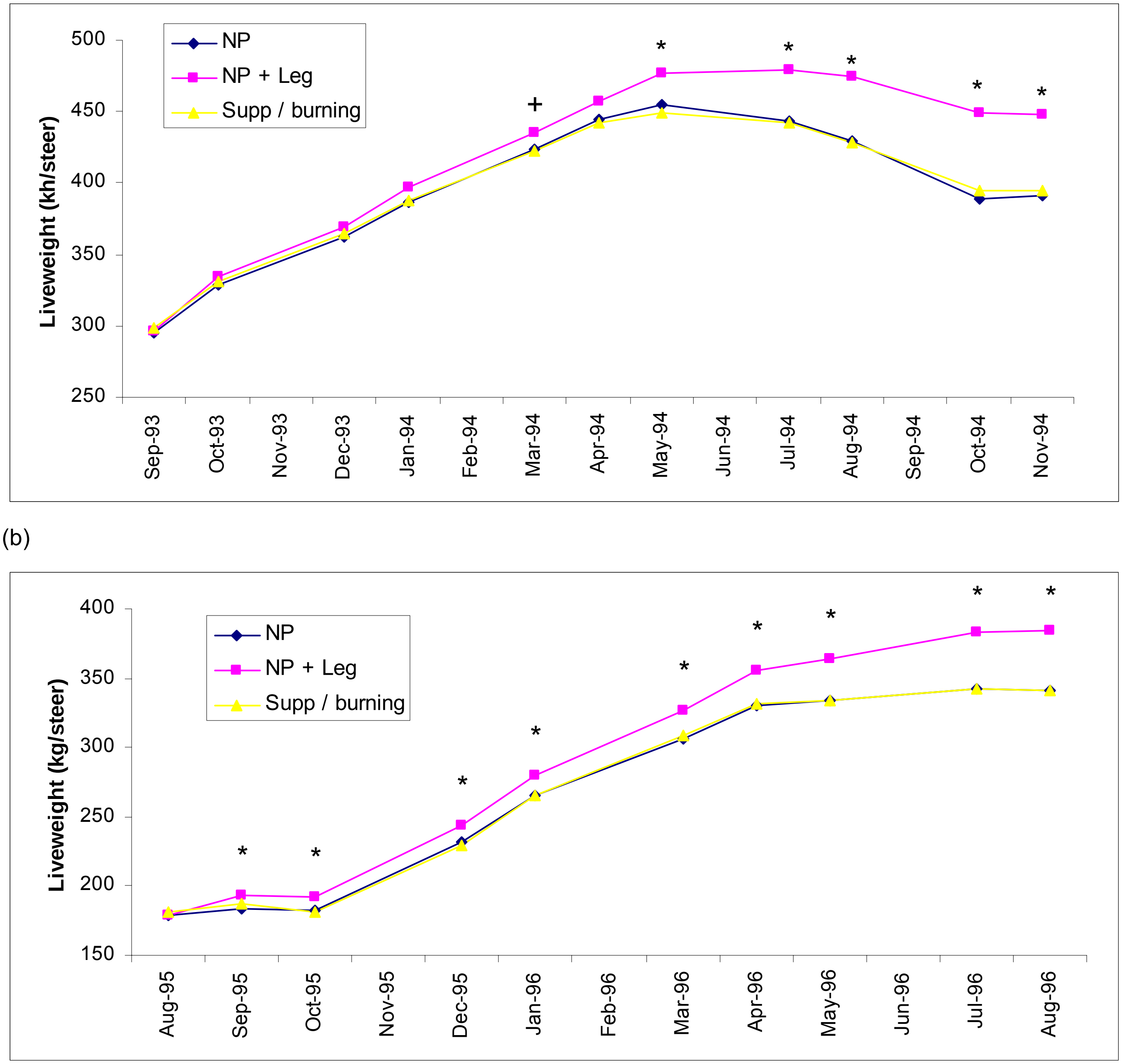
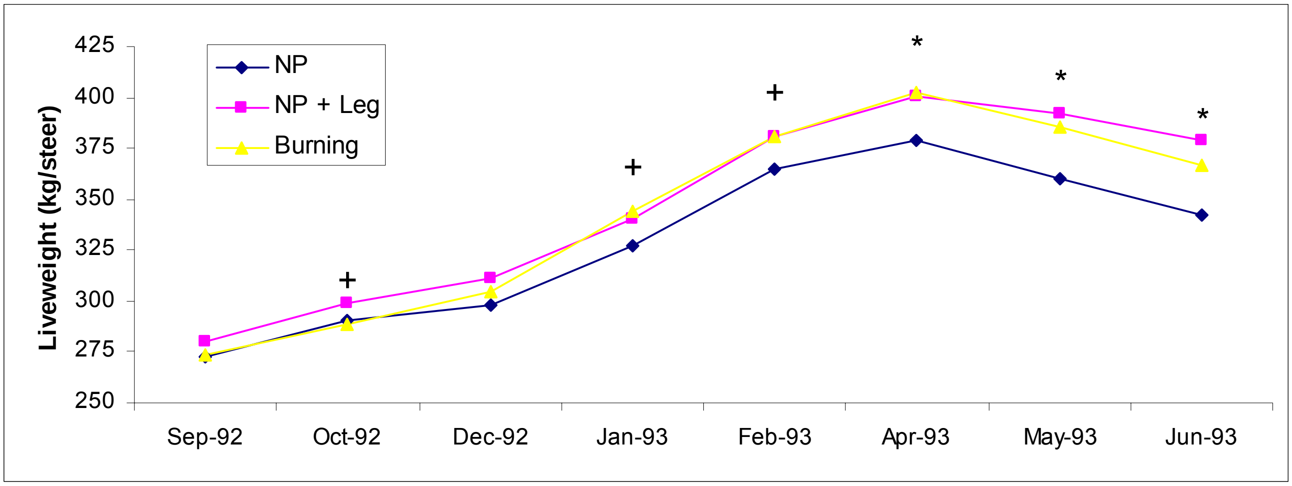


Figure 4.2.6 Unfasted liveweight change (kg/head) of steers grazing three pasture types (averaged over three stocking rates) for the (a) 1993-94 and (b) 1995-96 steer drafts at Galloway Plains.

4.2.3.5 Impact of burning

Due to the impact of grazing at 4, 3 and 2 ha/steer on total pasture yield (See Section 4.1. Impact of grazing on pastures), burning in spring at these 3 stocking rates was possible in only 1992 and 1999. The pattern of liveweight gain differed substantially between these 2 burns. The first burn was conducted in September 1992 and by April 1993, steers grazing the burnt pasture were similar in liveweight to those grazing legume oversown pastures. Both groups of steers were heavier ($P<0.05$) than the group grazing unburnt native pasture (Figure 4.2.7a). This liveweight advantage to burning compared with native pasture continued through May 1993 but by June the liveweight of steers grazing the burnt pasture was only intermediate between that of the legume oversown and native pasture steers. (No comparison is made beyond June 1993 because the three heaviest steers were removed in June due to drought). The second burn occurred in October 1999 but there were no differences (P>0.05) in liveweight between the burnt and unburnt native pasture steers while steers grazing legume oversown pasture were consistently heavier (P<0.05) than both native pasture and the steers on the burnt pasture except in March 2000 (Figure 4.2.7b).

(a)



(b)

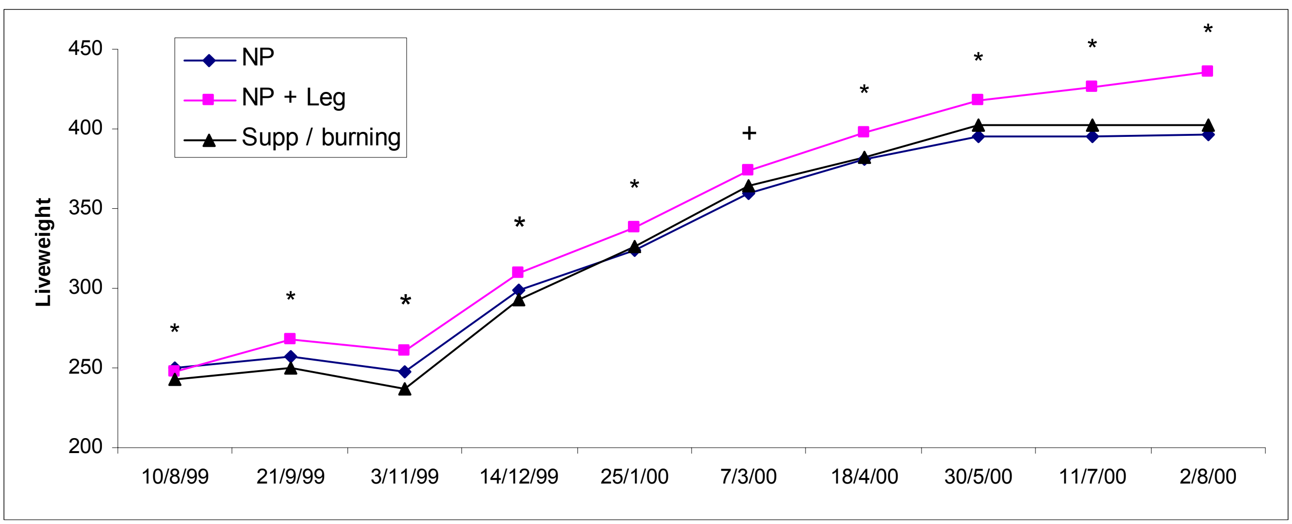


Figure 4.2.7 Unfasted liveweight change (kg/head) of steers grazing three pasture types (averaged over three stocking rates) for the (a) 1992-93 and (b) 1999-2000 steer drafts at Galloway Plains.

4.2.4 Discussion

4.2.4.1 Impacts of stocking rates and pasture types

Increasing stocking rate from 8 ha/steer to 2 ha/steer in native pasture progressively reduced annual liveweight gain on an individual steer basis but increased this annual liveweight gain on a per unit area basis. Reduced liveweight gain with increasing stocking rate is consistent with the reduction in total pasture yields (Section 4.1. Impact of grazing on pastures) and the reduction in the diet content of *H. contortus* (Section 4.3 Diet selection).These stocking rate trends were also evident in legume oversown pastures with both the intercept and slope of the regression lines for these legume oversown pastures being higher than that for native pasture. These overall patterns of liveweight gains with stocking rate are consistent with that in most managed pastures (Jones and Sandland 1974). Spring burning had an inconsistent effect on liveweight gain compared with unburnt native pasture.

A feature of the liveweight responses at Galloway Plains was the large variation between years that was apparent at all stocking rates and in all three pasture types. For example, annual liveweight gain in native pasture ranged from a minimum of 43 kg/steer at a stocking rate of 2 ha/steer ("dry" year in 1992-93) to a maximum of 182 kg/steer at 8 ha/steer ("wet" year of 1995-96) while for legume oversown pastures the range was 75 kg/steer at 2 ha/steer and 221 kg/steer at 4 ha/steer. Such large variation is common in commercial production and Bortolussi *et al.* (2005) quoted a co-efficient of variation of 18-29% for native and improved *H. contortus* pastures. Similar large variation was also demonstrated in other grazing studies in *H. contortus* pastures eg. Middleton *et al.* (1993), Jones (1997), and MacLeod and Cook (2004). This variation is usually explained by variation in both total annual rainfall and its seasonal distribution and, in commercial systems, by these factors combined with management regimes (Bortolussi *et al.* 2005). Jones (2003) derived a linear relationship between annual liveweight gain and the number of "green days" as an indication of rainfall distribution but was unable to demonstrate any relationship between liveweight gain and total annual rainfall.

The liveweight gains of steers at Galloway Plains were higher than that for similar aged steers in northern *H. contortus* pastures near Townsville in both native pasture only (Jones 1997) and legume oversown native pastures (Jones 2003). However, the 2-8 ha/steer stocking rates used at Galloway Plains were lighter than the 1.1-3.3 ha/steer used in the Townsville studies. Liveweight gains at Galloway Plains were similar to those in both native pasture and legume oversown native pasture in central Queensland (Middleton *et al.* 1993) but were less than liveweight gains recorded in legume oversown native pasture at 1.7 ha/steer at "Glenwood" in southern *H. contortus* pastures (MacLeod and Cook 2004). This overall trend of increasing annual liveweight gains from north to south in *H. contortus* pastures is consistent with the general patterns of liveweight gain described by Miller and Stockwell (1991) who attributed this trend to relatively more fertile soils in the south compared with those in the north. Another factor contributing to this trend would be the greater number of "green days" throughout the year due to the more even distribution of annual rainfall in the south compared with that in the north. This geographic trend is consistent with the results of Bortolussi *et al.* (2005).

4.2.4.2 Liveweight advantage to legume oversowing

For the 13 years at Galloway Plains, the average annual liveweight advantage on legume oversown pasture compared with native pasture was 37 kg/steer. This advantage is higher than the 22kg/steer annual advantage for steers grazing legume (five species) oversown *H. contortus* between 1989 and 1995 during protracted drought in the southern inland *H. contortus* region (MacLeod and Cook 2004). However, this 37 kg/steer liveweight advantage was similar to the 35 kg/steer advantage recorded between 1984 and 1989 in southern coastal *H. contortus* region which had been oversown with *Cassia rotundifolia* cv. Wynn (Partridge and Wright 1992). The 37 kg/steer advantage at Galloway Plains was at the lower end of the 40-70 kg per steer range measured elsewhere in central Queensland (Middleton *et al.* 1993). However, this 70 kg/steer figure was recorded from a pasture that had been fertilised with superphosphate whereas the phosphorous supplement was fed directly to the steers at Galloway Plains.

The liveweight advantage to steers grazing legume oversown pastures apparent in the initial year at Galloway Plains (legume content <1% of total pasture yield) is probably an artefact resulting from the soil disturbance associated with the sowing of the legumes in cultivated strips. Such soil disturbance stimulates the mineralisation of soil nitrogen which is taken up by plants and is reflected in increased liveweight gain in subsequent years following the soil disturbance. Nevertheless, there was a trend for the liveweight advantage to legume oversowing to increase with time. This increase was associated with the increasing legume content in the pasture from <1% yield and 3 plants/m^2 density in 1988 to 50% yield and 75 plants/m^2 in 2001. Despite this trend of increasing legume content and density in the pasture, the diet content in autumn between 1992 and 2000 failed to display a consistent increase in the content of Seca (See Section 4.3 Diet selection). The precise point at which the legume content begins to influence liveweight gain was not clear although 10% legume content may be a minimum. MacLeod and Cook (2004) reported liveweight gain advantages due to legume oversowing when legume content represented 5% of total pasture yield.

4.2.4.3 Steer age effects

Large differences were apparent in the rate of liveweight gain between young and old steers grazing in the same treatments during the same season (Figure 4.2.4). This result is similar to that for other mixed aged steers grazing both native and legume oversown *H. contortus* pastures near Townsville (Jones and Coates 1992, Jones 1997). This result indicates that the liveweight advantage achieved by legume oversowing should be cumulative for the life of steers. However, results from Galloway Plains indicate that the extent of this liveweight advantage on oversown pastures will be greatest for young steers.

4.2.4.4 Impacts of burning on animal production

The present study produced conflicting results on the impact of burning on annual liveweight gain. This finding is consistent with similar equivocal findings on the impact of burning on animal liveweight gain elsewhere in *H. contortus* pastures (Anderson *et al.* 1987). Generally, pasture burning involves the conflicting effects of reduced pasture yield and improved diet quality. Although the 1992-93 draft did display a substantial liveweight response over the summer, equivalent to that from legume oversowing, this response had dissipated by the 1993 winter. In contrast, the 1999-2000 draft failed to display any liveweight response above that of unburnt native pasture. Spring burning significantly reduced total pasture yields in spring 2002, autumn 1993 and autumn 2000 (i.e. the autumn following spring burnings) below that in the other two pasture types at the same pasture samplings. Thus, this reduced total pasture yield in autumn 1993 probably explains why the initial liveweight advantage in burnt compared with unburnt native pasture dissipated during the 1993 winter. This reduced pasture yield was probably further exacerbated by reduced pasture quality resulting from the very low seasonal rainfall at that time. Clearly, more research is necessary to further understand the conflicting impacts of spring burning on liveweight gain as measured at Galloway Plains.

4.2.5 Conclusions

This study has shown clearly that increasing stocking rate reduces liveweight gain on an individual steer basis but increases liveweight gain on a unit area basis. Oversowing legumes substantially increases liveweight gain over that in native pasture at the same stocking rate and most of this advantage occurred in the autumn – winter period. Young animals gain weight at a faster rate than older animals grazing the same treatments. Spring burning had an inconsistent impact on steer liveweight gain.

4.3 Diet selection

4.3.1 Introduction

Diet content estimated from extrusa collected from animals fitted with oesophageal fistulae represents the diet of non fistulated animals of similar history (Forbes and Beattie 1987; Holechek *et al.* 1982). Furthermore, Hall and Hamiliton (1975) have used a microscope point technique to establish botanical composition of extrusa as representative of the diet consumed despite variation due to the degree of mastication. In contrast, both Coates *et al.* (1987) and Jones & Lascano (1992) have reported biased estimates of diet legume content by fistulated steers grazing sown pastures. This section reports the on impacts of stocking rate, legume oversowing and supplement / burning treatments on the content of the diet selected by oesophageal fistulated steers at Galloway Plains.

4.3.2 Methods

4.3.2.1 Diet in autumn

The effect of stocking rate and pasture type on the wet season content of the diet selected by steers grazing *H. contortus* pastures was investigated as part of the overall Galloway Plains grazing study. The diet selection study was restricted to the nested 3 x 3 factorial treatments which were the 3 pasture types (native pasture, legume-oversown native pasture, supplement / burnt native pasture) x three stocking rates (4, 3 and 2 ha/steer).

Oesophageal fistulated (OF) Brahman cross steers, separate to those grazing the trial paddocks, were sampled in autumn (February-April) each year from 1992 to 1996 (inclusive) and in 1998 and 2000. Twelve steers were used in 1992 to 1995 and nine steers in 1996, 1998 and 2000. The steers grazed similar native pastures to the main experiment except during the sampling period. At sampling each year, the steers were randomly allocated to three groups and each group randomly allocated to a stocking rate treatment. A group was then used to sample their allocated stocking rate treatment across replicates and pasture management treatments for that year. When sampling, fistulated steers were restricted to an area which was representative of the pasture in each paddock and these areas were determined using pasture composition data described in Section 4.1 Impact of grazing on pastures.

4.3.2.2 Impact of spring burning

A further sampling was conducted in November/December 1992 following the September 1992 burning of those paddocks assigned to the strategic burning treatment. At this sampling, 12 steers were again randomly allocated to three groups and each group was randomly allocated to a stocking rate treatment. A group was then used to sample their allocated stocking rate treatment across replicates and pasture type treatments. The samplings in February 1992, November/December 1992 and March 1993 were then used to assess the effect of burning on diet content.

4.3.2.3 Diet across a pasture growing season

The effect of seasonal pasture growth on diet content was assessed by sampling the 3 native pasture treatments in November 1995 (break of wet), December 1995 (early wet) and January 1996 (mid wet) in conjunction with the standard autumn sampling in April 1996 (end of wet). Nine steers were randomly assigned to three groups with each group randomly allocated to a stocking rate treatment and used to sample their allocated stocking rate treatment across replicates within a sampling.

4.3.2.4 Extrusa collection

Although some steers were similar across sample times, there was variation among the group and stocking rate treatment to which they were allocated. Steers were fasted overnight prior to all sampling times. At each sampling, two extrusa samples were obtained from each fistulated steer following 30 minutes grazing an allocated paddock. Extrusa samples for the determination of diet content were frozen and were thawed immediately prior to identification. Plant species identification was determined using a microscope point hit technique measuring 200 points per sample (Hamilton and Hall 1975) to assess the proportion of green leaf, dead leaf, green stem and dead stem for each species in the diet.

4.3.2.5 Statistical analyses

Since a group of steers sampled all paddocks of a given stocking rate in any sampling time, stocking rate was confounded with sample group. Further, as steers within a group were not necessarily the same at each sample time, the groups across sample times were considered as independent (i.e. As if unique groups). Also, data were unbalanced and contained multi-strata, so data were analysed by residual maximum likelihood (REML) using GenStat (GenStat 6.1 Reference Manual, 2002). Data included the proportion of green leaf, green material (sum of green leaf and green stem) and total material (sum of green and dead leaf and stem) for 'Decreaser' species (*H. contortus* and *B. bladhii)*, 'Increaser' species (*C. divaricata and Eragrostis* spp.) as well as for these individual species. (Note that this Increaser group defined in the diet study includes only *C. divaricata and Eragrostis* spp. whereas this Increaser group in the Pasture section also includes *Bothriochloa decipiens*. *B. decipiens* content of the diet was negligible and was included in the Other grasses category). Other species recorded in the diet included *Aristida* spp., *Chrysopogon fallax*, Other grasses (grasses of minor occurrence), Forbs (aggregate of broad leaf species), Sedge (mainly *Fimbristylis* spp.) and *Stylosanthes scabra* cv. Seca.

To determine changes in species content in the diet in autumn across years, data for the seven autumn samplings for each species were analysed using a model that included the random effects of replicate x group, pasture type, animal and sample and the fixed effects of stocking rate, pasture type and year (sample time). As Seca stylo was present in the legume-oversown pasture only, the pasture type was removed from the model for this species. Similar models were used to determine the effect of burning using the February 1992, November 1992 and March 1993 samplings. For the analysis of the diet across a pasture growing season (November 1995, December 1995, January 1996, April 1996) data were obtained from the native pasture treatment only, the models included the random effects of replicate x group, animal and sample and the fixed effects of stocking rate and sample time.

To satisfy normality and variance assumptions, all data were transformed using the angular transformation ($ang(p)=180/\pi \times \arcsin(\sqrt{(p/100)})$ where $0<p<100$) prior to analysis. Means were backtransformed for presentation in figures.

4.3.3 Results

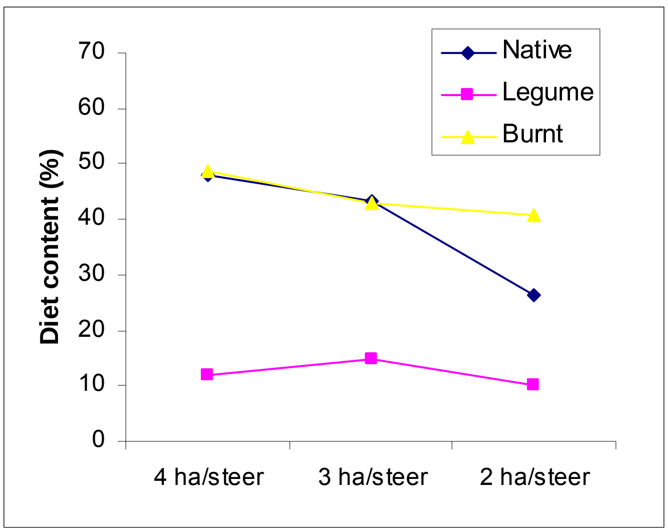
4.3.3.1 Diet in autumn

4.3.3.1.1 Decreaser and increaser species

Grazing treatment influenced the proportion of both decreaser and increaser species selected by fistulated steers. The interaction between stocking rate and pasture type (Figure 4.3.1) as well as between year and pasture type (Figure 4.3.2) were significant ($P<0.05$). These interactions were consistent for all three components of the diet (green leaf, green and total diet content). The diet content of decreaser species was highest in the native pasture and supplement / burning treatments at 4 ha/steer and declined with increasing stocking rate. In contrast, the diet content of increaser species was lowest at 4 ha/steer and increased with increasing stocking rate particularly in the supplement / burning treatments. Decreaser species were the major component of the diet in all treatments.

All three diet components for both decreaser and increaser species varied between years. The diet contents of decreaser species were consistently higher in both native pasture and supplement / burning than in the legume oversown treatments. There were no clear differences between pasture types in any of the increaser species diet contents although all three diet components tended to be higher in the supplement / burning treatment in 1996 than in the other two treatments in that year.

(a)



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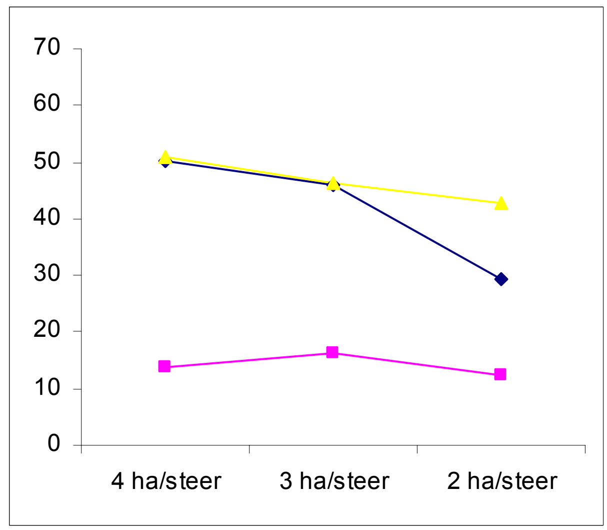

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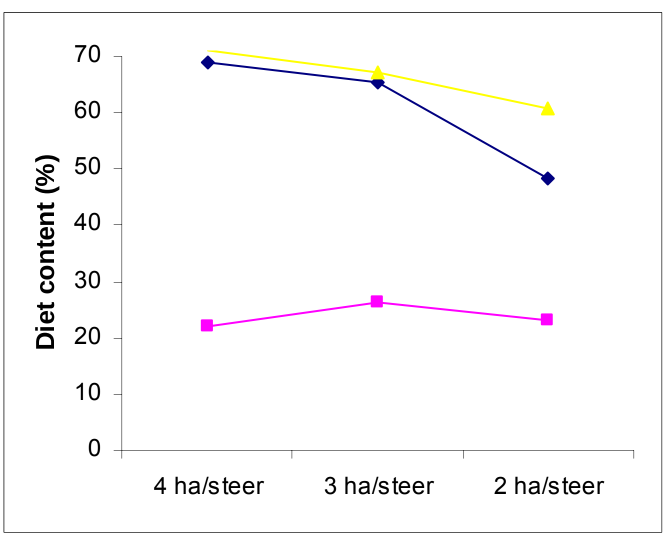

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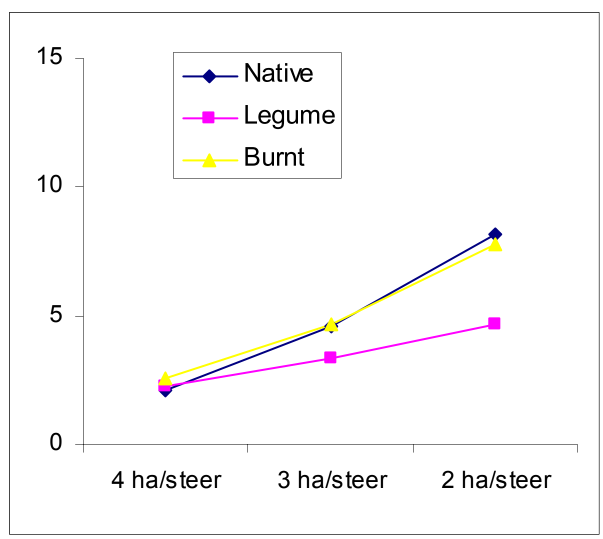
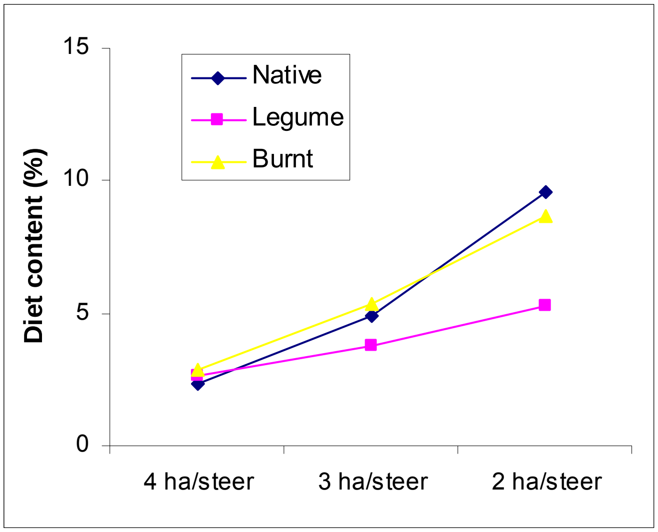


(e)



(f)

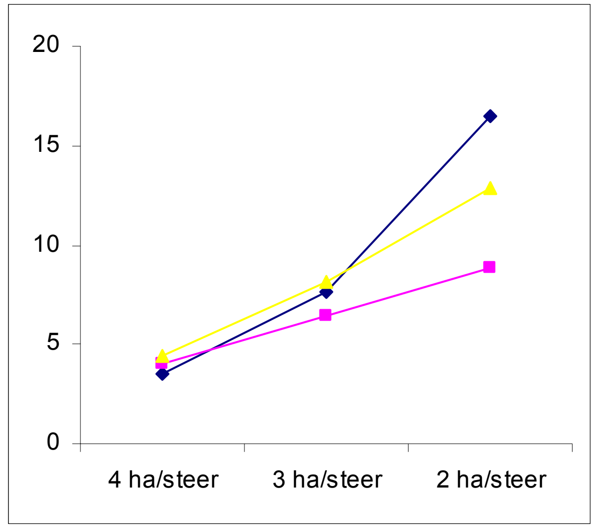
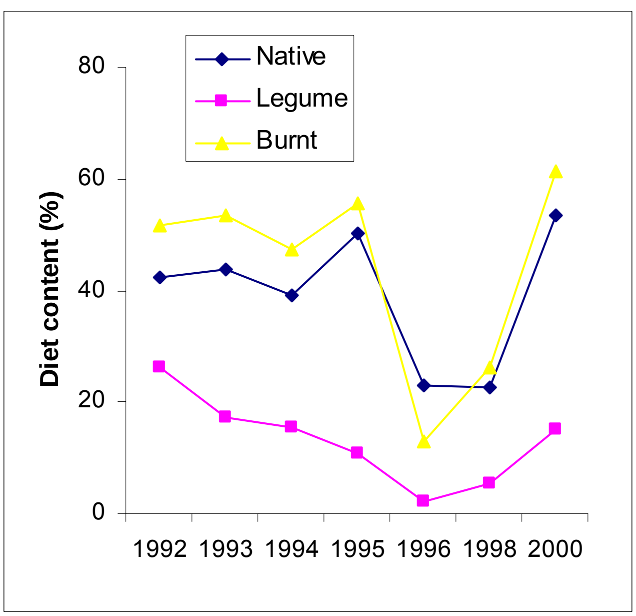
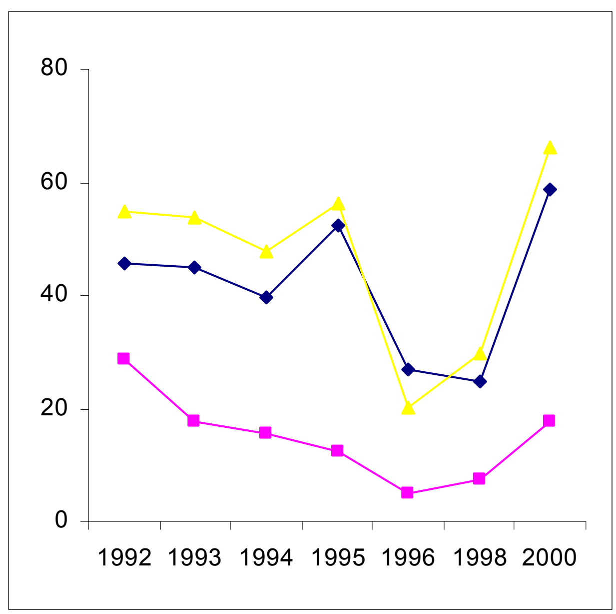


Figure 4.3.1 Proportion of (a) green leaf, (b) proportion green and (c) total proportions of decreaser species and (d) green leaf, (e) proportion green and (f) total of increaser species in relation to a pasture type x stocking rate interaction in *H. contortus* pasture between 1992 and 2000. (Analyses performed on angular transformed data). (Note differences in scales).

(a)



(b)



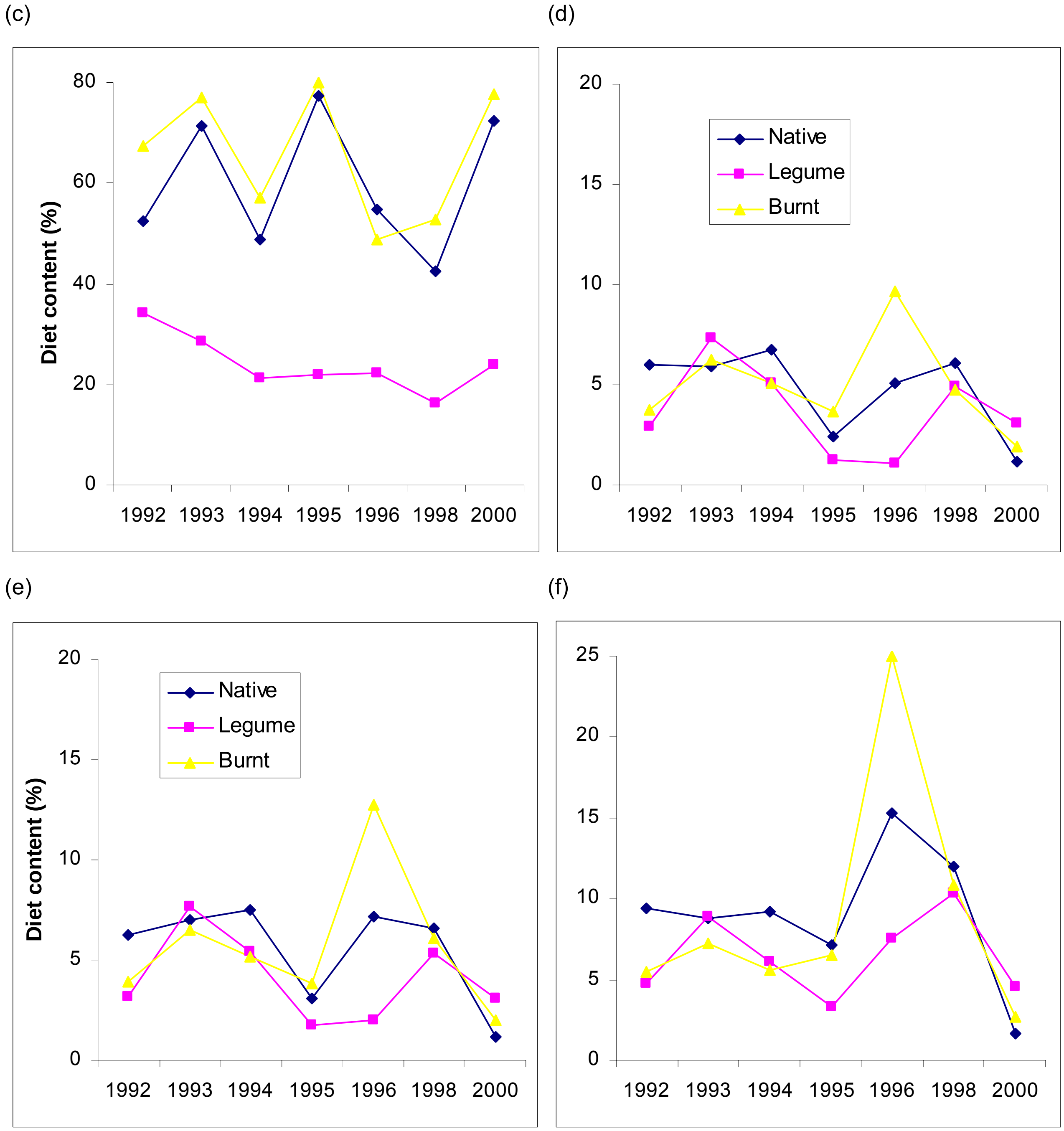


Figure 4.3.2 Proportion of (a) green leaf, (b) proportion green and (c) total proportions of decreaser species and (d) green leaf, (e) proportion green and (f) total of increaser species in relation to a pasture type x year interaction in *H. contortus* pasture between 1992 and 2000. (Analyses performed on angular transformed data). (Note differences in scales).

4.3.3.1.2 Individual species

The pasture type x stocking rate interaction for all three diet components for both *H. contortus* and *B. bladhii*, the two decreaser species, was significant (P<0.05) (Figure 4.3.3). However, data for total diet content only is presented because all three diet components responded similarly to the grazing treatments. In native pasture treatments, the *H. contortus* content of the diet varied from 47% to 18% as stocking rate increased from 4 ha/steer to 2 ha/steer. A similar trend was also measured for the supplement / burning treatment except that the levels recorded at 2 ha/steer were substantially higher than those at 3 ha/steer. In the legume oversown treatments, the *H. contortus* content of the diet was less than 20% irrespective of stocking rate. The *B. bladhii* content of the diet in native pasture increased from 17% to 25% with increasing stocking rate from 4 ha/steer to 2 ha/steer whereas the highest levels of 35% were recorded at a stocking rate of 3 ha/steer in the supplement / burning treatment. The diet content of *B. bladhii* in the legume oversown treatments was less than 12% and there was little variation due to stocking rate.

(a) (b)

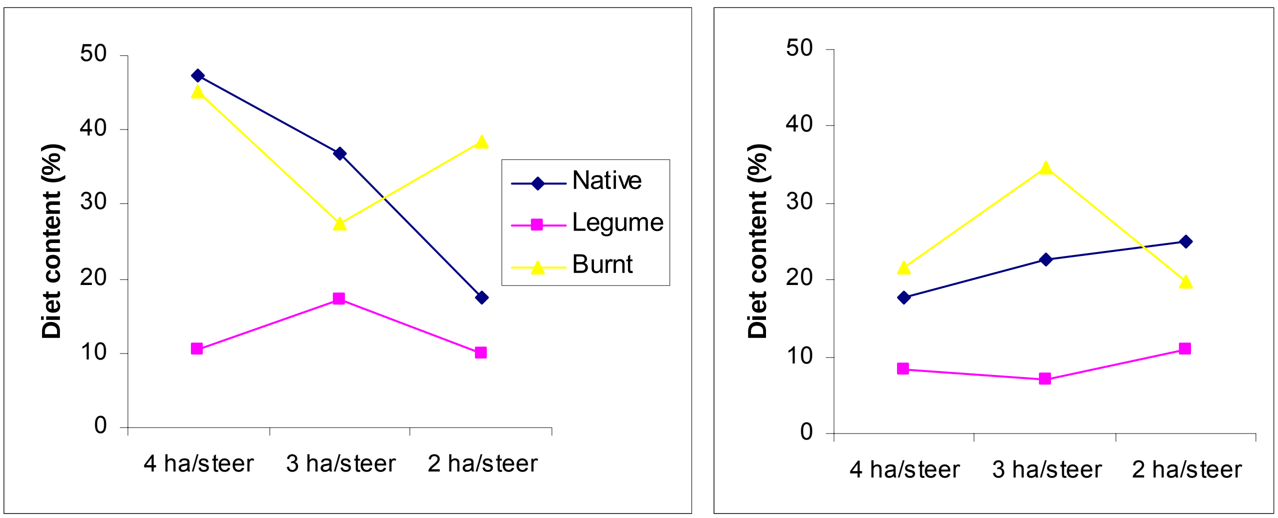


Figure 4.3.3 Diet content of (a) *H. contortus* and (b) *B. bladhii* in relation to a pasture type x stocking rate interaction in *H. contortus* pasture between 1992 and 2000. (Analyses performed on angular transformed data).

The diet content of the increaser species, *C. divaricata* and *Eragrostis* spp., was influenced (P<0.05) by pasture type x stocking rate and pasture type x year interactions. For the pasture type x stocking rate interaction (Figure 4.3.4), the diet content of *C. divaricata* was less than 2% at 4 ha/steer for all three pasture types and increased with stocking rate to be around 10% in native pasture grazed at 2 ha/steer but was only 5% in the legume oversown and supplement / burning treatments. For *Eragrostis* spp., diet content was negligible (<1%) irrespective of stocking rate or pasture type.

(a) (b)

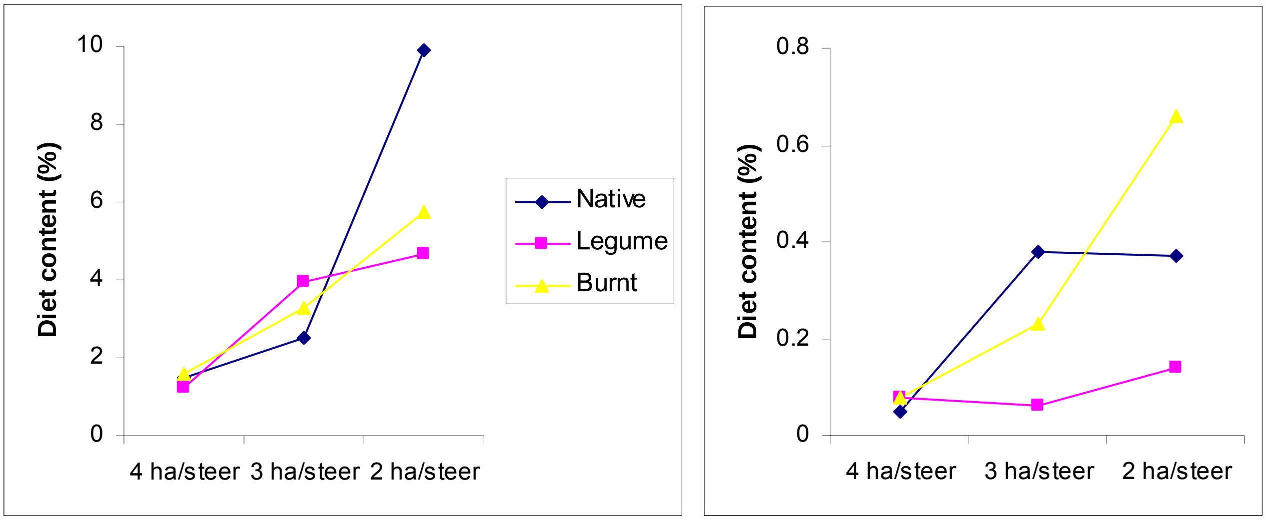


Figure 4.3.4 Diet content of (a) C*. divaricata* and (b) *Eragrostis* spp. in relation to a pasture type x stocking rate interaction in *H. contortus* pasture between 1992 and 2000. (Analyses performed on angular transformed data). (Note differences in scales).

The diet content of *C. divaricata* selected by fistulated steers (Figure 4.3 5) varied between years and pasture types from 0.1% to 12% being highest in the supplement / burning pasture in 1996. Similarly, the diet content of *Eragrostis* spp. varied between years from 3% in the supplement / burning treatment in 1996 and 0% in both legume oversown treatment in 1995 and 1996 and supplement / burning treatment in 1995.

(a) (b)

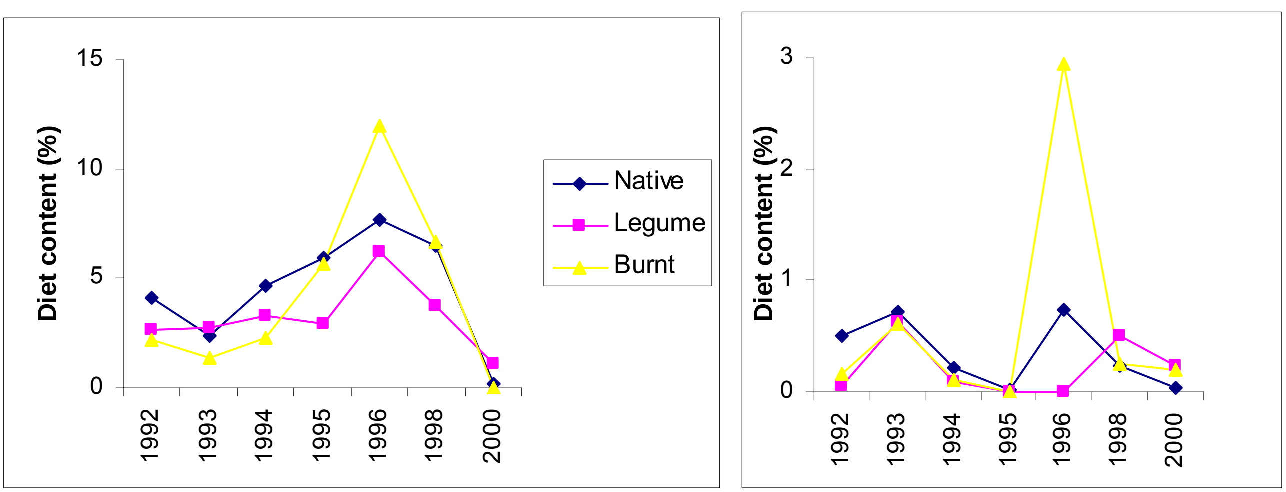


Figure 4.3.5 Diet content of (a) C*. divaricata* and (b) *Eragrostis* spp. in relation to a pasture type x year interaction in *H. contortus* pasture between 1992 and 2000. (Analyses performed on angular transformed data). (Note differences in scales).

The diet content of Seca stylo varied ($P<0.05$) with years (Figure 4.3.6) from 35% in 1992 to 66% in 1995. The diet content of *Chrysopogon fallax* was also influenced ($P<0.05$) by a pasture type x year interaction and was highest at 27% in the native pasture treatment in 1998 and was only 5% in 1995 also in the native pasture (Figure 4.3.7).

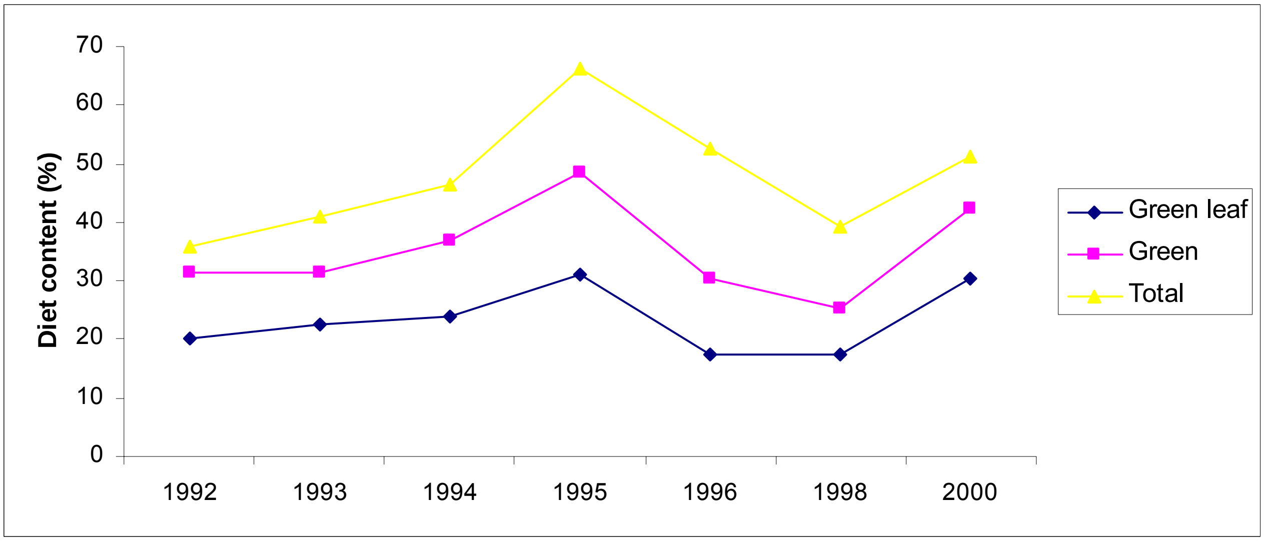


Figure 4.3.6 Green leaf, proportion green and total content (%) of Seca stylo in relation to years in *H. contortus* pasture between 1992 and 2000. (Analyses performed on angular transformed data).

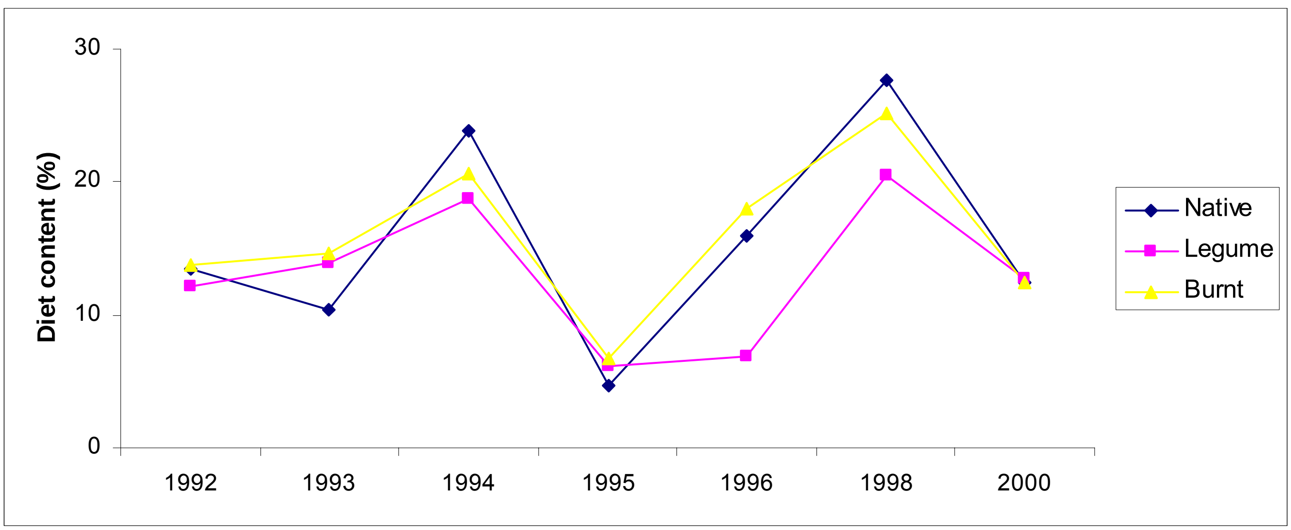


Figure 4.3.7 Diet content of *Chrysopogon fallax* in relation to a pasture type x year interaction in *H. contortus* pasture between 1992 and 2000. (Analyses performed on angular transformed data).

The occurrence of forbs in the diet was influenced ($P<0.05$) by both year and pasture type (Figure 4.3.8). Total forbs content varied with years to be highest at 7% in 1996 and lowest at 2% in 1995 while, for the pasture type effect, total forb content was highest at 8% in native pasture and lowest at 1% in the legume oversown treatments. Similarly, the Sedge content of the diet was influenced ($P<0.05$) by a pasture type x year interaction and was 14% in supplement / burning pasture in 1998 and 2% in 1995 legume oversown pasture (Figure 4.3.9).

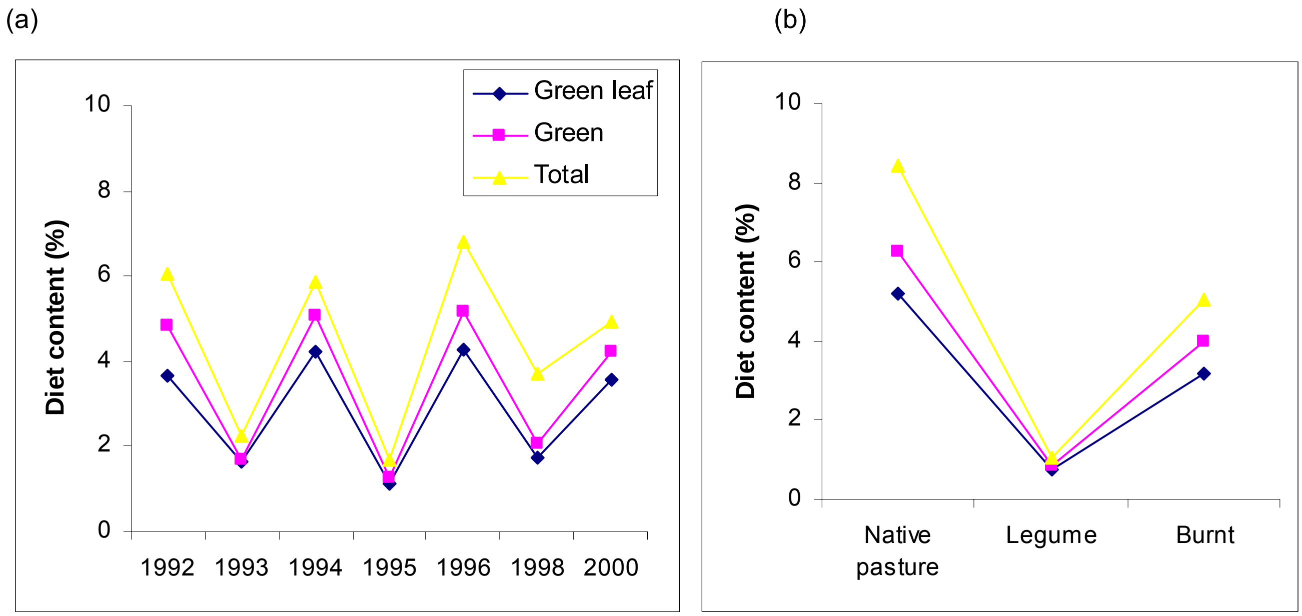


Figure 4.3.8 Green leaf, proportion green and total content (%) of forbs in relation to (a) year and (b) pasture type in *H. contortus* pasture between 1992 and 2000. (Analyses performed on angular transformed data).

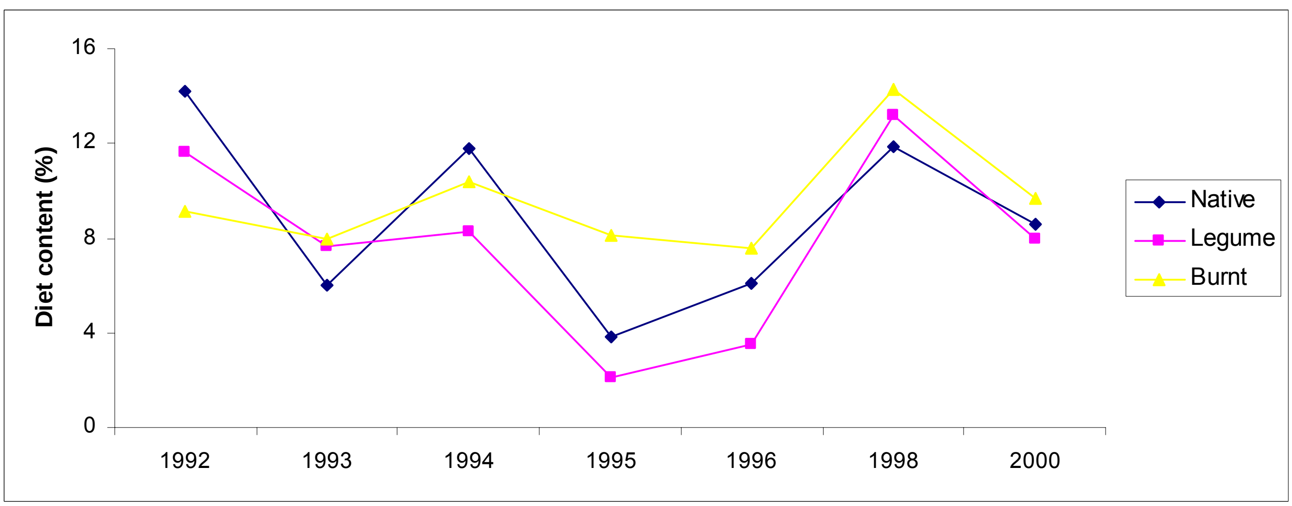


Figure 4.3.9 Diet content of Sedges in relation to a pasture type x year interaction in *H. contortus* pasture between 1992 and 2000. (Analyses performed on angular transformed data).

Of the other species measured in the diet, the occurrence of *Aristida* spp. was influenced ($P<0.05$) by year and pasture type (Figure 4.3.10) although the overall levels were minor and never exceeded 2%.

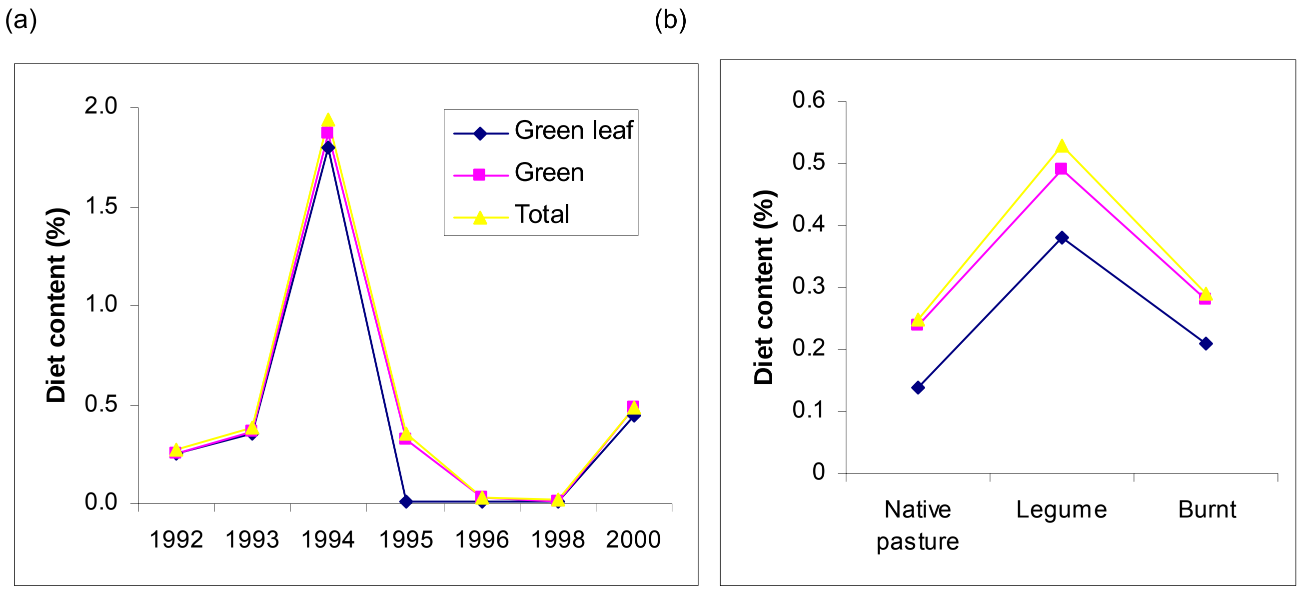


Figure 4.3.10 Green leaf, proportion green and total content (%) of *Aristida* spp. in relation to (a) year and (b) pasture type in *H. contortus* pasture between 1992 and 2000. (Analyses performed on angular transformed data). (Note differences in scales).

4.3.3.2 Impact of spring burning

Neither the 3 way pasture type x stocking rate x sampling date interaction nor the 2 way pasture type x sampling date nor the stocking rate x sampling date interactions were significant (P>0.05) for any species group or individual species. Consequently, the data were meaned across the three sampling dates (February 1992, November/December 1992 and March 1993) and data are presented for the significant (P<0.05) pasture type x stocking rate interaction for total diet content for *H. contortus, B. bladhii, C. divaricata* and *Chrysopogon fallax* (Figure 4.3.11). For *H. contortus* in native pasture, total diet content at 4 ha/steer was 38% and declined with increasing stocking rate to 33% at 2 ha/steer but there was no clear trend in the other 2 pasture types. The diet content of *B. bladhii* in the native pasture treatments increased from 20% at 4 ha/steer to 30% at 2 ha/steer and these overall levels of *B. bladhii* were intermediate between those in the legume oversown and supplement / burning pasture types. The diet content of *C. divaricata* in native pasture treatments increased from 2% at 4 ha/steer to 9% at 2 ha/steer and there was a similar increase in the supplement / burning pasture treatments, however, this trend was not apparent in the legume oversown pastures. For *C. fallax* in native pasture, total diet content at 4 ha/steer was 4% and increased with increasing stocking rate to 6% at 2 ha/steer and there was no clear trend in the other 2 pasture types although the overall levels in the supplement / burning were higher than in the other 2 pasture types.

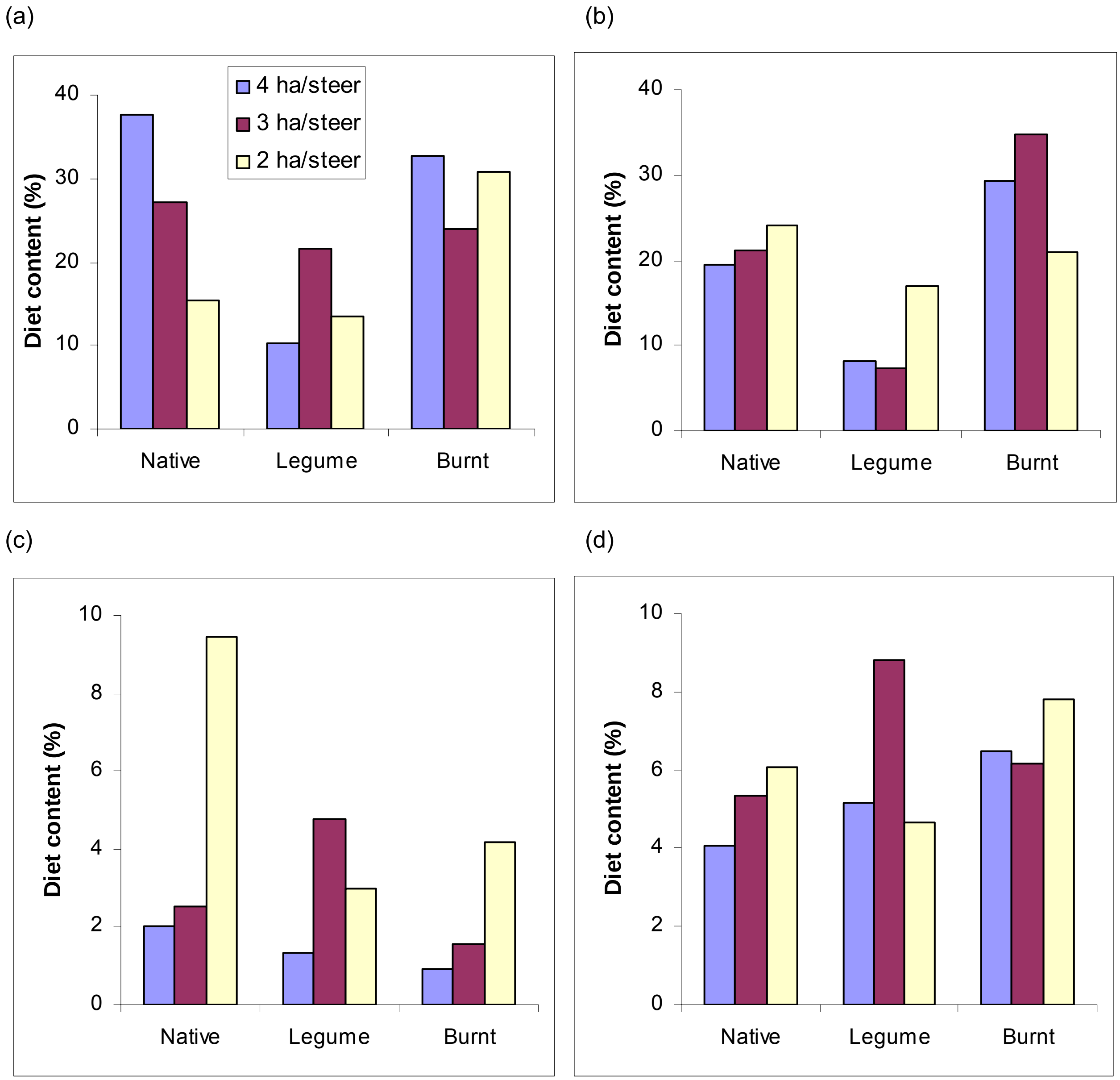


Figure 4.3.11 Diet content of (a) *H. contortus* and (b) *B. bladhii, (c) C. divaricata and (d)* C. fallax in relation to a pasture type x stocking rate interaction in *H. contortus* pasture between 1992 and 1993. (Analyses performed on angular transformed data). (Note differences in scales).

4.3.3.3 Diet across a pasture growing season

4.3.3.3.1 Seasonal rainfall

Seasonal rainfall totals varied from well above the long-term mean in January 1996 to well below the long-term monthly means from February through March to April 1996 (Table 4.3.1). This pattern of rainfall directly influenced animal diets through the impact of this rainfall on plant growth and hence species availability in pastures.

Table 4.3.1 A comparison of monthly rainfall totals between September 1995 and April 1996 at Galloway Plains with the long term means monthly totals for Calliope Station.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995								27	9	80	57	79
1996	306	39	0	14	30							
Mean	141	145	90	46	45	43	37	26	26	58	79	119

4.3.3.3.2 Decreaser and increaser species

Sampling from the break of the wet season in November 1995 through December 1995 and January 1996 and up until April 1996 showed major species shifts in the diet selected by fistulated steers. For the decreaser species, the green leaf and proportion green, but not the total diet content, were influenced (P<0.05) by sampling date with these diet components increasing from November to December, remaining similar from December to January and falling in April (Figure 4.3 12). For the increaser species, the green leaf, proportion green and total diet content were influenced (P<0.05) by stocking rate and the diet content of all three components increased as stocking rate increased from 4 to 2 ha/steer (Figure 4.3.13).

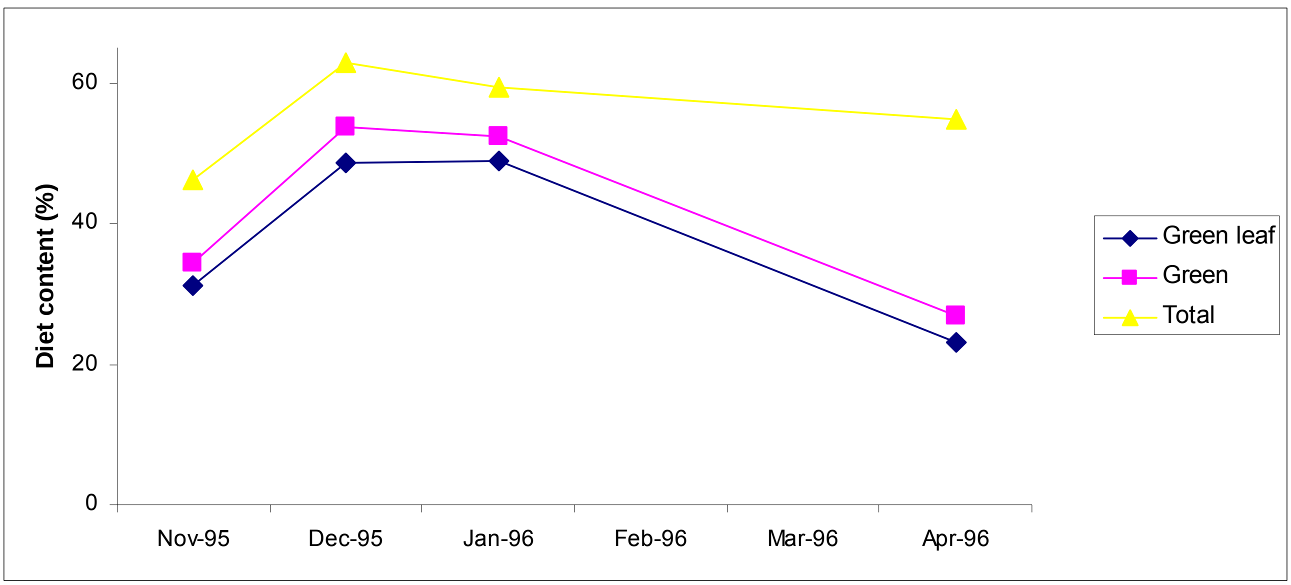


Figure 4.3.12 Green leaf, proportion green and total diet content of decreaser species in relation to sampling date between November 1995 and April 1996 in *H. contortus* pasture. (Analyses performed on angular transformed data).

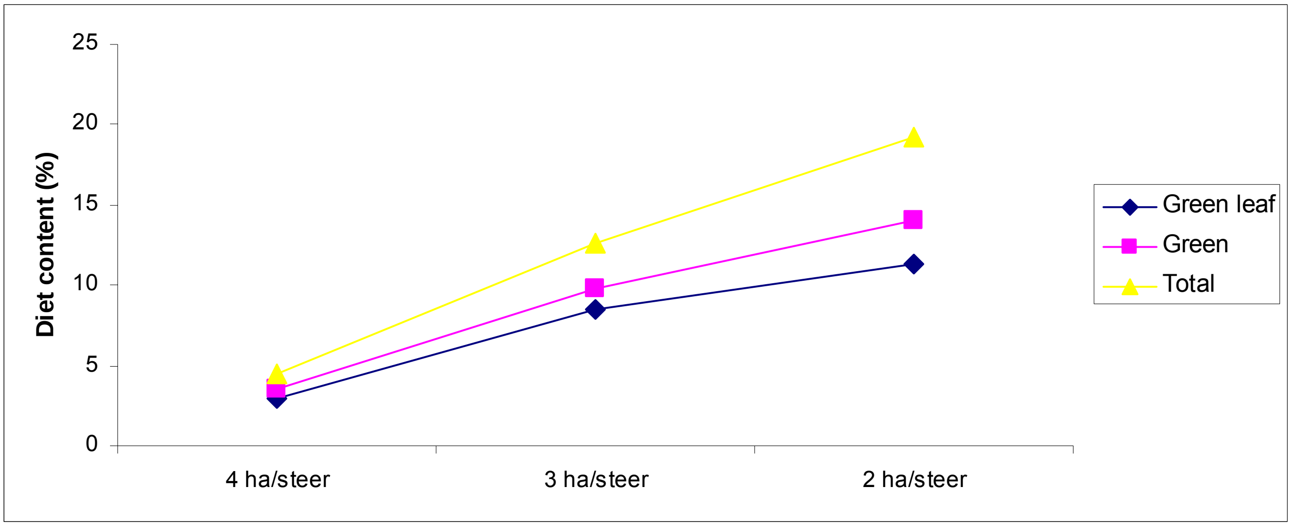
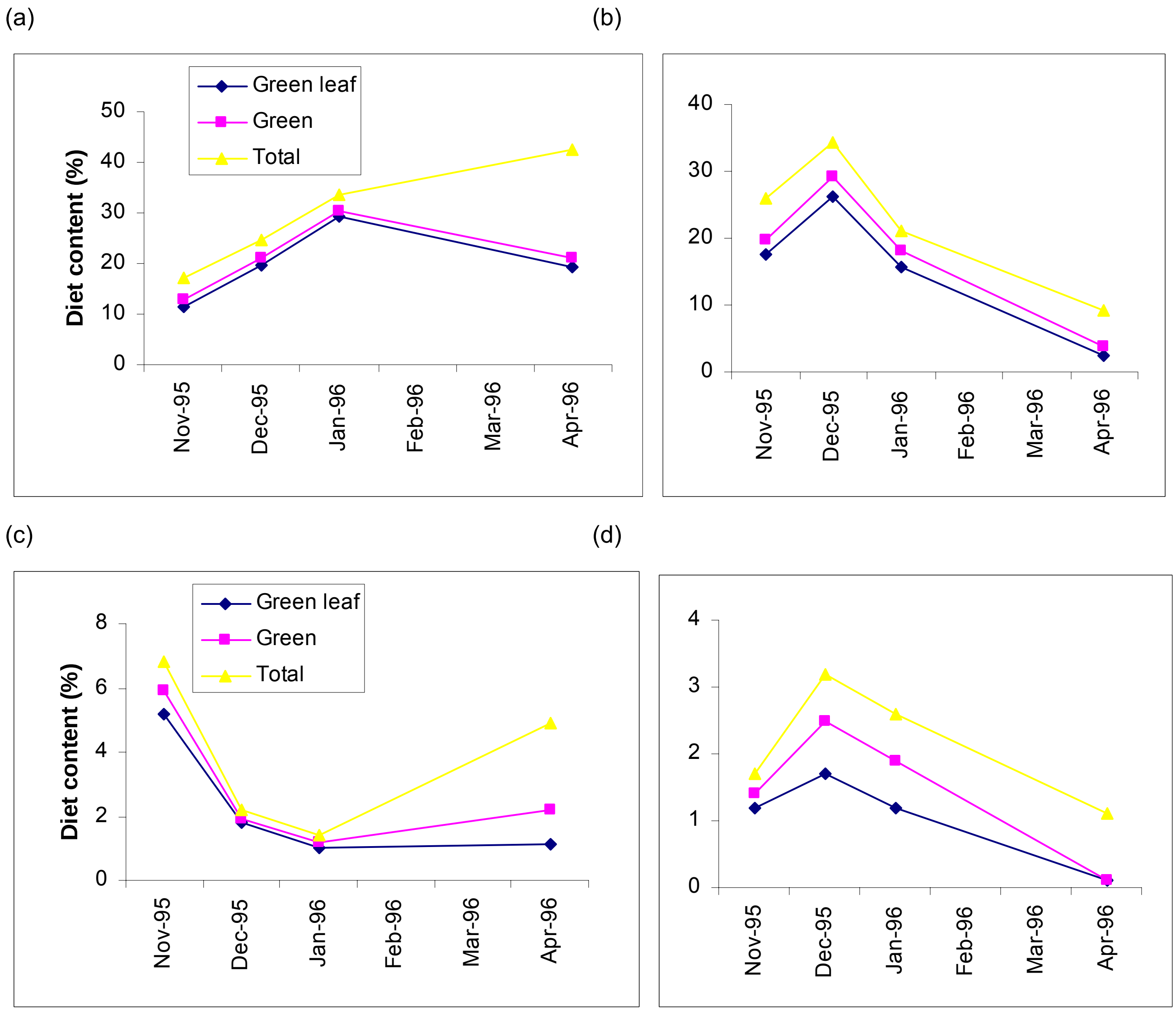


Figure 4.3.13 Green leaf, proportion green and total diet content of increaser species in relation to stocking rate between November 1995 and April 1996 in *H. contortus* pasture. (Analyses performed on angular transformed data).

4.3.3.3.3 Individual species

The green leaf, proportion green and total diet content of a range of individual species were influenced ($P<0.05$) by sampling date. For *H. contortus,* all components of the diet increased from 12% in November 1995 up to 30% in January 1996 and although the green leaf and proportion green declined to 20% after January, the total content continued to increase up to 40% in April 1996 (Figure 4.3.14a). For *B. bladhii,* all components of the diet increased from 20% in November 1995 to 30% in December 1995 and then continued to decline during January to be only 5% in April 1996 (Figure 4.3.14b). All three components of the diet of *Eragrostis* spp. continued to decline from 5% in November 1995 to 1% in April 1996 although the total diet content did increase after January 1996 to 5% in April 1996 (Figure 4.3.14c). The content of all three diet components of Sedge increased from 1% in November 1995 to 3% in December 1995 and then continued to fall progressively to <1% in April 1996 (Figure 4.3.14d) while there was a continuous decline in the Other grasses from 2% in November 1995 to <1% in April 1996 (Figure 4.3.14e).


(a)
(b)
(c)
(d)
Green leaf
Green
Total
Diet content (%)
0
10
20
30
40
50
8
6
4
2
1
3
Nov-95
Dec-95
Jan-96
Feb-96
Mar-96
Apr-96

(e)

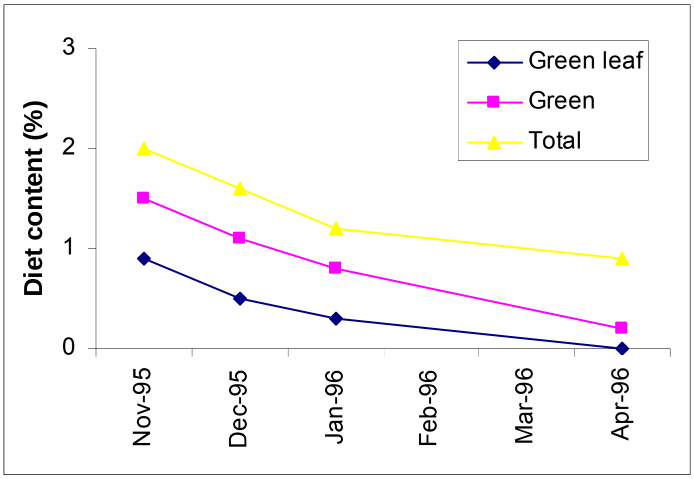
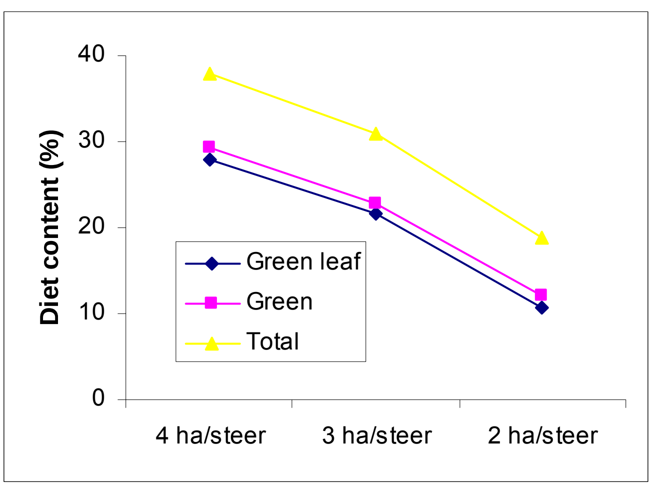
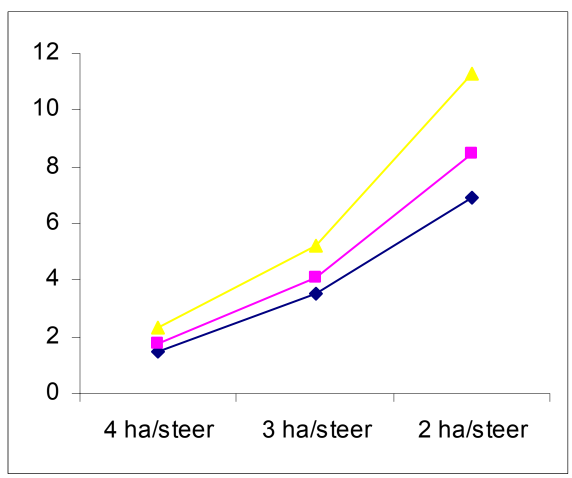


Figure 4.3.16 Green leaf, proportion green and total content (%) of (a) *H. contortus,* (b) *B. bladhii,* (c) *Eragrostis* spp., (d) Sedges and (e) Other grasses in relation to sampling date between November 1995 and April 1996 in *H. contortus* pasture. (Analyses performed on angular transformed data).

The green leaf, proportion green and total diet content of a range of individual species were influenced (P<0.05) by stocking rate. For *H. contortus,* all components of the diet were highest at 30% at 4 ha/steer and declined to 15% at 2 ha/steer (Figure 4.3.17a). The three diet components of *C. divaricata* were 2% at 4 ha/steer and increased progressively to 8% at 2 ha/steer (Figure 4.3.17b) while all three diet components of Eragrostis were 5% at the 3 ha/steer stocking rate and 1 an 2 % at the 4 and 2 ha/steer respectively (Figure 4.3.17c).

(a) (b)





(c)

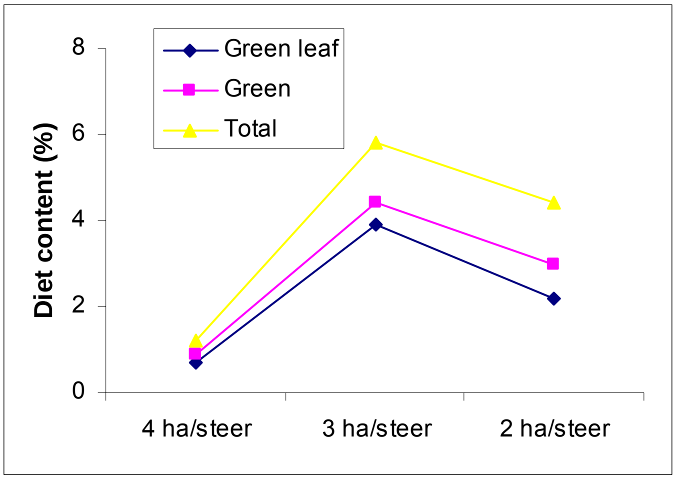


Figure 4.3.17 Green leaf, proportion green and total content (%) of (a) *H. contortus,* (b) C*. divaricata* and (c) *Eragrostis* spp. in relation to stocking rate between November 1995 and April 1996 in *H. contortus* pasture. (Analyses performed on angular transformed data).

4.3.4 Discussion

4.3.4.1 Diet in autumn

Between 1992 and 2000, steers selected a diet that consistently contained a high proportion of *H. contortus* when it was available in the pasture. Steers also selected Seca stylo, *Chrysopogon fallax*, forbs and Sedges in autumn. Increaser species *Chloris divaricata* and *Eragrostis* spp. were neither preferred nor rejected whereas *B. bladhii* was seldom preferred despite the that fact that it was a major contributor to total pasture yield (See Section 4.1. Impact of grazing on pastures). Diet content was influenced by stocking rate, pasture type and also by year and their interactions and results were similar whether species content of the diet was determined from either total content of a species, total green or green leaf.

The selection for *H. contortus* at Galloway Plains is consistent with the results from a similar study in a mixed *H. contortus* / *B. bladhii* pasture near Gayndah, elsewhere in southern Queensland and which also indicated a strong preference for *H. contortus* (R. E. Hendricksen, unpublished data). However, this measured selection for *H. contortus* contrasts with other studies where this species was the least preferred species in a *Themeda* veld in Zimbabwe (Gammon and Roberts 1978). Similarly, in tropical northern Queensland *H. contortus* pastures, *H. contortus* was preferred only at the start of the wet season (Hendricksen *et al.* 1999).

The major impact of increasing stocking rate was to reduce total yield and the availability of preferred species, particularly *H. contortus,* in the pasture. This reduced yield and availability of preferred species lead steers to select a range of other, less preferred species. For example, increasing stocking rate increased the availability of the Increaser species, *Chloris divaricata* and *Eragrostis* spp. (See Section 4.1. Impact of grazing on pastures). Consequently, these Increaser species were increasingly selected in the diet and were selected in similar proportion to their availability in the pasture. Thus, these Increaser species were neither preferred nor rejected. Anderson (1993) reported that *C. divaricata* is moderately palatable when young but lacks bulk and is, therefore, not highly valued as a grazing species while *E. sororia* is relatively insignificant because of its low yield compared with other native grasses.

Pasture type influenced the availability of the different species in the pasture: generally, most species were less available in legume oversown pasture compared with the other two pasture types. For example, the lower *H. contortus* diet content in legume oversown pastures reflects the fact that steers were selecting a diet that contained 20-60% of Seca stylo with a consequent reduction in the proportion of *H. contortus*. This selection of Seca stylo in autumn is consistent with other diet studies in legume oversown pastures (Coates 1996) showing that the proportion of stylo in the diet increased during the wet season reaching a peak of 80% in the late wet season or early dry season.

The content of the diet selected by fistulated steers also varied among years. This probably reflects the influence of rainfall conditions prior to sampling on species availability – especially of lower yielding Forbs and Sedges in the pasture. However, the year effect of Seca stylo is probably not a reflection of rainfall conditions and probably reflects the rapidly changing Seca content of the diet throughout the growing season (Coates 1996) because the fistula samplings at Galloway Plains occurred between the months of February to April between the years of 1992 to 2000. Interestingly, the levels of Seca stylo in the diet in autumn between 1992 and 2000 failed to reflect the large change in Seca availability in the pasture which increased from a plant density of 7 plants/m^2 and yield content of 20% in 1992 to 65 plants/m^2 and 50% in 2000. This finding suggests that by 1992, this density of 7 mature plants/m^2 and pasture content of 20% may represent a "threshold" level whereby animals were always able to select a satisfactory level of Seca leaf in their diet. However, this suggestion conflicts with the apparent trend for the liveweight advantage for steers grazing legume oversown pastures to increase with time and with increasing legume content in the pasture (Section 4.2 Animal production).

Andrew (1986) reported that cattle generally reject *Chrysopogon fallax* in northern Australia. On coarse textured soils in southern Queensland, Wandera (1993) classified *C. fallax* as undesirable because it forms dense patches which tend to exclude the growth of other, more productive pasture species in otherwise *H. contortus* dominant pastures. However, at Galloway Plains steers actively selected *C. fallax* as indicated by the fact that it comprised 18% of the diet at the time when its availability was only 2 % of the pasture. Reasons for these divergent results with this species are not clear.

Forbs comprised 2 to 8% of the diet but constituted always less than 1% of pasture yield. This preference is consistent with other reports of their usefulness to sheep in *Astrebla* (Mitchell grass) grassland and *Acacia aneura* (mulga) woodland (McMeniman *et al.* 1986). The pasture type effect on forb diet content may be a reflection of reduced forb frequency in legume oversown pasture or, alternatively, it may reflect the selection of oversown legumes, rather than forbs. McMeniman *et al.* (1986) also reported increased diet levels of nitrogen and some minerals when sheep selected forbs while Ash *et al.* (1995) suggested the superior protein nutrition of animals grazing a partially degraded monsoon tallgrass pasture was associated with a higher C_3 (i.e. forbs) content of the diet compared with pasture that was not degraded.

Sedges were often preferred as indicated by the 14% diet content of steers despite the availability in the pasture being always less than 1%. Reasons for the pasture x year interaction are not clear. The frequency of Sedges was increased in supplement / burning pastures particularly after 1998, however, this increased frequency was not reflected in higher diet contribution in this pasture type.

Steers did not prefer *B. bladhii* and this was most noticeable in wet years when the availability of other pasture components was high and steers had a greater opportunity to select more palatable species. This lack of preference for *B. bladhii* occurred in all years and across all treatments despite the fact that it was the major grass contributing around 50% of total pasture yield. Similarly, steers rejected *Themeda triandra* even though this species contributed 50% of the pasture yield in tropical, northern *H. contortus* pastures near Mareeba (Hendricksen *et al.* 1999). This lack of preference for *B. bladhii* supports the earlier suggestion (see Section 4.1 Impact of grazing on pastures) that *B. bladhii* may replace *H. contortus* under long term heavy grazing especially in the absence of burning.

Aristida spp. was recorded in the diet of steers albeit at low levels compared with its availability in the pasture. Levels in the diet were usually less than 1% although these levels did increase to be almost 2% in 1994, however the reason for more *Aristida* spp. in the legume oversown pasture compared with the other two pasture types is not clear. The low levels of *Aristida* spp. in the diet are consistent with this species being regarded as being unpalatable.

4.3.4.2 Impact of spring burning

Burning in September 1992 resulted in reduced total pasture yields in autumn 1993 in the supplement / burning treatments however, there were no differences in the yields of either *H. contortus* or *B. bladhii*. Therefore, there were few major differences in animal diets. Despite no change in pasture composition, a pasture type x stocking rate interaction influenced the content of four species in the diet. Three of these species, *H. contortus*, *B. bladhii* and *Chloris divaricata* displayed similar patterns to that measured in autumn between 1992 and 2000. The fourth species, *Chrysopogon fallax*, displayed a different response to its previously measured autumn diet pattern.

The occurrence of *Chrysopogon fallax* in the diet following the spring 1992 burning increased with increasing stocking rate whereas no stocking rate effect was recorded in any of the diet samplings in autumn. No clear explanation can be made as to why a stocking rate effect was apparent following spring burning but not apparent over seven autumn samplings. This stocking rate effect following the 1992 spring burning is even more puzzling given that there were no significant stocking rate or pasture type effects on the composition of *C. fallax* in the pasture in autumn 1993.

Clearly, this study of the impact of spring burning was conducted too early in the overall grazing study when few differences in pasture composition were apparent. Furthermore, as subsequent burning studies indicated, the stocking rates being used in 1992-93 were too high for the proper expression of the impact of spring burning on pasture composition to become apparent. Given this, it would have been better if the study of spring burning on diet content had been delayed until the 1999-2000 summer when substantial differences in the proportion of *H. contortus* in the pasture were achieved with spring burning and a more conservative stocking rate.

4.3.4.3 Diet across a pasture growing season

Rainfall conditions between October 1995 and January 1996 promoted good pasture growth and this ensured the availability of a wide range of species in the pasture. In contrast, extremely dry conditions between February and April 1996 restricted pasture growth and by the April 1996 sampling the availability of some species had been severely reduced particularly in the heavy stocking rate treatments. Consequently, sampling date influenced diet content through species availability in the pasture which, in turn, reflected rainfall driven pasture growth as evidenced by changes in Decreaser species across the four sampling occasions. Stocking rate influenced diet content through its increasing impacts on pasture composition as evidenced by the increased availability of increaser species and increasing competition between steers to select for better species.

The diet content of individual species reflected similar patterns to those recorded in the annual autumn diet samplings. For example, *H. contortus* was actively selected when it was available and this availability increased continuously over the sampling period. However, this availability was reduced by increased stocking rate as evidenced by the reducing diet content with increasing stocking rate. Interestingly, the total diet content of *H. contortus,* but not green leaf or proportion green, increased progressively across the four sampling dates to be highest in April 1996. *H. contortus* usually has mature inflorescences present on plants in April and this high proportion of *H. contortus* in the diet in April clearly indicates that cattle select this species even when mature inflorescences are present. Similarly, the annual autumn samplings indicated that Sedge was selected when it was available in the pasture and this study across the growing season reflected this preference for Sedge when it was available in the pasture.

The stocking rate impact evident for diet content of *Chloris divaricata* and *Eragrostis* spp. further supports the annual autumn sampling data indicating that these species are selected as stocking rates increase and so increases their availability in the pasture. However, no reason can be advanced for the diet content of *Eragrostis* spp. which was highest at 3 ha/steer and not 2 ha/steer even though overall levels were low.

4.3.5 Conclusions

Overall, this study has shown clearly that steers preferentially graze *H. contortus* when it is available in the pasture. This result was recorded in autumn following a range of growing seasons and across the early, mid and late wet season (October through until April). Steers also preferentially graze Seca stylo, *C. fallax,* Forbs and Sedges in autumn when they are available in the pasture. Except for Seca stylo, these species were relatively minor components of the pasture. As the impacts of increasing stocking rates changed pasture composition in this study, intermediate species such as *Chloris divaricata* and *Eragrostis* spp. increased in availability and steers increasingly grazed these species. Across all treatments and seasons, cattle seldom grazed *B. bladhii* despite the fact that this species often comprised around 50% of pasture yield.

4.4 Economic evaluation

An economic evaluation of the grazing treatments at Galloway Plains was conducted using the Net Present Value (NPV) method and was based on the following assumptions:

1. Animal liveweight gain was based on the liveweight gain per steer for each treatment meaned for the 12 drafts of steers.
2. A 1 000 ha paddock over a 12 year time scale with capital (livestock) inputs with borrowings and discount rate of 6% applying over the period.
3. Steers entered treatments at 180 kg liveweight and were retained until a mean liveweight of 450 kg when they were sold as stores for finishing.
4. Steers were priced into the paddock at $1.95 per kg liveweight which was the price paid at the Gracemere Saleyards in central Queensland for store steers on 19 March 2004.

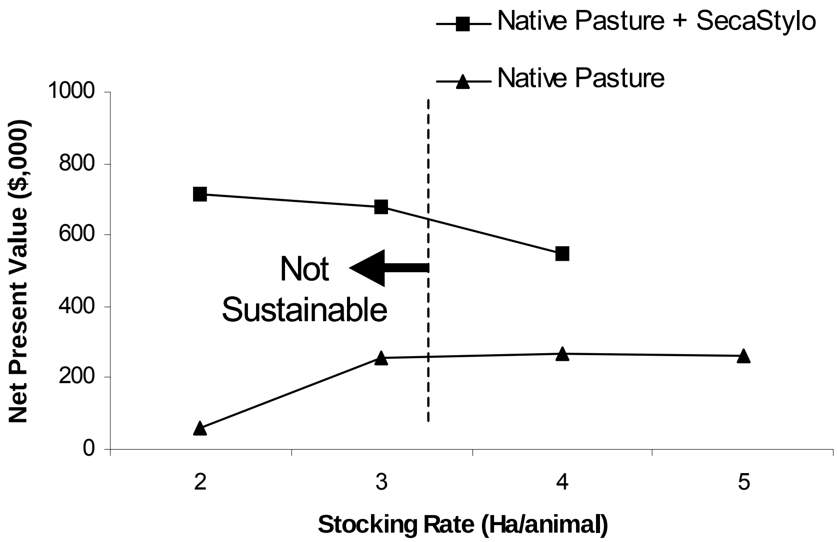


Figure 4.4.1 An economic evaluation of grazing at Galloway Plains using Net Present Value.

For steers grazing native pasture, financial returns were similar at 3, 4 and 5 ha/steer but were reduced at 2 ha/steer because of the reduced liveweight gain per head achieved at this heavy stocking rate (Figure 4.4.1). This analysis indicated that heavier stocking rates were profitable in the short term. However, this analysis failed to account for the deleterious impact of these heavier stocking rates on the pasture and soil resource. While large scale changes in pasture content were not readily evident, the landscape function analysis provided clear evidence that heavier stocking rates are unsustainable in the long term.

Financial returns from grazing legume oversown pastures were higher than at the same stocking rate in native pasture. For the legume oversown treatments, grazing at 3 and 2 ha/steer was economic in the short term however this analysis failed to take into account the deleterious impacts of these stocking rates on soil and pasture conditions and so must be considered to be unsustainable.

5 Success in Achieving Objectives

Objective (1). Assess the productivity and stability of native pastures grazed at a range of stocking rates, with or without the addition of legumes and fire.

This objective was fully achieved. The grazing study clearly established that cattle production is sustainable when native pasture is grazed continuously at 4 ha/steer which equates to 30% pasture utilisation. Increasing stocking rate to 3 or 2 ha/steer increased pasture utilisation beyond 30% and became increasingly unsustainable. This was indicated by reduced total pasture yield, reduced occurrence of desirable perennial grasses, increased occurrence of intermediate grasses and changes in the occurrence of a range of minor species. Oversowing legumes into native pasture resulted in a substantial increase in the contribution of legume to total pasture yield, reduced the contribution of *H. contortus* and changed the occurrence of a range of minor species. Spring burning increased the occurrence of *H. contortus* but only at light stocking rates.

Animal production per head was greatest at the lightest stocking rate but declined with increasing stocking rate. Animal production per hectare was highest at the heaviest stocking rate and decreased with increasingly light stocking rate. Oversowing legumes substantially increased animal liveweight gain over native pasture at the same stocking rate. Burning had a variable impact on animal production compared with native pasture. Animal diet studies using oesophageal fistulated steers indicated that cattle preferentially grazed *H. contortus* when it was available in the pasture. Cattle also selected *Chrysopogon fallax*, Seca stylo, forbs and sedge species when they were available in the pasture. Cattle seldom preferred *Bothriochloa bladhii* despite the fact that this species often comprised around 50% of the pasture yield.

Objective (ii). Use the results recorded between 1988 and 1996 to demonstrate to producer groups that lenient grazing together with other pasture technologies can be both ecological and economically viable.

Throughout the duration of the grazing study, large numbers of individual producers and LandCare groups visited the site. Field days were conducted for a number of regional groups including Calliope, Miriam Vale, Marlborough and Mornish LandCare groups. The Mornish and Marlborough LandCare group visits were particularly successful as both groups travelled to and from the site by bus with lively discussion on the return trips following the results presented during their visits. A final Galloway Plains field day was held at Galloway Plains on 10 May 2001 with over 200 producers attending. A number of the producer present had attended earlier field days and discussion days and had returned to seek further information.

A producer friendly booklet of the Galloway Plains grazing study entitled “Sustainable cattle production from Black Speargrass pastures in central Queensland” is at an advanced stage of preparation. This booklet details the results from the grazing study and presents practical guidelines for the sustainable grazing management of *H. contortus* pastures in central Queensland.

Results from Galloway Plains grazing study are being incorporated into the Grazing Land Management Education Package. The DPI&F staff who were responsible for the conduct of the Galloway Plains grazing study are actively assisting Grazing Land Management Education staff in central Queensland to tailor the package for the Fitzroy Basin

Objective (iii). Promote basic pasture science and monitoring techniques so that producers can better recognise ecological processes.

This objective was achieved through a series of field and discussion days conducted with local producers and LandCare groups.

This objective was achieved through a Producer Advisory group which was selected to represent a range of producers, scientist and extension staff throughout central Queensland. This Producer Advisory Group met twice per year between 1998 and June 2001 and challenged the Galloway Plains research team in a wide range of sustainability and production issues. For example, the theme of what was the right balance of grass: stylo and how to maintain that balance was a recurring issue. This issue was the focus of further research including the “Strathmuir” Producer Demonstration Site (1997-2001) and subsequent “Belmont” stylo management study (2000-current).

Results from Galloway Plains grazing study are being incorporated into the Grazing Land Management Education Package. The DPI&F staff who were responsible for the conduct of the Galloway Plains grazing study are actively assisting Grazing Land Management Education staff in central Queensland to tailor the package for the Fitzroy Basin.

Objective (iv). Conduct comprehensive economic analyses of animal production from all pasture treatments including the application of the results to commercial case studies. A designated economist will be appointed by 31-12-1997 pending the Beef Institute restructuring.

This objective was not achieved. A designated economist was not appointed to conduct the comprehensive economic analyses of animal production. Nevertheless, a detailed economic analysis was conducted and this analysis reinforced the conclusions supporting a stocking rate of 4 ha/steer. Any economic advantage achieved by stocking at 3 or 2 ha/steer dissipated with time as the impact of this heavy grazing resulted in deleterious changes in the condition of the soil and pasture resources (Section 4.1 Impacts of grazing on pastures). In turn, this decline in soil and pasture condition resulted in reduced animal liveweight performance.

Objective (v). Incorporate results from this study using GRASP to determine optimum stocking rate and economic performance for commercial beef enterprises in the black speargrass region.

This objective has not been met within the current project. However, the Galloway Plains data is being incorporated in GRASP calibration and modelling research being undertaken as part of the MLA funded modelling project “NBP.338 Improving grazing management using the GRASP model”.

Objective (vi). Promote the results from this study and encourage adoption of optimum stock management strategies as outlined in the draft communication strategy.

Staff involved with the Galloway Plains grazing study have actively promoted the results throughout the duration of the study and encouraged the adoption of sustainable grazing management practices. Major field days were conducted at approximately 3 year intervals and these days were well attended by regional producers from Marlborough / St Laurence in the north to Miriam Vale / Gin Gin in the south.

6 Impact on Meat and Livestock Industry – now & in five years time

This project established that stocking rates in excess of 4 ha/steer are unsustainable in the long term. It identified plant species whose increased presence act as indicators of unsustainable grazing practices. The landscape function study indicated the nature of those subtle changes that occurred in the soil surface under heavy grazing. Throughout this project, maximum liveweight gain per hectare has continued to be achieved at the heaviest stocking rates and, in the later years, this has been achieved increasingly at the expense of pasture sustainability and is uneconomic. Despite the widespread distribution, discussion and promotion of the results of this study, it is clear that these results have had little apparent impact on the adoption of sustainable grazing management practices in central Queensland. Comparisons between paddocks at Galloway Plains and regional, commercially grazed paddocks – regional “fence line contrasts” - readily indicate that commercial stocking rates are, in some cases, heavier that the 2 ha/steer which was the heaviest employed at Galloway Plains. It follows, therefore, that a number of commercially grazed properties in the central *H. contortus* region are being grazed unsustainably. Such a conclusion is consistent with the recent findings of McKeon (2004).

Beef production which cannot demonstrate long-term sustainability has important ramifications for the Australian beef industry. Firstly, international trade is moving towards quality assurance programs for land management practices and it is likely that there will be sanctions on those producers who cannot comply with such programs. Secondly, increasing community concern is focusing on the impacts of land management practices on downstream effects including water quality and the ecology of the Great Barrier Reef. These indications strongly suggest that grazing management practices in *H. contortus* pastures in central Queensland need to be improved to achieve long term sustainability in order to comply with quality assurance programs and community expectations of sustainable land use practices.

7 Conclusions and Recommendations

7.1 Conclusions

This study indicates that cattle production in *H. contortus* pastures is sustainable when native pasture is grazed continuously at 4 ha/steer. Increasing stocking rates above 4 ha/steer, in the long term, results in increasingly deleterious changes in the pasture resource such that cattle production will eventually become unsustainable. The proportion of *Stylosanthes scabra* cv. Seca in the pasture increased over time and resulted in some deleterious changes in pasture species. The unsustainable nature of grazing at a stocking rate of 2 ha/steer, both in native pasture and legume oversown native pasture, was highlighted by the landscape function analysis study conducted at the end of this grazing study. Spring burning promotes the establishment of *H. contortus* but only at light stocking rates.

Annual liveweight gain per steer was highest at the lightest stocking rate although annual liveweight gain per hectare was highest at the heaviest stocking rate. Annual liveweight gain was highly variable between years. Oversowing legumes into these pastures resulted in a liveweight advantage over native pasture at the same stocking rate and this advantage averaged 37 kg/steer over the 13 years of this study. The impact of spring burning on liveweight was highly variable. Animal diet studies indicated that cattle preferentially grazed *H. contortus* and also selected *Chrysopogon fallax*, Seca stylo, forbs and sedge species when these species were available in the pasture. Cattle failed to select *Bothriochloa bladhii* despite the fact that this species was a major contributor to pasture yield.

The findings from this extensive grazing study have been extended widely however there is little evidence that these results have had much impact on commercial grazing practices.

7.2 Recommendations

Recommendation 1. Further research into plant species diversity under grazing.

Pasture sampling in this study failed to address individual plant species diversity because pasture sampling measured the occurrence of many minor species only as plant groups such as “Native legumes”. Further research is required to identify the ecological role of individual species, how they may indicate stocking rate trends and how they can contribute to overall measures of plant species diversity.

Recommendation 2. Further research into the role of *Bothriochloa bladhii* in *H. contortus* pastures.

This study has highlighted that *Bothriochloa bladhii* is a major contributor to pasture yield in the *H. contortus* pastures at Galloway Plains yet the animal diet studies indicate that *B. bladhii* is not always a major component of cattle diets. Little is known of the ecological role of *B. bladhii* either in *H. contortus* or in other pasture types in Queensland. Further research is required to (a) identify the ecological role of *B. bladhii* in both *H. contortus* and other native pasture communities in Queensland and (b) from an animal production perspective, would it be desirable to replace *B. bladhii* with more the more desirable *H. contortus.*

Recommendation 3. Further research into the role of maintaining grass: stylo balance and the role of stylo content in improving animal liveweight.

This study recorded a progressive increase in Seca stylo density from <1 plant/m2 in 1988 to almost 100 plants/m^2 in 2001. This increase was associated with a trend of increasing liveweight advantage to legume oversown pastures compared with native pastures. However, the levels of Seca stylo in steer diets after 1992 failed to reflect this increase in Seca availability. Further research is required to (a) identify what constitutes a suitable grass: stylo balance, (b) devise grazing management strategies to maintain this balance and (c) define what level of legume content in the pasture gives maximum benefit to animal production.

Recommendation 4. Further research into the role of spring burning on ecological aspects of pasture condition and on cattle liveweight gains.

This study has given inconsistent information on the impact of spring burning on pasture content and animal liveweight gain. Little burning was possible particularly between 1992 and 1996 due to reduced fuel loads due to increased stocking rates and below average rainfall. Further research is required to determine the impacts of spring burning on (a) pasture species diversity and landscape functioning and (b) those factors resulting in the variable impacts on animal liveweight gain.

Recommendation 5. Promotion of impacts of this study for the adoption of sustainable stocking rates in *H. contortus* pastures.

Despite widespread distribution of the results of the Galloway Plains grazing study, it is clear from regional “fence line” contrasts that a number of properties in the *H. contortus* pasture zone of central Queensland are using unsustainable grazing practices. It is recommended that further extension of the results from Galloway Plains needs to be undertaken.

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9 Appendices

9.1 Publications arising from the Galloway Plains grazing study

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9.2 Links with Faecal NIRS – development and applications

The Galloway Plains grazing experiment contributed to the development of faecal NIRS calibration equations to predict two variables:

1. The proportion of non-grass in the diet
2. Liveweight change of cattle.

In addition, F.NIRS provided information for the Galloway Plains experiment by providing estimates of the quality of the diet (specifically dietary crude protein and diet digestibility) for some paddocks where faecal samples were taken on a sequential basis, thus allowing comparisons between treatments in the quality of the diet selected.

9.2.1 Faecal NIRS for predicting faecal δ13C and thus the proportion of non-grass in the diet.

A total of 162 faecal samples (bulked within individual paddocks) representing collections made on 8 occasions August 1996 – May 1998 were used to validate the faecal NIRS calibration equation for predicting faecal δ^{13}C. Samples were derived from nine treatments; these were the 4, 3 and 2 ha/steer stocking rates for the native pasture, legume oversown and supplements / burning treatments. The milled faecal samples (1 mm screen) were scanned using a NIRSystems 6500 spectroscope at the CSIRO Davies Laboratory to provide NIR spectra of the faecal samples, while reference δ^{13}C values were determined by mass spectrometric analysis (Central Queensland University) after fine grinding with a Tema mill. The reference values obtained from the mass spectrometer analysis were compared with values predicted by faecal NIRS. The validation relationship, the relationship between the reference and the predicted values, was considered to be most satisfactory with a Standard Error of Prediction (SEP) of 0.57 and R^2 of 0.94 (Figure 1).

In a second step, these samples from the Galloway Plains experiment were then merged with the existing calibration set and a new, more robust calibration equation was developed. The results from samples obtained from other experiments have subsequently been added to the calibration set; this set now contains just over 1500 samples of which 162 were derived from the Galloway Plains experiment. When the Galloway Plains samples are predicted from the NIR calibration equation based on the complete data set the relationship between reference and predicted faecal $\delta^{13}C$ values for the Galloway Plains samples had a SEP of 0.41 and R^2 of 0.97 and was therefore highly satisfactory.

Dietary non-grass proportions are calculated from faecal $\delta^{13}C$ using the equation:

$$\text{Dietary non-grass (\%)} = (\text{Faecal } \delta^{13}C - 13.5) * 7$$

This equation uses the absolute values for faecal $\delta^{13}C$ (negative sign ignored) and assumes that the average faecal $\delta^{13}C$ for a pure C_4 grass diet is 13.5 and for a pure C_3 non-grass diet is 27.5.

These results indicate that the faecal NIRS calibration equation did provide a reliable and accurate prediction of the faecal $\delta^{13}C$, and therefore of the proportion of non-grass, in the diet selected by grazing cattle.

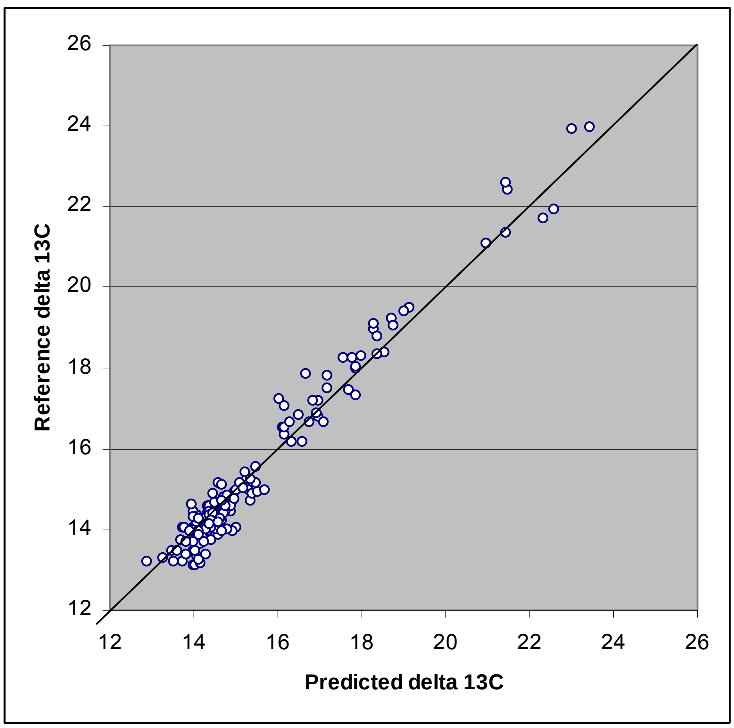

Figure 1. Relationship between reference and predicted faecal $\delta^{13}C$ for 162 samples from the Galloway Plains grazing experiment based on predictions made with the most recent calibration equation (June 2004). Note the omission of negative signs for faecal $\delta^{13}C$ values.

9.2.2 Faecal NIRS for predicting the liveweight change of grazing cattle

Faecal samples and liveweight change data were used from the paddocks where the treatment imposed was a stocking rate of 4 ha/steer native pasture and legume oversown treatments for the period August 1999 to May 2000. Faecal samples (bulked within individual paddocks) were collected for the 14 occasions and cattle liveweight growth rate reference values coinciding with the time of sampling were calculated from the liveweight gain curves. Sample spectra and reference values for 45 samples were included in the faecal NIRS growth rate calibration set. The current growth rate calibration set consists of 1150 samples and includes 43 samples from Galloway Plains. Thus data from the Galloway Plains experiment made a substantial contribution to the general faecal NIRS calibration equations to predict liveweight change.

9.2.3 Prediction of the quality of the diet selected from faecal NIRS measurements

Faecal samples were collected periodically for the duration of the trial from paddocks of 9 treatments where the pasture was native pasture, pasture oversown with legume, and the supplement/burning treatments, each with stocking rates of 4, 3 and 2 ha/steer. Predictions of dietary crude protein, faecal N concentration, digestibility and dietary non-grass proportions were made using faecal NIRS calibration equations. By way of example, nutritional profiles generated from faecal NIRS predictions for the period March 1999 to May 2000 are presented in Figure 2. These nutritional profiles will add to the library of dietary profiles for cattle grazing in a variety of pasture systems and regions of northern Australia and across a number of seasons.

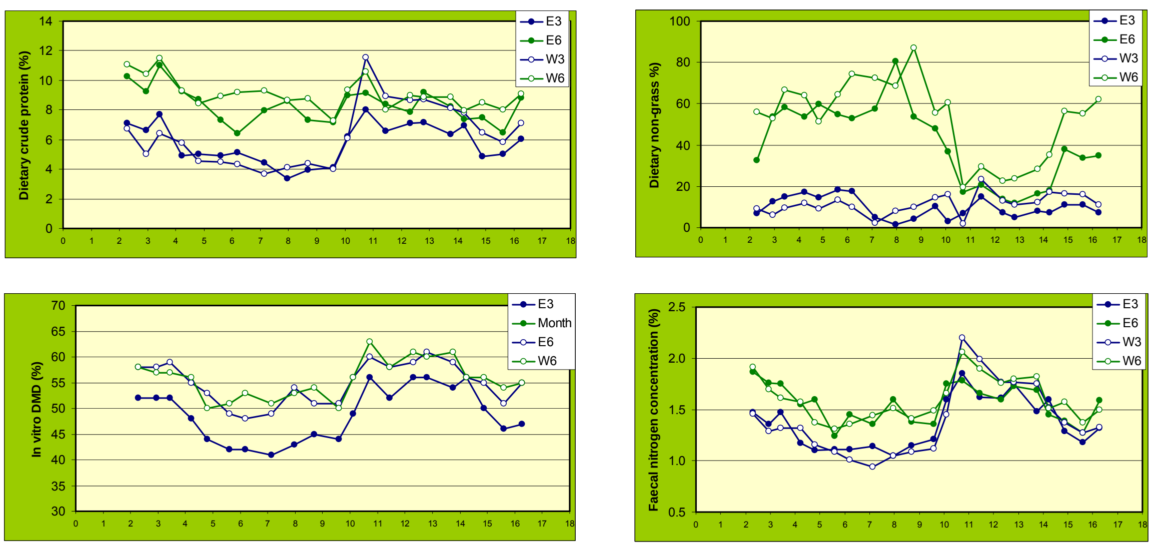

Figure 2. Faecal NIRS predictions on samples from light stocking rate treatments for the period March 1999 to May 2000.