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Testing and developing principles and management guidelines for the sustainable management of the seasonably variable tropical savannas

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Abstract

A large scale trial was conducted over eight years to test the ability of different grazing strategies to cope with rainfall variability, a major challenge to profitable and sustainable beef production in much of northern Australia. Strategies included continuous set-stocking at either a modest or high stocking rate (SR), continuous stocking with SR varied annually based on either pasture available at the end of the wet season or the SOI forecast at the end of the dry season, and a 3-paddock system of wet-season spelling.

Grazing strategies which consistently produced moderate grazing pressures (annual utilisation rates of up to 25%), especially in drier years, gave superior animal growth and economic return, maintained pasture condition, and reduced runoff in comparison to grazing strategies which did not. Importantly, the type of year in which heavy utilisation (>40-50%) occurred was as important as the *average* annual grazing pressure in determining pasture condition and profitability. As tested here, the most successful grazing strategies were continuous grazing at a modest SR and flexible stocking, although the latter strategy needs work to reduce risk and be less reactive. Wet-season spelling is widely acknowledged to be beneficial but the desired frequency and its effects on the sustainable level of utilisation were not clarified in this study. Guidelines and rules of thumb were developed to help implement different grazing strategies, and these related to carrying capacity, varying stock numbers, the use of climate forecasts, dry season fodder budgeting and fire.

Executive summary

Graziers in the northern savannas are under increasing pressure to be profitable and sustainable in an environment with extreme rainfall variability. Guidelines for sustainable grazing management do exist but their profitability and sustainability have not been rigorously tested or demonstrated at the paddock scale. A grazing trial at Wambiana Station, near Charters Towers, was initiated in 1998 to test and develop principles and guidelines for sustainable, profitable management. Strategies tested were: (i) moderate stocking (LSR), stocked at the recommended long-term carrying capacity (*c*. 8 ha/ Animal Equivalent (AE)); (ii) heavy stocking (HSR) run at twice the long term carrying capacity (*c.* 4 ha/AE), (iii) variable stocking (VAR), with an annual stocking rate adjustment based on available pasture at the end of the growing season (range: 4-12 ha/AE), (iv) variable stocking (SOI) with an annual stocking rate adjustment based on the Southern Oscillation index and available pasture at the end of the dry season (range: 4-12 ha/AE), and (v) rotational wet season spelling (R/Spell) with an intermediate level of stocking (1.5 x long-term carrying capacity, *c.* 6 ha/AE) in a 3-paddock system. Trial management was conducted in close consultation with a grazier advisory committee.

Good rainfall in the first 4 years was followed by 5 consecutive below-average years. Pasture biomass consequently varied 5-fold over the 9-year trial period. In the VAR and SOI, stocking rates were initially very high (*c*. 4 ha/AE) but were later reduced to *c.* 10 ha/AE. In the R/Spell stocking rates were also reduced in November 2004 to *c.* 10 ha/AE due to the combined effects of an ill-timed fire and drought. Stocking rates had to be cut by *c.* 30 % in the HSR in 2005 due to reduced carrying capacity arising from overgrazing. Pasture utilisation rates were initially low in all treatments (<20%) but increased 3 - 6 fold in 2001-2003, depending upon treatment. Utilisation rates later declined in most treatments but remained very high (> 70%) in the HSR.

Annual live weight gain per head declined as pasture utilisation rate increased: average annual LWG/hd was consistently higher under LSR (126 kg/hd) than under HSR (96 kg/hd). Consequently, after 2 years on the trial, lighter-stocked cattle were 50-100 kg heavier, in better condition, and received better meatworks prices than those from heavily-stocked paddocks. In contrast, LWG/ha was greatest in the HSR with production in the wetter period being almost twice that in the LSR (27.8 versus 15.5 kg/ha/yr). However, this difference narrowed markedly as rainfall declined and the impacts of heavy grazing emerged, and average annual LWG/ha over the whole trial period was 23.2 and 15.2 kg/ha for HSR and LSR, respectively. Importantly, HSR cattle had to be maintained with drought feeding in dry years.

In the first four years, HSR had far higher annual gross margins than the LSR strategy ($3,522 versus $1,895 per 100ha). However, HSR gross margins were consistently negative during the latter five years of the trial (average of -$1,527 /100 ha) due to poor animal performance and greater costs. In contrast, LSR gross margins stayed positive in all years irrespective of rainfall and, as a result, accumulated cash surplus per 100 ha over the nine years was substantially higher for LSR than HSR ($17,410 versus $10,112).

For the VAR and SOI strategies, higher stocking rates in the 4-year wet period of the trial produced more profit than LSR, but this advantage was neutralised by poor LWG and selling losses in the initial year of the 5-year dry period. In contrast to the HSR strategy, however, the reduced stocking rate for VAR and SOI strategies during the subsequent 4 years resulted in a return to positive annual gross margins. Annual gross margins for the R/Spell strategy tended to track those of LSR, being slightly higher in the wetter period and slightly lower in the drier period. As a result, after 9 years,

there was no increase in accumulated cash flow from applying VAR, SOI or R/Spell strategies above that achieved by moderate stocking. All these strategies, in turn, were more profitable than HSR.

Pasture species composition varied over time due to rainfall with perennial grasses like *Bothriochloa ewartiana* forming a relatively stable matrix within which annuals and weaker perennial species fluctuated. Management strongly affected pasture condition with the frequency of 3-P (palatable, perennial, productive) grasses (such as *B. ewartiana* and *Heteropogon contortus)*, pasture yield and ground cover all declining with increased utilisation. By May 2006 the proportional contribution to yield of 3-P species in the LSR was double (52 vs 21%), and that of wiregrasses and annuals half (12 vs 22% and 9 vs 18%, respectively), that in the HSR.

3-P basal cover in LSR was about 2.5 % when measured in 2004, 3-4 times greater than in the VAR, SOI or HSR paddocks; basal cover in R/Spell paddocks was intermediate. 3-P tussock density was highest in the LSR and R/Spell, lowest in the HSR and intermediate in the VAR and SOI. Basal cover and tussock density appeared to be as sensitive to the *timing* of utilisation relative to particular rainfall years as it was to average long term utilisation rate. These changes also affected runoff with the frequency and intensity of runoff events increasing under heavier stocking.

A prescribed hot fire in October 1999 shifted woodland structure to smaller size classes but had little effect on tree density. Subsequent pasture recovery was rapid due to good rains. However, a second fire on yellow kandosols in the R/Spell paddocks in 2001 coupled with poor rainfall caused significant pasture damage, and this persisted despite subsequent wet season spelling.

Overall, the performance of the different grazing strategies may be summarised as follows:

(1) **Moderate stocking** at the recommended long-term carrying capacity gave good LWG and economic returns, and maintained pasture condition despite below-average rainfall. The strategy is therefore sustainable and profitable but would likely be improved through integration of wet-season spelling and judicious variation of stocking rate to: (a) allow recovery of selectively grazed patches, (b) avoid overgrazing in very dry years and (c) take advantage of wetter years.

(2) **Heavy stocking** at twice the long-term carrying capacity performed well in early good seasons but profitability later plummeted due to high costs and poor LWG. Pasture condition also declined increasing runoff and reducing carrying capacity. The strategy thus appears to be neither sustainable nor profitable in the long term.

(3) **Variable stocking** (VAR and SOI) generally gave acceptable animal and economic performance but economic loss and pasture damage occurred in the one transition year that occurred between a wet period and a dry period. Variable stocking therefore shows some potential to both improve profitability in wetter periods and avoid overgrazing in dry periods. However, the strategies applied here were not responsive enough, were risky, and may well have performed more poorly had there been a greater frequency of ‘transition’ years. Variable stocking strategies may be improved by (a) setting clear upper limits to stocking rates, (b) ‘dampening’ fluctuations (particularly increases) in stocking rate and (c) inclusion of additional decision points during the year.

(4) **Rotational wet season spelling** (with intermediate stocking) had mixed effects due to confounding with fire. While it generally maintained pasture condition and gave acceptable LWG and profitability, this was only achieved by cutting stocking rates in later years. The sustainability and profitability of such a 3-paddock system, stocked at 1.5 times long-term carrying capacity, are therefore questionable: the strategy may be improved if used in

conjunction with flexible stocking. The net benefits of wet season spelling, taking into account the effects of relatively heavy stocking in paddocks hosting cattle from those paddocks being spelled at any one time, were less obvious than expected.

The Wambiana trial has confirmed the general guideline for tropical savannas that average annual utilisation rates of up to 25% maintain pasture condition, reduce runoff and improve individual LWG relative to heavy constant stocking. Significantly, stocking at the long-term carrying capacity was the most profitable and least risk-prone strategy tested. The trial has also indicated the potential benefits from varying stock numbers with seasonal conditions but has highlighted the associated economic and ecological risks. Implementing more timely and judicious adjustment of stocking rate, to produce benefits above that achieved by simply stocking at the long-term carrying capacity, presents a management challenge. The trial has clouded, somewhat, the net benefits of wet season spelling for land condition, although this seems related to effective implementation and rate of response rather than to any issues with the ecological basis of spelling per se. Questions also remain on the potential of on-property spelling systems to support increased utilisation rates while maintaining land condition, and this will likely depend on the frequency and duration of spelling that is achievable in practice.

Most importantly, the trial has provided key empirical evidence showing that sustainable grazing management is essential for optimising medium to long term profit in the northern savannas. This evidence and the practical demonstration of these different grazing strategies will be critical in promoting the adoption of sustainable and profitable grazing management in northern Australia.

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Abbreviations

3-P Grass	Productive, perennial and palatable grasses
2-P Grass	Grasses with two of the three characteristics of 3-P species.
ACS	Accumulated cash surplus
Alloc	Allocation
ANOVA	Analysis of variance
B.butt	Blackbutt soil vegetation
CNRS	Climate Impacts and Natural Resource Systems
CP	Crude protein
CS	Condition score
DM	Dry matter
DS	Dry season
EOD	End of Dry
EOW	End of Wet
Excl.	The Wambiana trail exclosure
Fuse	(Dry Season) % Feed use
FVR	Fletcherview Research Station
GI Index	Growth Index
GIS	Geographic Information System
GM	Gross margin
GRASP	GRASs Production pasture growth model
ha	Hectare
hd	Head
HGP	Hormone growth promotant
HSR	Heavy stocking rate
I/Bark	Ironbark vegetation
IVD	In vitro digestibility
KW	Kruskal – Wallis value
L.Den	Linear density
LSR	Light stocking rate
LSU	Large stock unit
LTBA	Live tussock basal area
LWG	Live Weight Gain
M8U	Molasses and urea (8:1)
MVA	Multivariate analysis
N	Nitrogen
NG	Non grass
NIRS	Near Infra-Red Reflectance Spectrometry
NPP	Net Primary Production
NRW	Natural Resources and Water
P	Phosphorus
R/Spell	Rotational spell strategy
SLR	Swan's Lagoon Research Station
SOD	Start of Dry
SOI	Southern Oscillation Index strategy
spp	Species

Abbreviations

SR	Stocking rate
SR2Y	Stocking rate (2yr mean)
SR.PrevYear	Previous year’s stocking rate
SV	Stress value
SWYFTSYND	Exclosure for measuring NPP
TSDM	Total standing dry matter
TBA	Tree basal area
TSS	Total suspended sediment
VAR	Variable Stocking strategy
ULTRM	Long term mean (pasture) utilisation rate
WS	Wet Season
YLD	Yield

Contents

1. Background

1.1. Introduction

Increasing economic pressures in the beef industry are exerting strong pressures on producers to intensify. In many cases, it appears that graziers achieve this simply by raising stock numbers and, consequently, increasing pasture utilisation rates. The extreme variability of annual rainfall that characterises much of northern Australia makes this strategy extremely risky, so it may well result in persistent over-grazing and associated financial loss and decline in land condition

Evidence from the MLA-funded ECOGRAZE (Ash, Corfield *et al.* 2001) project showed, on a very small scale, that managing grazing pressure from year to year, to achieve annual utilisation rates of about 25%, improved or maintained land condition whereas rates of 50% and 75% did not. Further, annual spelling for the early part of the wet season accelerated recovery of land condition and appeared to permit tolerance of higher over-all utilisation rates, up to 50%. However, implementing these guiding principles in practice presents challenges, e.g. it is impossible in most situations for stock numbers to closely track variation in pasture supply, especially when management is based on two musters per year; annual wet-season spelling, even for 8-12 weeks, is again impossible to achieve in practice, and less frequent spelling still requires a degree of paddock sub-division and for stock from the spelled area to be grazed elsewhere for that time. Moreover, the financial, animal production and land condition outcomes from pragmatic implementation of these guidelines has not been quantified.

Hence, a number of limitations exist with these recommendations that limit their adoption and application by the grazing industry.

First, few of the recommended strategies have been tested at a scale relevant to property management. There is thus little empirical data on their long-term impact on profitability and sustainability, and consequently, limited direct support for their benefits relative to existing management systems of sustained, heavy utilisation.

Second, there are only limited guidelines regarding the practical implementation of strategies or their integration with other management decisions. For example, there are few guidelines on the practical implementation of Southern Oscillation Index (SOI) based stock adjustments or their integration with activities such as spelling, burning, supplementation or breeder management.

Third, there are relatively few practical decision tools available for the direct implementation of such strategies at the paddock level. Tools like *Stocktake (Anon 2004)* are effective for dry season forage budgeting but would be considerably improved by the addition of empirical relations relating say, live weight gain to standing pasture yield.

Fourth, most commercial paddocks contain a mix of land types of varying attractiveness to grazing animals. This suggests that overuse and degradation of certain areas is inevitable regardless of the application of some overall ‘safe utilisation rate’.

For these and other reasons (O'Reagain, McKeon *et al.* 2003), many properties persist with the application of high utilisation levels and consequently are at risk of severe resource degradation and economic loss, particularly in low rainfall years. Even where recommended practices are applied, the potential for significant degradation still remains due to differential grazing pressure on different soil types.

In 1997 a grazing trial was established near Charters Towers with the objective of addressing these issues by:

1. Quantifying the relative effects of different grazing strategies on resource condition and animal production at a scale relevant to commercial properties,
2. Developing a suite of practical options, guidelines and rules-of thumb for implementing sustainable grazing management ,
3. Promoting the adoption of such guidelines and decision tools through direct demonstration and linkages to, and involvement with, community-driven extension and other grazier initiatives and projects.

2. Project objectives

2.1. Purpose of project

The aim of the project was to test the effects of different utilisation strategies on resource condition and animal production at a scale relevant to commercial properties. This would, in turn, identify guidelines and tools to assist producers to manage their properties in a sustainable and profitable manner. The objectives were as follows:

By June 2006, the project aimed to:

1. Quantify the medium-term (8 years) effect of different utilisation rates and grazing strategies on resource condition, animal production and economic return.

2. Identify key management principles for the sustainable management of tropical savannas.

3. Develop practical management guidelines that allow graziers to manage their natural resources in a sustainable and viable manner.

4. Develop practical decision tools that producers can use in pasture condition assessment and forage budgeting, using climate forecasts to adjust stock numbers and adjusting animal numbers in relation to feed supply.

5. Develop empirical relationships that relate pasture production, animal production and soil loss to utilisation rate.

6. Make at least 60% of producers in the Burdekin and Flinders catchments aware of these principles, guidelines and decision tools.

3. Site description

3.1. General

The study site is located on Wambiana station (20° 34’ S, 146° 07’ E) near Charters Towers and has been grazed by cattle for at least the last 100 years. Previous management had been relatively conservative and the pasture was in moderate to good condition. Historically, fire had been used relatively infrequently on the site (J. Lyons, *pers. comm., Wambiana station*)

Mean annual rainfall (MAR) is 650 mm (C.V. = 40%) with most precipitation falling during the hot summer months. MAR was calculated from long term (1910-2004) rainfall records for 'Trafalgar' 20 km N of the trial site using Rainman ((Clewett, Clarkson *et al.* 2003).

3.2. Soils and vegetation

The study area occurs in the *Aristida-Bothriochloa* pasture community (Tothill and Gillies 1992), and is an open savanna dominated by *Eucalypt*, and to a lesser extent, *Acacia,* woodland species, overlying a herbaceous layer of C4 tropical grasses. The native shrub *Carissa ovata* also occurs at relatively high densities across the site, mainly on the brown sodosol and chromosol soils.

Soils are derived from tertiary sediments and relatively infertile ((De Corte, Cannon *et al.* 1991). The site contains a number of soil types (See Appendix 1 for soil profile descriptions) but in the main there are three clear soil-vegetation associations occupying characteristic positions on the landscape (Table 3.1). These are as follows:

Ironbark
Silver Leaf Ironbark (*Eucalyptus melanophloia*) woodlands on yellow, brown or red kandosols (Fig 3.1). These relatively well drained but low fertility soils tend to be dominated by unpalatable species like *Eriachne mucronata* and *Aristida* but may contain appreciable quantities of *Chrysopogon fallax* and *Heteropogon contortus* where soils are darker and more fertile.

Box
Reid River Box (*E. brownii*) woodlands with False Sandalwood (*Eremophila mitchelli)* and, in some places, Black Butt (*E. cambageana*). Moderate to dense stands of *Carissa ovata* are also common. The Box areas occupy gentle slopes and the edges of run-on areas. Soils are generally texture contrast in nature and include sodosols, chromosols, dermosols and sodosol-kandosol gradations. Soils are relatively shallow (30-40 cm), of moderate fertility relative to the Ironbark and overlie a dense clay subsoil. Box areas are commonly dominated by a *Chrysopogon fallax - Bothriochloa ewartiana* pasture layer.

Brigalow
Brigalow (*Acacia harpophylla)* and/or Box woodland, or almost treeless in some areas, on heavy clay soils. Some small areas of very open Coolibah (*E. Coolibah*) woodland also occur. These heavy clays are relatively fertile, and vary from vertosols to grey earths. In places gilgais are strongly developed. The heavy clay areas are largely dominated by *Dicanthium sericeum, B. ewartiana* and *Eulalia aurea.*

3.3. Layout of grazing trial

A soil survey of the general experimental area was conducted by a pedologist in 1997 (Cannon 1997) and formed the basis of a detailed soil map of the site. A GIS was then used to lay out experimental paddocks so that each paddock contained similar percentages of the three main soil–vegetation associations described above. These were briefly as follows: Ironbark (23 %), Brigalow (22 %) and Box (55%). This design was chosen to approximate the conditions in commercial paddocks where cattle usually have access to a range of landtypes.

Paddocks range in size from 92 to 115 ha and are laid out in a randomised block design of 5 treatments by two replicates (Fig. 3.1). All paddocks have two watering points so that the maximum distance from any point in a paddock to water is less than 1.2 km. In addition, a cattle grazing exclosure of about 3 ha was also erected in paddock 8 on the Box soil. The exclosure excludes cattle but is accessible by macropods and feral pigs

Print 2: Silver leaf Ironbark (*Eucalyptus melanophloia*) on low fertility yellow-red kandosols dominated by *Eriachne mucronata*. Note the low cover – in wetter seasons these spaces filled up with annuals and forbs.

Print 3: Brigalow (*Acacia harpophloia*) on higher fertility grey vertosols with *Dicanthium sericeum* in the foreground

Print 4: Box (*Eucalyptus brownii*) on medium fertility sodosols and chromosols dominated by *Bothriochloa ewartiana, Chrysopogon fallax* and other species.

Table 3.1: Description of soils and vegetation communities found on the Wambiana grazing trial. See Appendix 1 for profile descriptions. (Soil nomenclature follows (Isbell 1996).

Dalrymple term[1]	Classification	Abbreviation	Australian soil classification	Common term	Description	Grazing preference	Grasses
Black	Grey/black sodosol	GSO	Calcic hypernatric grey sodosol	Sodic box	*E. brownii* with sedge lawns	Moderate	*Sedges, C. fallax*
Black	Grey/black sodosol	GSO	Eutrophic mottled grey sodosol	Blackbutt/box	*E. cambageana & E. brownii*	Moderate to high	*B. ewartiana & C. fallax*
Boston	Yellow/brown kandosol	YKA	Bleached ferric petroferric yellow kandosol	Ironbark	*E. melanophloia*	Low-moderate	*Aristida spp., H. contortus*
Cool????	Grey sodosol/dermosol	GDE	Vertic mesanatric grey sodosol	Coolibah	Open *E. coolibah* on heavy clay wet, run-on areas	Moderate, avoided when rank	*D. sericeum, B. ewartiana*
Liontown	Brown sodosol-yellow kandosol	BSO-YKA	*	Box	*E. brownii* with *Eremophila mitchelli*	Moderate	*B. ewartiana & C. fallax*
Liontown	Brown/grey sodosol	BSO	Calcic mesanatric grey sodosol	Box	*E. brownii* woodland	Moderate	*B. ewartiana & C. fallax*
-	Grey earth	GE		Flooded box	*E. brownii* woodland run-on areas	Low-moderate	*B. ewartiana, sedges etc*
Powlathanga	Grey vertosol	GVE	Epihypersodic epipedal grey vertosol	Brigalow	*A. harpophylla* and/or *E. brownii* on heavy clays, can get wet	Moderate-high, avoided when rank	*D. sericeum, E. aurea, B. ewartiana*
Wattlevale	Yellow/brown kandosol	YKA	Ferric-acidic petroferric brown kandosol	Ironbark	*E. melanophloia* on *Eriachne* ridges	Low	*Eriachne mucronata*

[1] (Rogers, Cannon *et al.* 1999)Rodgers and Cannon (1998)

4. Treatment and stocking rates

4.1. Stocking rates

The different stocking rates and stocking rate ranges employed in the trail were derived in three basic steps:

1. All available empirical data on expected pasture growth on different soil types was collated from the few trails previously conducted in the wider region. As most of this previous work had been conducted on markedly different soil types (basalt, grano-diorite) the available data was limited and had to be adjusted using the available expert knowledge e.g. R. Shepherd, *pers. comm*., *QDPI&F, Charters Towers*) Expected growth for the three soil types at the site were then subjectively estimated for good, poor and average rainfall seasons.
2. Based on published data on 'safe' (*c.* 20%) and 'heavy' (*c.* 40%) utilization rates (McKeon, Day *et al.* 1990) appropriate stocking rates were then calculated for each of the three soil types under consideration as detailed below.
3. Grazier estimates for 'safe stocking' rates for the different soil types were then obtained at a meeting of the Grazier Advisory Committee at the site in September 1997. As calculated stocking rates were generally heavier than grazier estimates, trial stocking rates were then reduced by about 20% in order to be acceptable to the Advisory Committee.

4.2. Grazing strategies

Five grazing strategies were selected for the trial. With the exception of the SOI-Variable strategy, all are currently used in one form or another by commercial graziers in the district e.g. (Landsberg, Ash *et al.* 1998); (Mann 1993). The strategies applied were:

Continuous set-stocking at a moderate stocking rate (stocked at long-term carrying capacity) (MSR)Paddocks are stocked to achieve the recommended safe utilisation i.e. 20 - 30%, of the herbage which could be expected to be produced in most, e.g. 70%, years (Table 4.1). Based on expected growth this is about 8 ha per large stock unit (LSU) where a LSU is a 450 kg steer. The underlying philosophy of this strategy is that paddocks are stocked lightly enough to cope with most droughts (up to 1 in 10 year), without having to provide drought feeding or causing a decline in pasture condition.

Continuous set-stocking at a high stocking rate (stocked at about twice the MSR) (HSR)Paddocks are stocked to achieve heavier utilisation of the available herbage, e.g. 40 - 50% which would be expected to be produced most years (Table 4.1). This translates into a stocking rate of 4 ha per LSU. This strategy mimics the common grazier strategy of heavier stocking which attempts to capitalise on good years and which copes with drought through feeding and/or agistment.

Table 4.1: Planned stocking rates and expected dry matter (DM) utilisation rates over wet, average and dry years at the Wambiana trial. Utilisation rates in the Variable and SOI-Variable are presumed to be constant but in practice would vary subject to the rainfall received the following season.

Treatment	Stocking rate (ha/ LSU)	Expected DM utilisation (%)		
		Wet year (2500 kg/ha)	**Average year** (2000 kg/ha)	**Dry year** (1000 kg/ha)
Light	8	19	23	46
Heavy	4	38	45	90
Rotational Spell	6	26	30	61
Variable	3 -10	33	33	33
SOI-Variable	3 -10	33	33	33

Continuous variable stocking with stocking rate adjusted once annually at the end of the wet season based on available pasture (VAR) Involves assessing the total standing dry matter (TSDM) as described below at the end of the wet season (May) and adjusting stock numbers so as to leave an acceptable ground cover at the expected end of the dry season. Potential stocking rates in this treatment are limited to between 3 and 10 ha per LSU. Stocking rates are calculated according to the following formula:

*Stocking rate (ha/LSU) = (Paddock size *Available herbage)/ (Daily intake*Length of season)*

Where:

- Available herbage = (TSDM-Residue)* Wastage factor
- Stocking rate between 3 and 10 ha/LSU.
- Residue (kg/ha) is the minimum residue required to prevent soil erosion (usually 800 kg/ha).
- Wastage factor (%) is the herbage loss due to trampling, dunging, macropod consumption etc.
- Daily intake (kg/beast) is the expected dry matter consumption per day, usually 2.5% of body weight
- Length of season is measured in days, i.e. 365.

Continuous variable stocking with stocking rate adjusted once annually at the end of the dry season based on available pasture and seasonal forecast (SOI) This strategy adjusts stock numbers based partly on TSDM and partly on Southern Oscillation Index based climate predictions for the coming wet season (www.longpaddock.qld.gov.au). As SOI predictions currently only have an acceptable lead-time of about three months, stocking rate adjustments are made in October/November. Initially, a table similar to the one below (Table 4.2) was used to select a stocking rate based on TSDM and SOI. However, in later years a more detailed methodology was developed as outlined in Appendix 8.

Table 4.2: Integrated stocking rate selector based on SOI value and standing herbage at the end of the dry season.(Very High, high, moderate, low and very low correspond to stocking rates of 3,4, 6,8 and 10 ha/LSU respectively)

End of dry season Standing Herbage	SOI Value		
	SOI < -5	*SOI –5 to + 5*	*SOI > +5*
	Stocking Rate Selected		
Very high (> 3000 kg/ha)	High	High	Very high
High (> 2500 kg/ha)	Moderate	Moderate	High
Moderate (> 2000 kg/ha)	Low	Moderate	Moderate
Low (> 1000 kg/ha)	Very low	Low	Moderate
Very Low(< 1000 kg/ha)	Very low	Very low	Low

e) Wet-season spelling in a 3-paddock system in which the whole area is continuously set-stocked, at 30%? above MSR, but with each sub-paddock rested for the wet season every third year. For this strategy paddocks were divided into three sections of similar size. Due to the trial lay-out these sections differ markedly in soil type (Fig. 3.1). One section is spelled for a complete wet season each year on a rotational basis i.e. each section generally had a complete wet season spell every three years (but see below). The spelled area acts as a fodder bank in the event of a drought but also allows the pasture an opportunity to replenish reserves, set seed and recruit (Danckwerts, O'Reagain *et al.* 1993; McKeon, Brook *et al.* 1994)new plants. The spelled area was locked up after the first rainfall of 50 mm over three consecutive days (usually October or November). When conditions permitted as in 2000 and 2001, these areas were burnt immediately prior to being spelled. The R/Spell treatment was initially stocked at a rate midway between the heavy and light stocking treatments i.e. 6 ha / LSU based on the assumption that spelling would buffer the effects of increased stock numbers on pasture condition.

4.3. Site management

All major management decisions for the site e.g. burning, drought feeding, de-stocking, were made following close consultation with the 10 person Grazier Advisory Committee drawn from across the Dalrymple Shire (Chapter 21)

Print 5: In the Rotational Spell treatment one of the three sections was locked up for the entire wet season (right) while the remaining sections (left) were grazed.

5. Seasonal conditions and site history

5.1. Rainfall

The first four years of the trial were characterised by well distributed, above average rainfall (decile 70-80). The 1998/1999 season was particularly good with rainfall occurring in nearly every month of the year leading to an exceptionally large number of growth days for that season: indeed older graziers in the district judged this to be the best season in sixty years (J. Allingham, *pers. comm.,* Fletcher Vale).

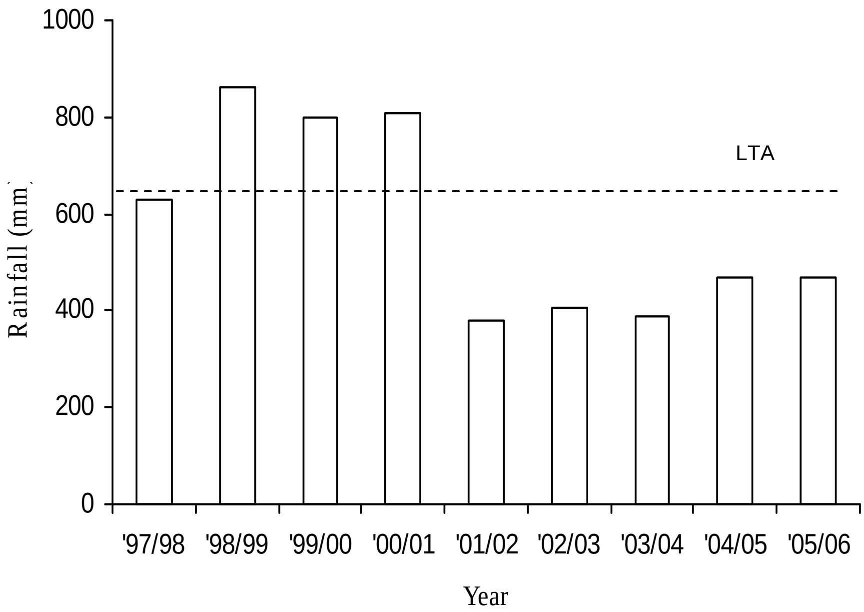


Figure 5.1: Annual rainfall (July/June) between 1997 and 2006 at the Wambiana trial (LTA=long term average).

Rainfall declined abruptly post 2000/01 with the four successive seasons between 2001/02 and 2004/05 all being in or close to the lowest 20% (decile 20) of rainfall years (Fig. 5.1). Rainfall was also poorly distributed through these years with most precipitation occurring in a few large events (Fig. 5.2). For example, although 441 mm was recorded in 2004/05, over 200 mm was recorded in a single event in January, while February to April 2005 was classified as the driest for that period on record. Rainfall in the 2005/06 season (469 mm) was also below average but was very well distributed with rain in most months.

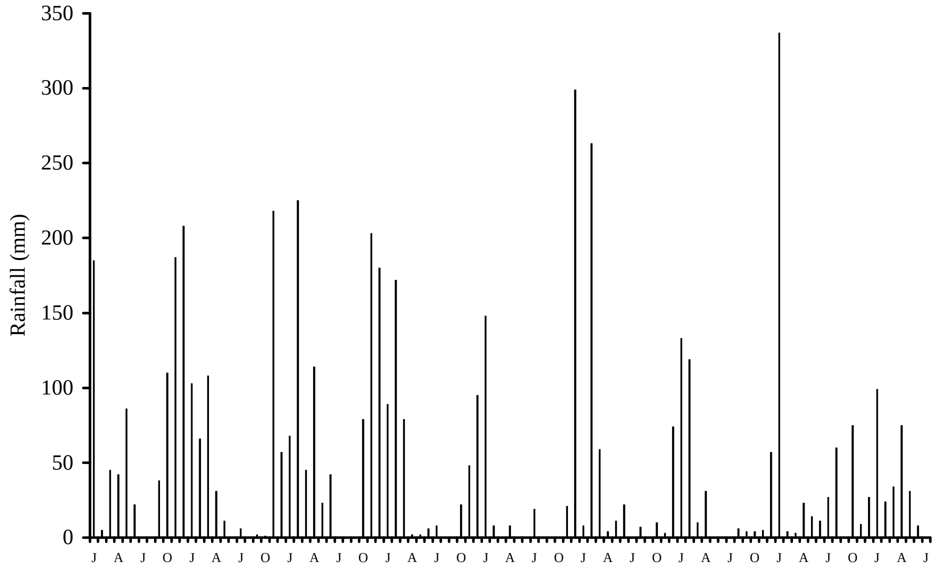


Figure 5.2: Monthly rainfall at the Wambiana trial January 1998 to June 2006

5.2. Treatment histories

Stocking rates for each paddock were set based on the expected mean mass of individual animals over the duration of the grazing season i.e. (initial mass + expected annual mass gain)/2)). Expected annual gain was taken to be 100 kg in all years. In practice, actual stocking rates usually differed from those planned for a particular year because of differences between actual and expected mass gains (Table 5.1).

Table 5.1: Stocking rates (ha/LSU) in the different grazing strategies at the Wambiana trial between 1997 and 2005. Stocking rates based on actual metabolic masses of all animals in a treatment meaned over the grazing season. (LSU=450 kg steer).

Treat-ment	***Season***								
	97/98	**98/99**	**99/00**	**00/01**	**01/02**	**02/03**	**03/04**	**04/05**	**05/06**
Var	12.45	5.18	5.70	3.92	4.11	8.55	9.50	10.84	9.49
R/Spell	9.11	6.97	8.03	7.32	6.97	6.89	7.90	9.54	8.58
SOI	12.31	6.21	5.80	4.40	5.93	8.17	8.60	8.74	8.21
HSR	6.51	5.03	5.74	5.22	4.91	4.82	4.12	4.04	5.75
LSR	12.47	9.43	11.65	10.42	9.49	9.41	7.74	7.60	7.39

In summary, stocking rates in the different strategies were as follows:

- *Light stocking (LSR*), run at a constant rate of c. 10 ha per large stock unit between 1998 and 2000, and at c. 8ha/LSU thereafter (Fig. 5.3).
- *Heavy stocking rate (HSR),* run at a constant rate of *c*. 5 ha/LSU between 1998 and 2000, and at about 4 ha/LSU thereafter. In June 2005 stock numbers had to be cut by about a third due to the extreme scarcity of feed (Fig. 5.3).
- *Variable stocking (VAR)* - During the good rainfall years between 1998 and 2000 the VAR strategy was run at between 3.5 to 5 ha/LSU but stocking rates were progressively reduced thereafter as TSDM declined due to poor seasons (Fig. 5.3).

- *Southern Oscillation Index (SOI) - variable strategy* – This strategy was also relatively heavily stocked initially, but stocking rates were reduced from November 2001 onwards due to reduced yields and negative or indifferent SOI forecasts for the approaching wet seasons.
- *Rotational spelling (R/Spell)* - This treatment was stocked at 8 ha/LSU (1998-2000) and at 6 ha/LSU between 2000 and 2003. In 2000 and 2001 the sections to be spelled were burnt following early storms before being rested (Sections 3 and 1 respectively). Recovery from the 2001 fire was very poor due to low rainfall and, in consultation with the GAC, section 1 had to be given three consecutive wet season spells to allow pasture recovery. The remaining two thirds of this treatment consequently endured three years of heavy wet season grazing. This, together with the continuing low rainfall, lead to an obvious decline in pasture cover and condition. Following consultation with the GAC and technical staff, stocking rates were reduced from 6 to about 10 ha/LSU in November 2003, to avoid further pasture damage.

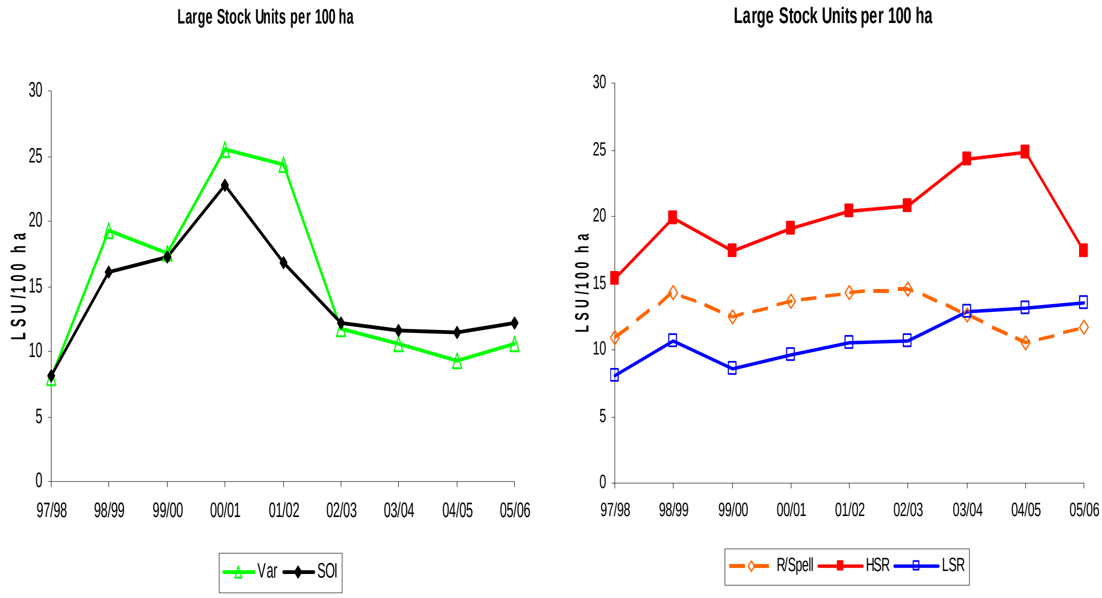


Figure 5.3: Changes in stocking rate in large stock units per 100 ha for (L) the SOI and VAR and (R) the R/Spell, HSR and LSR treatments 1998-2006 at the Wambiana trial.

5.3. Burning

On 1 October 1999 all cattle were temporarily removed and the site burnt to remove moribund pasture and to control woody species. The site was then spelled for three months to allow pasture recovery. During this period, animals grazed together in a nearby agistment paddock, which had the same soil-vegetation associations as the trial site. Cattle were returned to their respective treatments on 12 January 2000 once sufficient pasture growth had occurred.

6. Pasture utilisation under different grazing strategies

6.1. Introduction

Grazing pressure is generally accepted to be the major management-related factor driving animal production and land condition in rangelands. Pasture utilisation rate is a measure of grazing pressure that is commonly used in Northern Australia, especially as a means for interpreting and understanding the effects of nominal stocking rates in a variable environment. stocking rate effects . Utilisation rate is a very useful concept in extension, and can also be used to help calculate the long-term carrying capacity of different land types and paddocks e.g. the Edge Network's Grazing Land Management education package (Chilcott *et al.* 2003). The concept of an 'average' utilisation rate in a spatially heterogenous paddock, grazed by selective cattle in an unpredictable, fluctuating environment has obvious shortcomings which are often glossed over. Nevertheless the concept provides a relatively robust reference or standard by which grazing trials and stocking rates can be compared across time and space. More importantly, it can be used to translate research results into practical grazing systems and permits some general rules of thumb to be constructed to allow extrapolation between different soil types and climates.

Despite its wide use, quantification of pasture utilisation is difficult and is usually conducted in two ways. Firstly, utilisation rates can be estimated retrospectively using pasture and animal production models like GRASP linked to appropriate feed intake equations. Secondly, utilisation rates can be quantified in the field using exclosure cages or by comparing pasture yields before and after grazing.

In this Chapter, the results of these two approaches to assessing or predicting utilisation rates in the different grazing treatments are presented. With both methodologies, estimates or predictions of utilisation are relatively coarse and imprecise and should be used accordingly.

6.2. Objectives

1. Retrospectively predict the annual rates of pasture utilisation in each treatment using the pasture growth model GRASP.
2. Quantify pasture utilisation rates on the major soil types in each treatment using grazing exclosures (cages).
3. Quantify the longer term effects of stocking strategy on the inherent above ground net primary production (NPP) potential of the pasture i.e. pasture 'vigour'.

6.3. Methodology

6.3.1 GRASP Method (*Contributed by Grant Stone*)

GRASP is a point based pasture model that runs on a daily soil water balance and predicts pasture growth as well as losses to grazing, trampling and detachment (McKeon *et al. 1999*). To estimate pasture utilisation, the pasture growth model was linked to a daily model for animal intake. An average utilisation value over 12 months was then calculated for each year for each paddock as:

*% Utilisation = (Sum of daily steer intake for given period [kg/DM/head/day] / Sum of daily pasture growth for given period [kg DM/day]) * 100*

Briefly, the overall modelling process was conducted as follows:

- Detailed data from the Wambiana trial e.g. rainfall, soil moisture, pasture yield, N uptake etc were used to parameterise GRASP for the three main soil types. Daily pasture growth over the course of the trial was then simulated for individual soil types using daily rainfall values at the site. Total pasture growth for each paddock was summed for the particular percentage of the different land types found in that paddock. Importantly, the values of utilisation that are provided are based upon 'potential' growth values and no discounts were used for any change in land condition over time.

- Stocking rates were calculated using animal numbers and the six weekly weights of cattle in each paddock. Interpolation was used to convert periodic data to daily values (e.g. steer live weight, digestibility values).
- Animal daily intake was estimated using the *QuikIntake* calculator (McLennan & Poppi *pers. comm.*) using NIRS estimates of dietary quality (Chapter 12) and recorded changes in live weight in each paddock. Supplementation was not taken into account in these calculations. Total daily intake was then estimated for the entire paddock, and for simplicity it was assumed that there was no selection for soil type. At the end of a grazing period (usually the end of May), the utilisation was calculated using the equation described above.
- A difficult issue to address was how to calculate utilisation rates in the R/Spell treatments (Paddocks 2 and 8): when all cells (sections) are open during the dry season steers have full access to all three cells but in the wet-season spell (~Nov/Dec to 1 June) one section is closed off. For simplicity, utilisation was calculated as if steers had access to all sections of these paddocks during the wet-season spell period. In later analyses, GRASP will be run to account for the effects of this wet season spell.

6.3.2 Exclosure cage method

From 1999 (Ironbark only) and 2000 (all soils) to 2006, utilisation was measured using 4 m^2 weld-mesh exclosure cages ((Milner and Elfyn Hughes 1970). Each year 15 to 19 cages were placed in each paddock in late October before the beginning of the wet season. Cages were progressively moved every year to avoid re-sampling the same area. Cages were stratified according to soil type in approximate proportion to total soil area i.e. 5 cages each for clay and Ironbark soils and 7 to 8 for Box soils (Fig. 6.1). Preliminary work conducted in 1999 in the Ironbark indicated that 5 to 6 cages would be sufficient to provide a reasonable precise estimate of NPP per soil type.

Figure 6.1: Map showing the distribution of exclosure cages across soil types at the Wambiana trial.

Within each land type in each paddock cages were placed so as to sample a similar range of diverse patches e.g. 3-P grasses, wiregrass, annuals, under trees, away from trees etc. Areas of frequent trampling, termitaria or showing obvious signs of disturbance were avoided. An area close to the cage with similar species composition and yield was also chosen and marked with a wooden peg in the SW corner to demarcate a 1 m^2 quadrat. This was termed the 'grazed area' of the paired site (Fig. 6.2).

Figure 6.2: Diagram showing layout of cage and grazed plot for cage based estimated of net primary production and pasture utilisation rate. See text for details

On initial cage placement in the late dry, the cage area was harvested and weighed to estimate residual TSDM from the previous season (1999-2002). From 2003 onwards, the caged areas were not clipped and pre-season TSDM was estimated for both the cage and grazed plots using the BOTANAL (Tothill, Hargreaves *et al.* 1992)method (Table 6.1).

Table 6.1: Pre-treatment of caged area, estimate of residual yield and formulae used in the estimate of above ground net primary productivity (NPP) and percentage pasture utilisation rate (*See text for other abbreviations)***.**

Year	Cage Pre-treatment	Residual yield	NPP	% Utilisation
1999	Mown	Clipped mass	C_1	$((C_1+C_O)-(G_1))/(C_1+C_O)$
2000	Burnt	None	C_1	$(C_1-G_1)/C_1$
2001	Mown	Clipped mass	C_1	$((C_1+C_O)-(G_1))/(C_1+C_O)$
2002	Mown	Clipped mass	C_1	$((C_1+C_O)-(G_1))/(C_1+C_O)$
2003	Mown	Clipped mass	C_1	$((C_1+C_O)-(G_1))/(C_1+C_O)$
2004	None	Estimated	$C_1-(C_O*df)$	$((C_1+C_O)-(G_1+G_0))/(C_1+C_O)$
2005	None	Estimated	$C_1-(C_O*df)$	$((C_1+C_O)-(G_1+G_0))/(C_1+C_O)$
2006	None	Estimated	$C_1-(C_O*df)$	$((C_1+C_O)-(G_1+G_0))/(C_1+C_O)$

Cages and their paired 'grazed' plot were visited again in the early dry season in June or July and the following observations recorded for each: species present, percentage contribution to TSDM, ground cover (score: 1-7), distance to the nearest tree, status of tree, tree species, soil type, vegetation association etc. The grazed and ungrazed areas were then clipped, bagged separately, dried in a forced air oven at 60 C and weighed. Utilisation was calculated as the difference in yield between the grazed area and the caged area, corrected for the weight of TSDM carried over from the previous season. NPP was assumed to be the total end of season cage yield, adjusted, where necessary, for residual yield at the start of the season. When cages were not clipped at the start of the measurement period, residual yield was discounted by 50% for detachment and decay (Table 6.1).

6.4. Results

6.4.1 GRASP based estimates of utilisation rate

GRASP predictions of utilisation rate varied between years depending upon rainfall and the stocking rate applied (Fig. 6.3). Overall three main phases were evident:

1. In the initial years to 2000/01, utilisation rates were low (<12%) in all treatments due to good rains and exceptional pasture growth. Utilisation rates were lowest for the LSR (5%) and only about half those in HSR and VAR strategies (10%).
2. From 2001/02 to 2002/03 however, utilisation rates jumped 3- to 6- fold in all treatments due to low rainfall and the heavy stocking rates applied in some strategies. Despite this, pasture

utilisation rates remained substantially lower in the LSR (26%) than in the VAR (64%) or HSR (52%). Utilisation rates were very high in the VAR due to the increased stocking rate in response to the previous good seasons. Importantly, while stocking rates had also been increased in the SOI, the early initiation of de-stocking in response to SOI forecasts resulted in predicted utilisation rates only reaching 45% in 2002/03.

3. In the final phase from 2003/04 onwards, utilisation rates dropped sharply in the VAR, and to a lesser extent in the SOI and R/Spell, due to stocking rate reductions in all three treatments. In subsequent years, utilisation rates in these treatments have remained between 20 and 30%, i.e. marginally below those in the LSR.

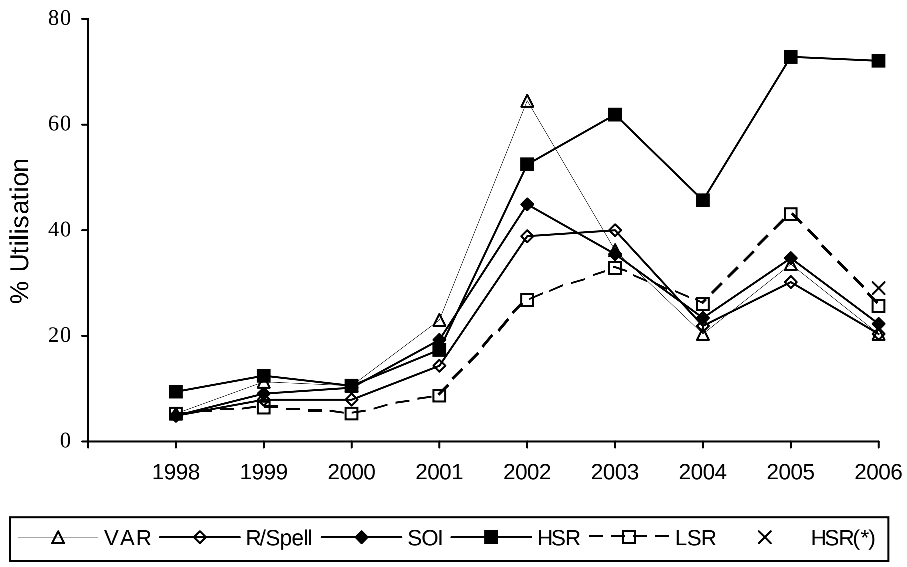


Figure 6.3: Predicted annual pasture utilisation rates from GRASP from 1997/98 to the 2005/06 seasons for the five grazing strategies at Wambiana. Note: HSR (*) = GRASP prediction for 05/06: the actual point used for the HSR has been extrapolated from the previous year.

In complete contrast, utilisation rates in the HSR have remained at a high level because stock numbers have not been reduced in line with the lower rainfall. When HSR stock numbers were reduced in mid-2005, GRASP predicted utilisation rates dropped to *c.* 30% (Fig. 6.3). Paddock observations however, indicated that utilisation rates in the HSR *did not* decline, and remained at extremely high levels (*c.* 80%) in 2005/06. This is supported by data from the exclosure cages (see below). The GRASP prediction of utilisation rate of 30 % for 2005/06 should thus probably be replaced with the more realistic rate (72 %) estimated for the previous year (Fig. 6.3).

The box-and-whisker plot of predicted utilisation levels for all treatments over all years (Fig. 6.4) highlights three main points: First, the median utilisation rate (45%) in the HSR was nearly double that of any of the other treatments, which were all between 20 and 25%. Second, the *range* of utilisations in the HSR and VAR were the greatest, with utilisation rates of > 60% occurring in some years. Importantly, the quartiles indicate that heavy utilisation rates occurred less often in the VAR than the HSR strategy. Compared to the VAR and HSR, the ranges of utilisation in the SOI, R/Spell and LSR were relatively restricted. Third, despite the similarity in the median utilisation rates of the latter treatments, comparison of the 3rd inter-quartile ranges indicates that light utilisation rates occurred more frequently in the LSR than in the SOI, VAR or R/Spell treatments.

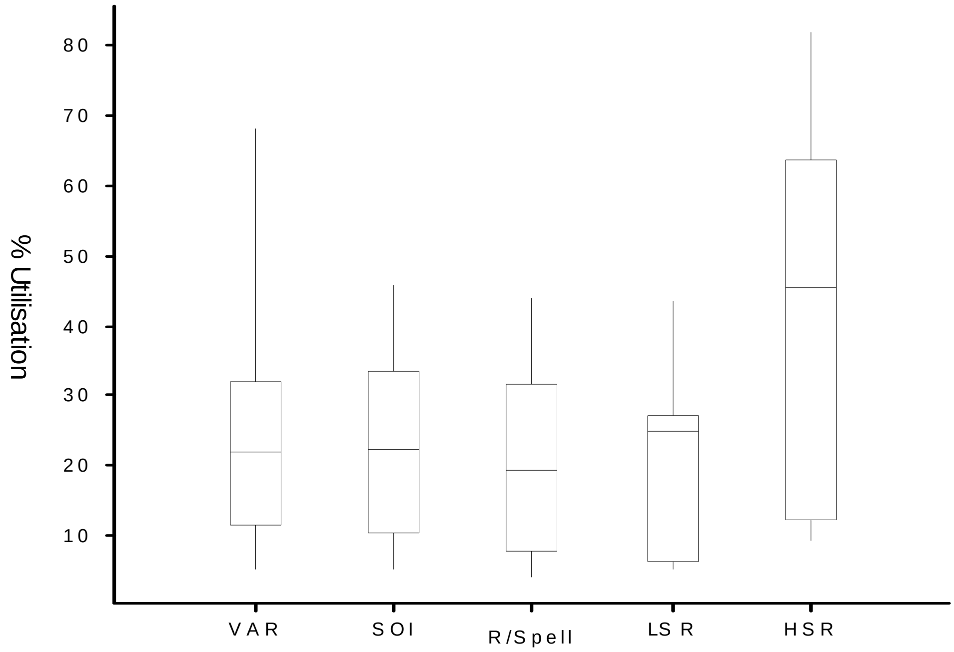


Figure 6.4: Box and whisker plot showing the median, upper and lower quartiles, and range for predicted pasture utilisation rates across all years for the five grazing strategies at Wambiana

6.4.2 Exclosure cage based estimates of NPP and utilisation rate

As expected, above ground net primary production (NPP) across all soil types was greatest in the high rainfall years of 2000 and 2001 (Fig. 6.5). Overall, NPP was highest in the heavy clays and Box (2500-3800 kg/ha) and lowest (2000-2500 kg/ha) on the Ironbark areas. From 2002 onwards, NPP on all soils dropped sharply due to low rainfall with NPP levels of just 500 to 700 kg/ha in 2003. The low NPP on the Box soils in 2003 was also at least partly due to armyworm damage.

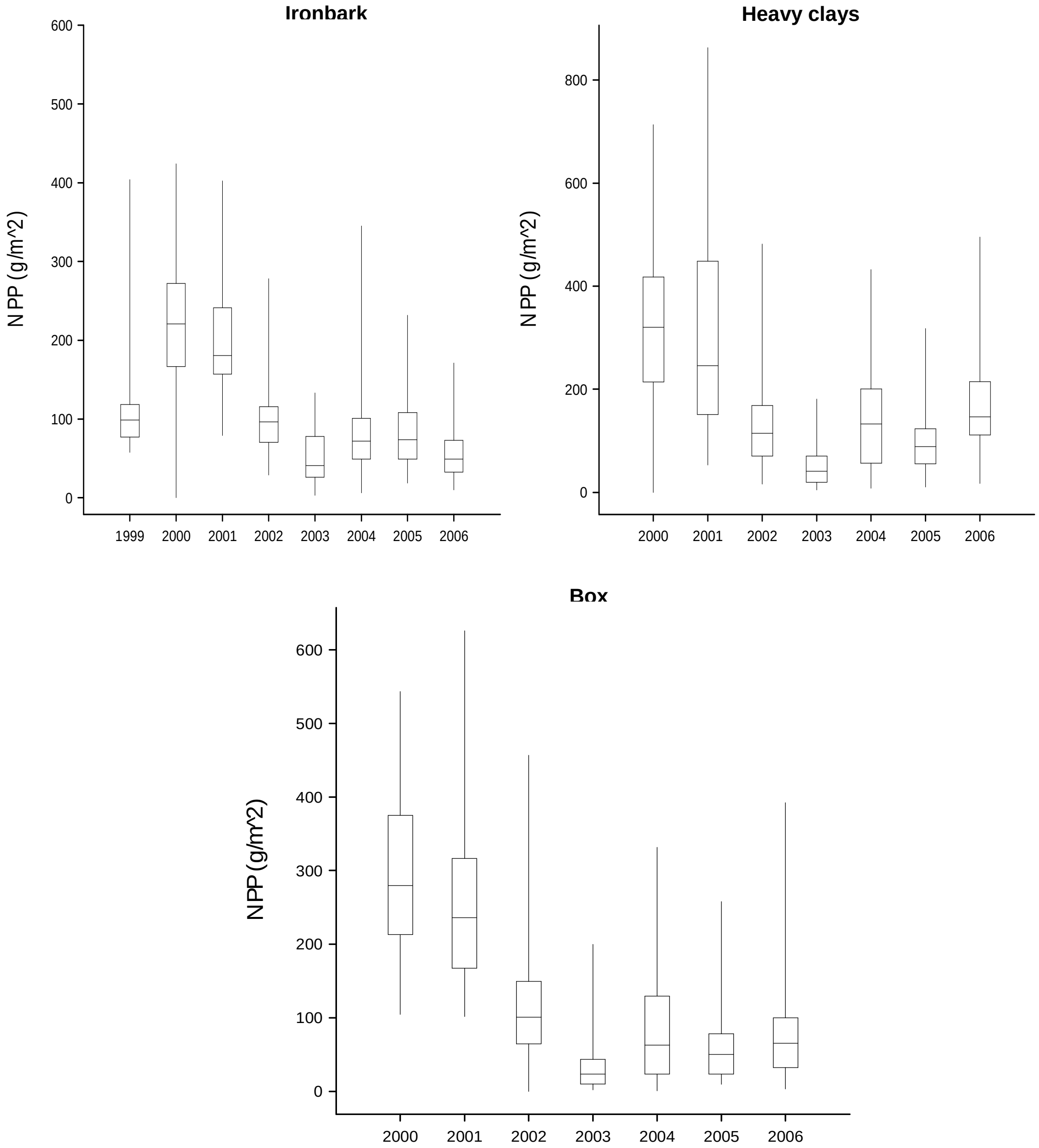


Figure 6.5: Box and whisker plots of above ground net primary production (NPP) on three soil types estimated from grazing exclosures (cages) across all treatments between 1999 and 2006. NB: In 1999 data was only collected on Ironbark soils

Net primary productivity on the clay soils has gradually increased since 2003, reaching *c.* 1500 kg/ha in 2006. In contrast, NPP has recovered only slightly (500 – 900 kg/ha) on the Box and Ironbark soils. Aside from the relatively low rainfall, the poor NPP in these later years appears to have also resulted from a general decline in land condition on the Box and Ironbark areas caused by the combination of grazing and unfavourable growing conditions.

There were no obvious treatment effects on NPP but two points are worth noting (Fig. 6.6). First, between 2000 and 2003, NPP appeared to be higher in the LSR than in the other treatments, particularly on the Box soils. However, these differences may simply reflect natural variability or sampling error as it is unlikely that treatment effects would have emerged at this early stage. Secondly, and more importantly, there has been no apparent decline in NPP in the HSR relative to other treatments in the later years of the trial e.g. 2006 (Fig. 6.6). Superficially, this suggests that eight years of heavy stocking has not reduced the relative productive potential of the HSR. In reality, while the productive potential of the patch types selected for cage placement may be intact e.g. 3-P patches, observation suggests that the density of the more productive patches is far lower in the HSR than in other treatments.

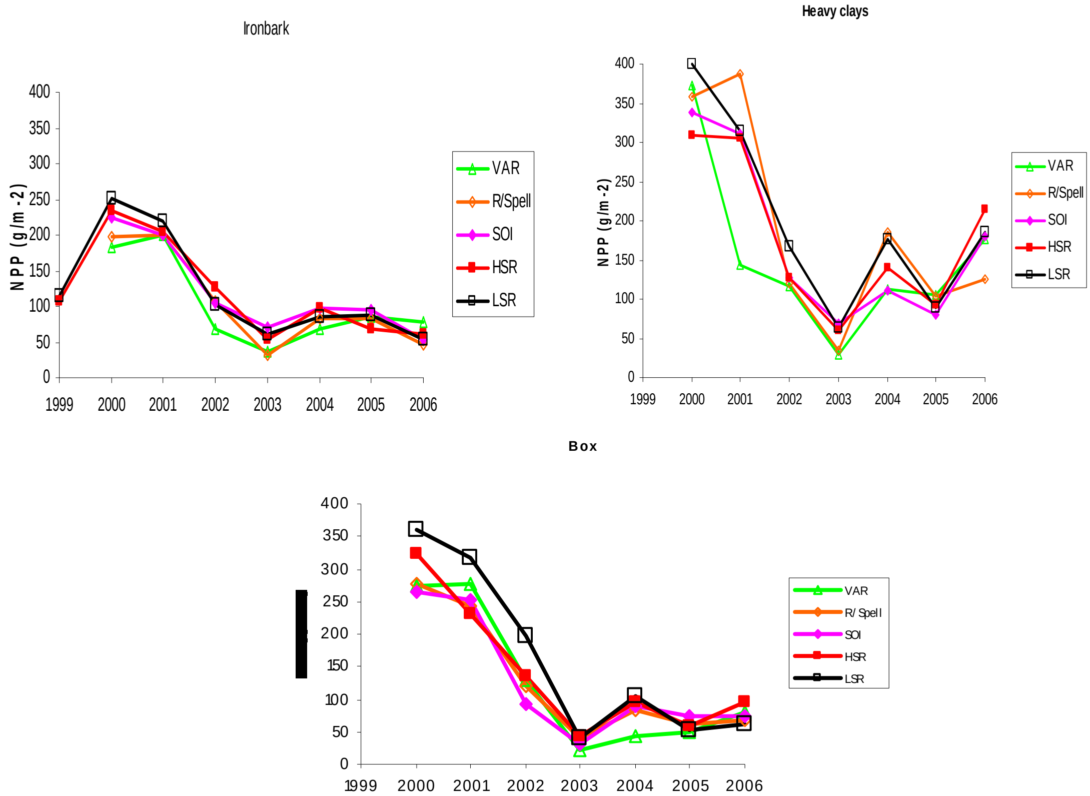


Figure 6.6: Change in mean net primary production (NPP) estimated from grazing exclosures (cages) under different grazing treatments on three soil types between 1999 and 2006. NB: In 1999 data was only collected on Ironbark soils

Cage based estimates of utilisation rate - differences between years

Utilisation rates followed three distinct phases between 2000 and 2006. Initially, utilisation rates were extremely low with all treatments excepting the VAR having median utilisation rates substantially less than 20% in 2000 (Fig. 6.7). A wide range of utilisation rates occurred within treatments (Fig. 6.8) with negative values occurring in some instances due to apparently greater pasture growth outside cages. These very low initial utilisation rates are an obvious result of the very high NPP in 2000 (Fig 6.5) and the resultant light grazing pressure in all paddocks.

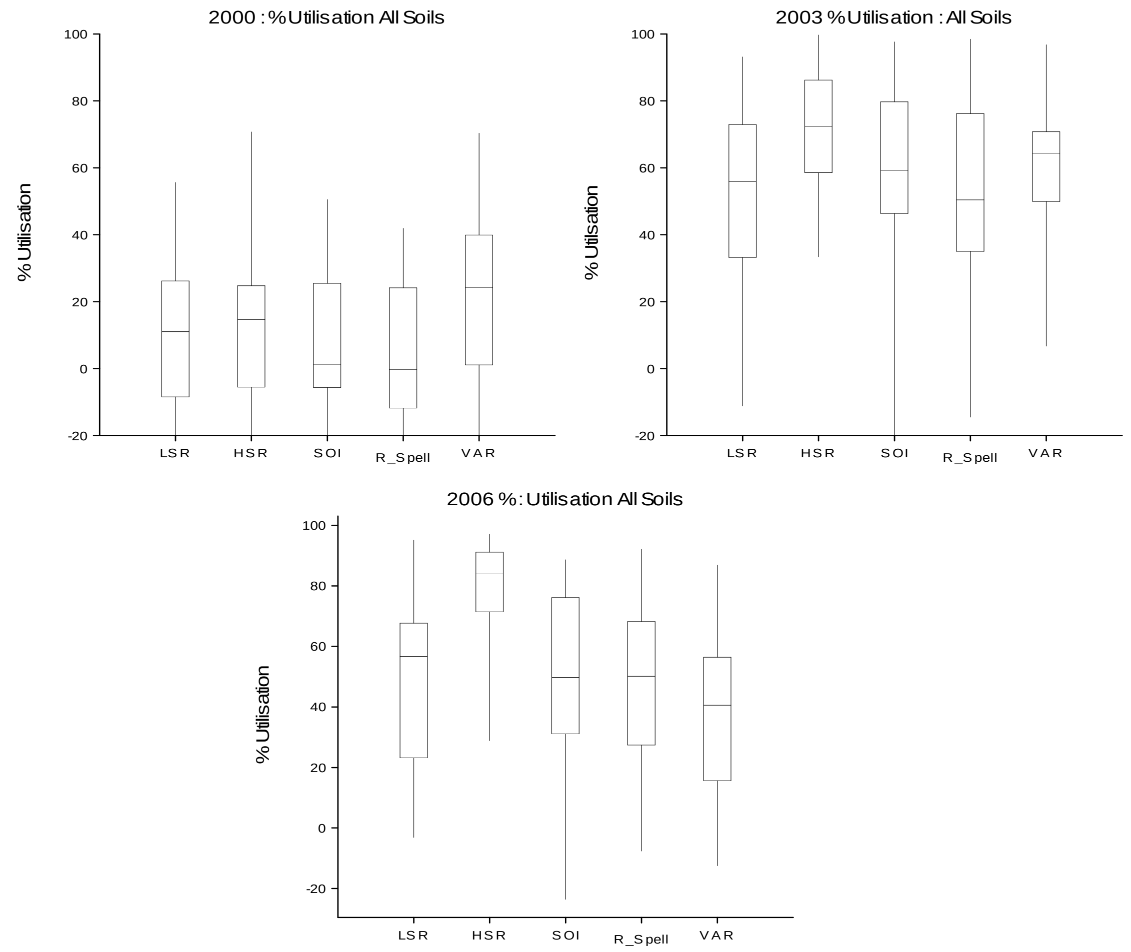


Figure 6.7: Box and whisker plots of the percentage pasture utilisation across all soil types estimated from grazing exclosures (cages) under different grazing treatments in 2000, 2003 and 2006.

Utilisation rates increased sharply through 2001 across most treatments to reach a high of 40 - 70% in 2002 and 2003. These large increases in utilisation rate reflected the low NPP due to reduced rainfall, the high stock numbers applied in the SOI and VAR strategies in these years and armyworm grazing in March 2003.

Post 2003, utilisation rates decreased to *c.* 30 to 40% in most treatments in line with stocking rate reductions in the VAR, SOI and R/Spell strategies, and the continuing low stocking rate in the LSR. In contrast, utilisation rates in the HSR did not decline between 2003 and 2006 but stayed fairly constant increasing to a median of 80% across all soil types (Fig. 6.8). Significantly, utilisation rates in the HSR actually *increased* in 2006 despite a 33% decline in stocking rate in this treatment. As noted earlier, this high utilisation rate in the HSR (80%) is considerably greater than the GRASP prediction of 30% for 2006.

Cage based estimates of utilisation rate - differences between land types
Pasture utilisation rates varied markedly between years, but were also influenced by landtype (Fig. 6.8). Overall, utilisation rates tended to be highest on the heavy clay, and, to a lesser extent, on the Box, but lowest on the Ironbark areas. Consequently, with the advent of dry years in 2001, utilisation rates on the heavy clays jumped to nearly 50% compared to only 10 – 30% on the Box or Ironbark. Peak pasture utilisation rates on the Ironbark also only occurred in 2003, nearly a year later than on the other two soils. This indicates that animals resisted grazing the Ironbark until the Box and heavy clays had been relatively heavily utilised. In 2005 and 2006 the

heaviest pressure occurred on the heavy clays with a utilisation rate of 80% and more recorded in the HSR.

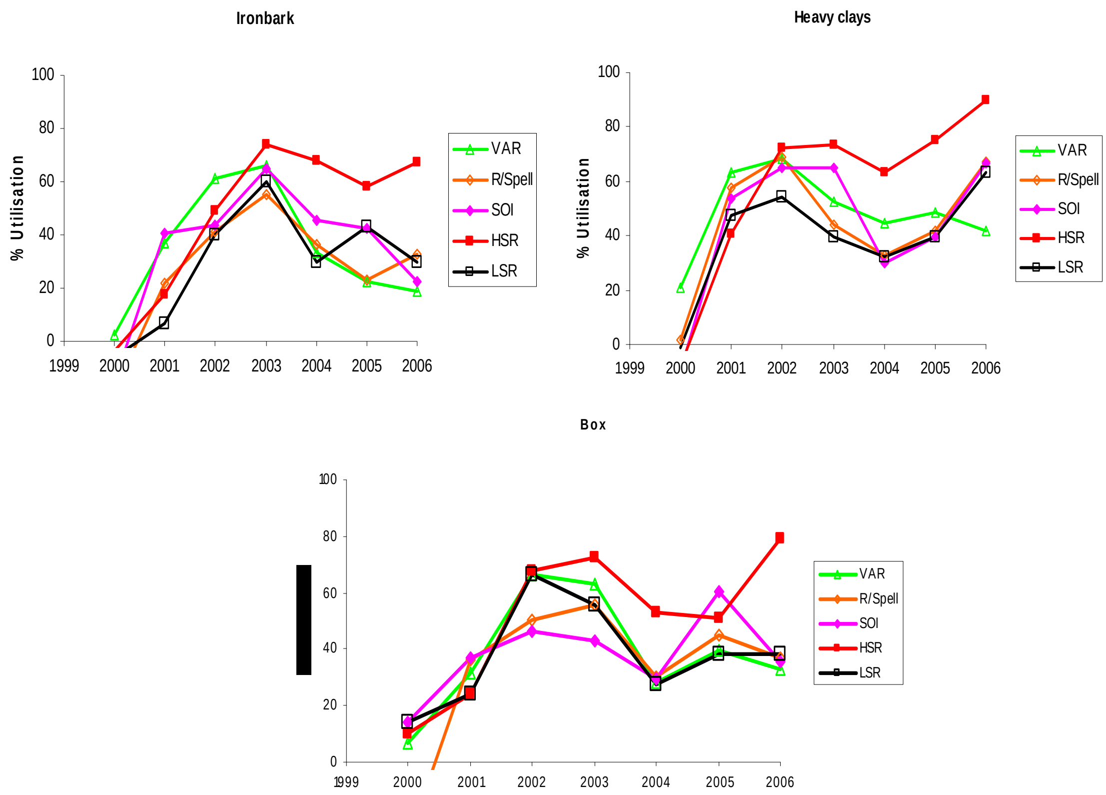


Figure 6.8: Change in mean percentage pasture utilisation estimated from grazing exclosures (cages) under different grazing treatments on three soil types between 1999 and 2006. NB: In 1999 data was only collected on Ironbark soils

Importantly, utilisation rates also varied markedly *within* landtypes due to patchiness in species composition, soil fertility, previous grazing history and the presence or absence of trees etc. Thus, whilst the Ironbark tended to have a lower *average* utilisation, some patches were very heavily utilised e.g. patches of 3-P grasses under tree canopies. Conversely, patches of *Eriachne* were only ever grazed under heavy stocking in poor years when alternative pasture was unavailable. Analysis of the relationship between patch selection and the various biotic, edaphic and management factors will be conducted and presented at a later date.

Comparison of cage and GRASP based estimates of utilisation rate

There was reasonably good agreement between GRASP and cage based estimates of pasture utilisation (R^2=59 %; *P<0.001*) although a few outliers were obvious (Fig. 6.9) These were first, the negative utilisations recorded from the cages for certain treatments in 2000/01 and second, the unusually low GRASP predicted utilisation rate for the HSR in 2005/06. Removing the latter outlier and changing the former three outliers from a negative to a zero value substantially improved the relationship between predicted (UR_{GRASP}) and cage-based (UR_{Cage}) estimates of utilisation:

$$UR_{GRASP} = 1.670 + 0.704^{*}\ UR_{cage} \quad (R^2 = 68\ \%;\ P<0.001)$$

Overall, GRASP appeared to under-estimate pasture utilisation relative to the cages, possibly because the model fails to adequately cover both the short (within-season) and long term (between season) impacts of grazing on pasture production.

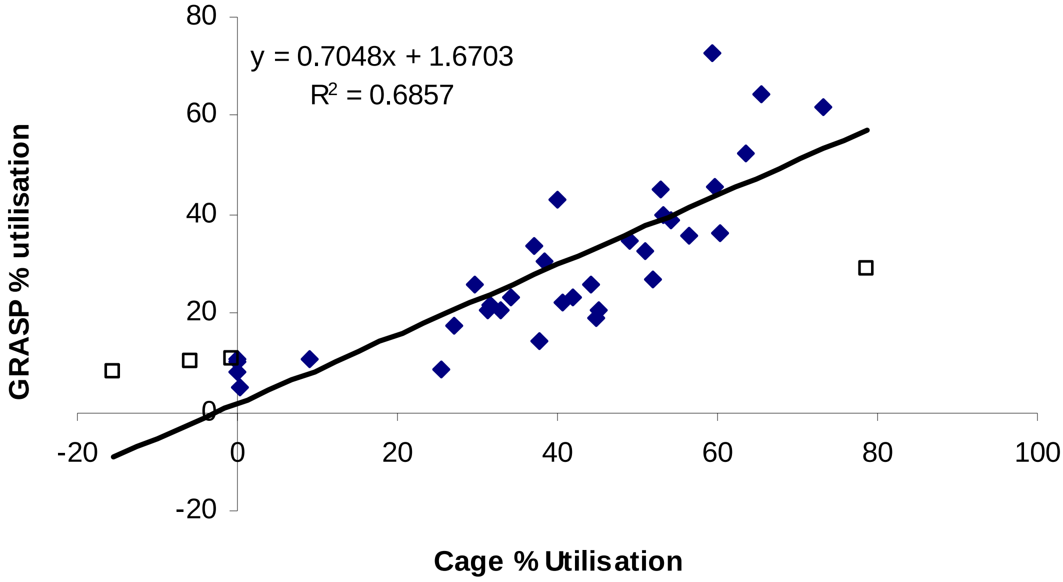


Figure 6.9: GRASP predictions vs. cage-based estimates of percentage pasture utilisation. Outliers marked with an open square were not included in the regression model.

Print 6: An exclosure cage after nine months of protection from grazing (background) and its matching grazed plot (foreground) in July 2006 in the heavy stocking rate treatment.

6.5. Discussion

In general, GRASP predicted utilisation rates agreed well with field observations and cage based estimates over the course of the trial. In the initial years when measured yields were very high (Chapter 10) the observed levels of utilisation in the paddock were low and are in close agreement with predicted levels. In later years predicted utilisations were also in agreement with paddock observations and field data, with utilisations increasing three to six-fold as rainfall and pasture productivity declined. Relative differences in utilisation between treatments also appeared to be generally correct, with utilisation rates generally following stocking rate changes.

An important disjunction between prediction and observation nevertheless did occur in 2006 with predicted utilisation rates being only half those measured in the HSR. This reflects the fact that that in the present GRASP simulations, pasture growth was not discounted for previous heavy grazing i.e. longer term treatment effects on production potential were ignored. The GRASP utilisation estimates presented here are thus based upon *potential* as opposed to *actual* pasture growth.

Further simulations of the Wambiana trial will be performed in the near future as part of the MLA funded GRASP project in which management and climate driven feedbacks on pasture growth (e.g. via basal area) will be included using trial data. The effects of supplementary feeding on animal intake and the variation in walking distance between treatments and its effects on net energy balance will also be assessed. These simulations should reflect the observed situation more closely and deliver actual utilisation values higher than the present 'potential' utilisation values.

The exclosure cages did deliver realistic utilisation values but the technique has shortcomings given that it was originally developed for use in relatively small paddocks. Applying the technique to large heterogenous paddocks was difficult and a number of underlying assumptions and potential problems need to be recognised in interpreting cage based data. Aside from the normal experimental error associated with clipping and weighing pasture samples these are as follows:

1. Small scale heterogeneity in rangelands makes exact matching of the cage and corresponding grazed plot in yield and species composition difficult. This is particularly hard in the late dry season when pastures are dry and short, species are hard to identify and annual species largely absent.
2. Differences between cages due to patchiness *within* land types strongly impacts upon land type level comparisons e.g. Box vs. Ironbark. While this issue can be partially addressed through having an adequate sampling regime, NPP comparisons between land types should be used with caution. Where sample numbers are limited, comparisons should possibly be restricted to plots with equivalent species compositions and basal areas.
3. The assumption of similar growth for the caged and grazed area may be erroneous: total NPP in the cage area could be limited by shading from accumulated pasture while clipping can stimulate growth by increasing light penetration to basal meristems. Alternatively, clipping may adversely affect subsequent growth in caged plots, as possibly happened in 2003. Theoretically, dry season defoliation should have little effect on dormant pastures but similar effects have been noted by others (J. Corfield, *pers. comm*., CSIRO, Townville).
4. The assumption that cage NPP represents the total pasture growth of the grazed areas over the season is not strictly true. Firstly, total growth outside the cage over the wet season could actually be far greater than estimated due to repeated cycles of growth and grazing. Conversely, outside growth could be negatively affected by grazing, reducing the total actual amount grown, and inflating estimates of utilisation.
5. The assumption of similar detachment/decomposition rates of residual herbage over the wet season for inside and outside cages is unlikely to be true. In practice, detachment rates outside the cage are likely to be markedly greater due to grazing and trampling.
6. Utilisation rate and total quadrat yield appear to be inversely related. Consequently, utilisation rates on low yielding quadrats are often inflated since small absolute differences between the grazed and caged area magnify estimates of utilisation. For example, a 2 g difference for a yield of 10 g and 100 g respectively, gives estimated utilisations of 20% and 2% respectively.

Given these limitations, cage based estimates of utilisation rate cannot be assumed to be precise estimates of the overall utilisation rate of different treatments or land types. Nevertheless, cage-based estimates are vital for comparisons of the *relative* utilisation rates observed between different treatments and critical for validating predictions of utilisation rate from simulation models like GRASP.

6.6. Summary

1. Pasture utilisation rates for all years were predicted retrospectively for all treatments using the GRASP model calibrated for the Wambiana site. Utilisation was also quantified empirically between 2000 and 2006 using a relatively small number of paired grazed- vs. exclosure-plots on all major soil types.

2. Predicted utilisation rates varied widely due to changes in stocking rate and/or rainfall variability. Pasture utilisation was low (<20%) across all treatments for the early wet years. However, in 2001/02 and 2002/03 utilisation rates increased 3 - 6 fold across all strategies and ranged from 26% in the LSR up to 64% in the VAR and 40% in the HSR strategy.

3. Utilisation rates generally declined in later years due to a reduction in stocking rate but were still relatively high due to the reduced rainfall. In the HSR predicted utilisation rates remained high (> 70%) until 2005 but declined thereafter due to a *c.* 30% reduction in stocking rate: this conflicts with observations that utilisation rates remained very high (> 80%) in the HSR despite the enforced reduction in stock numbers.

4. Over all years, median predicted utilisation rates in the HSR (45%) were almost twice those in the VAR, R/Spell, SOI and LSR (median: 20-25%).

5. Despite this, the *frequency* of light utilisation was greater in the LSR than in the other treatments. Similarly, while the HSR and VAR had a similar *range* of utilisations, heavy utilisation rates occurred more frequently in the HSR than in the VAR strategy.

6. Above ground net primary production (NPP) in exclosure cages was greatest (2000 – 3000 kg/ha/) in 2000 and 2001 but declined to about 500 – 1000 kg/ha in the subsequent, drier seasons. NPP varied sharply within land types depending upon species composition, but was generally higher on the clay and Box soils than on the Ironbark soils.

7. No treatment effects on NPP were observed between 2000 and 2006. Nevertheless although NPP did not decline in the later years in the HSR, this does not necessarily indicate that the long term productive potential of this strategy is intact.

8. Overall, cage based estimates of utilisation rate were: clay > Box soils >> Ironbark. However, utilisation rate varied markedly within landtype due to small scale patchiness in fertility, species composition, sward structure etc.

9. Cage based estimates of utilisation rate varied markedly between years. Utilisation rates were initially low in all treatments (<20%) but increased sharply to 40 - 70% in 2002/03 but thereafter declined in most treatments. However, in the HSR utilisation rates remained high and increased to 80% in 2006, despite a *c.* 30% reduction in stocking rate.

10. There was generally good agreement between GRASP and cage-based estimates of utilisation (R^2=68 %) although GRASP appeared to underestimate utilisation to some extent. This probably reflects the lack of adequate feedback effects of grazing and management on pasture production in the model.

6.7. Acknowledgments

Pasture simulations were run by Grant Fraser with Macro program construction by Peter Timmers. Simulations were done under the conceptual direction of Greg McKeon. Inception and coordination of the model and collating and processing of field data for GRASP was done by Grant Stone. The *QuikIntake* Model was built by S. McLennan and D. Poppi and funded by MLA.

7. Effect of grazing strategy on animal production

7.1. Introduction

In this chapter data is presented on the effects of the different grazing strategies on animal production. Data on pasture condition, economic performance, dietary quality, soil loss and runoff is presented in later chapters.

7.2. Objective

Quantify the relative ability of different grazing strategies to cope with climate variability in terms of their effects on animal production.

7.3. Materials and methods

7.3.1 Experimental animals

Experimental animals were initially ¾ cross Brahman steers from the DPI & F's research station 'Swans Lagoon'. Due to a shortage of appropriate animals, from 2003 onwards 7/8 Brahman cross steers were sourced from the James Cook University's research station 'Fletcherview', 30 km N of Charters Towers.

Paddocks were stocked with 11-35 steers, depending upon grazing strategy. Between 1998 and 2000, all animals were *c.* 2 year of age and were replaced annually in May. However, from 2000 onwards, paddocks contained two similar sized cohorts of 2 and 3 year old animals, with the older cohort being replaced by new, younger animals each year. Animals thus spent two years on the trial giving ample time for treatments to affect animal production.

7.3.2 Animal husbandry and supplementary feeding

All animal husbandry actions on the trial are accepted commercial practice and based on advice received from the Grazier Advisory Committee. Cattle were initially unsupplemented (1998-2002) but a commercial dry-season urea lick (32% urea) was provided from May 2003 onwards and wet season P supplementation (14.76% P, 21.87% urea) from December 2004 onwards (Table 7.1). Cattle were implanted annually with 400 day Compudose *(Elanco Animal Health, Australia)* hormone growth promotants (HGP) from May 2003 onwards.

Molasses and urea (M8U) drought feeding was provided to the heavy stocking rate (HSR) treatment from September 2003 to January 2004 due to feed shortages and declining animal condition. Poor seasonal conditions in late 2004 again necessitated the initial feeding of M8U to the HSR treatment, followed by M3U and protein meal. All cattle were removed from the first replicate (P4) in December 2004 due to an almost complete absence of dry matter and rapidly declining animal condition. Cattle were fed *Chloris gayana* hay and M8U. Following good rains in late January, animals were returned to their paddock on 7 February 2005. Animals in the HSR were also fed M8U in the 2005/06 dry season due to an extreme shortage of pasture.

7.3.3 Animal production measurements

Cattle were fasted overnight (wet) and weighed at the start and end of each season (1 June) using an electronic cattle scale. Animals were also weighed (un-fasted) six weekly throughout the year. Cattle heights were measured at the start and end of each season from 2003 onwards. Condition score was visually rated on a scale of 1 to 9 by trained observers where 1 is extremely emaciated (death imminent), 5 is 'store' condition and 9 is obese.

Table 7.1: Animal husbandry actions and origin of experimental animals on the Wambiana grazing trial between 1997 and 2006. (SWL=Swans Lagoon Research Station, FVR=Fletcher View Research Station, Bot=Botulism vaccination, M8U= molasses and urea, CS=condition score; P=Paddock; HSR=heavy stocking rate, # refers to year of branding). See text for details.

Year	Origin	Breed	Age (mths)	Bot.	HGPs	Ticks	Wet season Supplement	Dry season Supplement	Drought feeding	Comment
1997/98	SWL	3/4 Brahman	12	Y	N	Bayticol + & dipping	N	N	N	Trial begins 17 Dec 1997 R/Spell section 1 spelled
1998/99	SWL	3/4 Brahman	18	N	N	N	N	N	N	Very good season R/Spell section 3 spelled
1999/00	SWL	3/4 Brahman	18	Y	N	Bayticol	N	N	N	Trial burnt October 1999. Steers agisted to Jan 2000 R/Spell section 2 spelled
2000/01	SWL	3/4 Brahman	18	Y	N	Bayticol	N	N	N	R/Spell section 3 burnt & spelled
2001/02	SWL	3/4 Brahman	18 & 30	Y	N	Bayticol & Tactic	N	N	Weaner + P fed to some cattle in SOI & HSR	R/Spell section 1 burnt & spelled
2002/03	SWL	3/4 Brahman	18 & 30	Y	N	Cydectin & Tactic	N	32% Urea 3.27% P, blocks	N	Wet season very late & armyworm outbreak. R/Spell section 1 spelled
2003/04	SWL	3/4 Brahman	18 & 30	Y	N	Bayticol &, Tactic	N	32% Urea + 3.27% P +salt mix	M8U in HSR paddocks	R/Spell section 1 spelled
2004/05	SWL (#2) and FVR (#3)	3/4 and 7/8 Brahman	18 & 30	Y	400 day Compu dose	N	21.68 % urea 15.23 % Ca 14.76 % P	32% Urea + 3.27% P + salt mix	M8U Hay for P4 cattle: Dec 10 to Jan 28	R/Spell section 2 spelled P4 destocked as CS approached 2
2005/06	FVR	7/8 Brahman	18 & 30	Y	400 day Compu dose	N	As above	As above	M8U in HSR paddocks	R/Spell section 3 spelled Only #3 steers in HSR

7.3.4 Marketing

Between 1999 and 2003 animals leaving the trial were disposed of locally or sent on to other research trials. During these years cattle agents indicated that there was little, if any, difference in value/kilogram between treatments. From 2004 however, animals were either sent to the meatworks or to the local yards, depending upon a local cattle agent's assessment of their value and condition. Carcass grades and scores were collected individually for all meatworks animals.

7.3.5 Statistical analysis

All statistical analyses were undertaken using Genstat 5 (Lawes Agricultural Trust Rothamsted Experimental Station). Animal weight gains and height changes were analysed as a randomised block design using ANOVA with 'grazing strategies' as treatments and 'paddock' as replication. Pair wise comparisons between strategies were made using protected least significant differences.

The numbers of animals in each condition score category for each year were analysed using log-linear models (Poisson distribution and log link function).

7.4. Results

7.4.1 Live weight gain per animal

Effect of year and season on individual LWG

Mean live weight gain per head (LWG/hd) varied significantly *($P<0.001$)* between years across all strategies, with animals gaining 30 to 180 kg per annum, depending upon rainfall and season (Fig. 7.1). For example, while animals in the HSR gained 152 kg in the relatively wet year of 2000/01 (812 mm) they only gained 50 kg in the below average rainfall year (380 mm) of 2001/02. The actual distribution of rainfall was also of critical importance: although rainfall in the 2004/05 and 2005/06 seasons was identical (470 mm) individual LWGs in the latter season were 20 to 50 kg greater due to the more even distribution of rainfall.

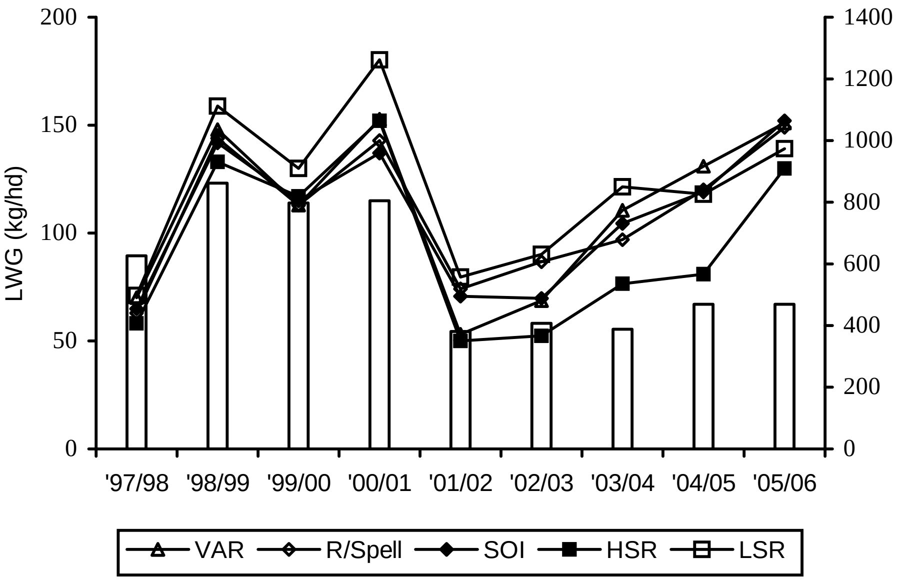


Figure 7.1: Annual rainfall and live weight gain (LWG) per animal for different grazing strategies at the Wambiana trial between 1997 and 2005/06.

In all years, LWG showed a distinct seasonal trend irrespective of grazing strategy with weight gains generally being confined to the relatively short wet season between approximately

December and April (Fig. 7.2). In some years, wet season average daily gains of more than 1 kg/ day resulted in total LWGs in excess of 100 kg/hd over relatively short, three month periods as happened in 2004/05. During the dry season (May-November) animals generally only maintained weight or, in many instances, lost mass (Fig. 7.2). In some years this weight loss was severe with, for example, (unsupplemented) animals in the SOI losing 100 kg of body mass in the 2001 dry season. Dry season weight gains did sometimes occur, as for example happened after unseasonable falls of rain in August and September 2005. In general, dry season gains only occurred where animals were supplemented with urea and/or adequate forage was available e.g. the LSR strategy in 2003/04. However, these dry season gains were generally relatively small compared to those in the wet season.

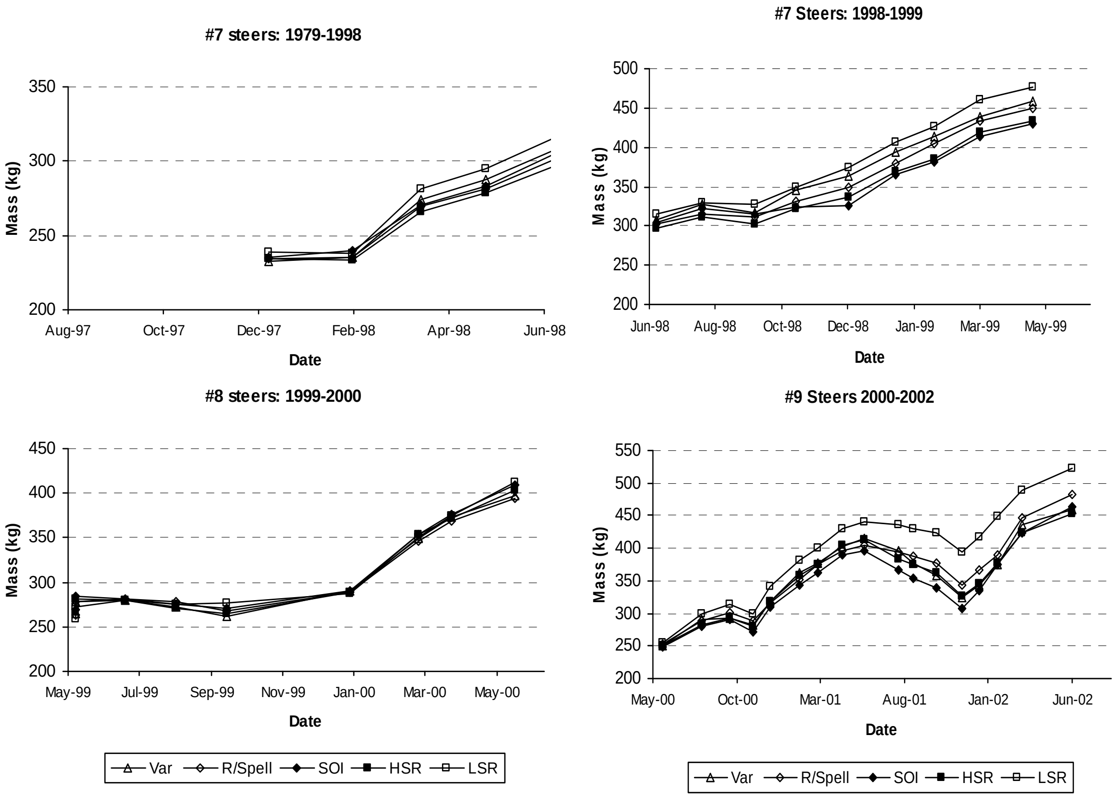


Figure 7.2a: Mean live weights (unfasted) of steers in different grazing strategies over one and two year grazing cycles at Wambiana. Note differences in scale between graphs

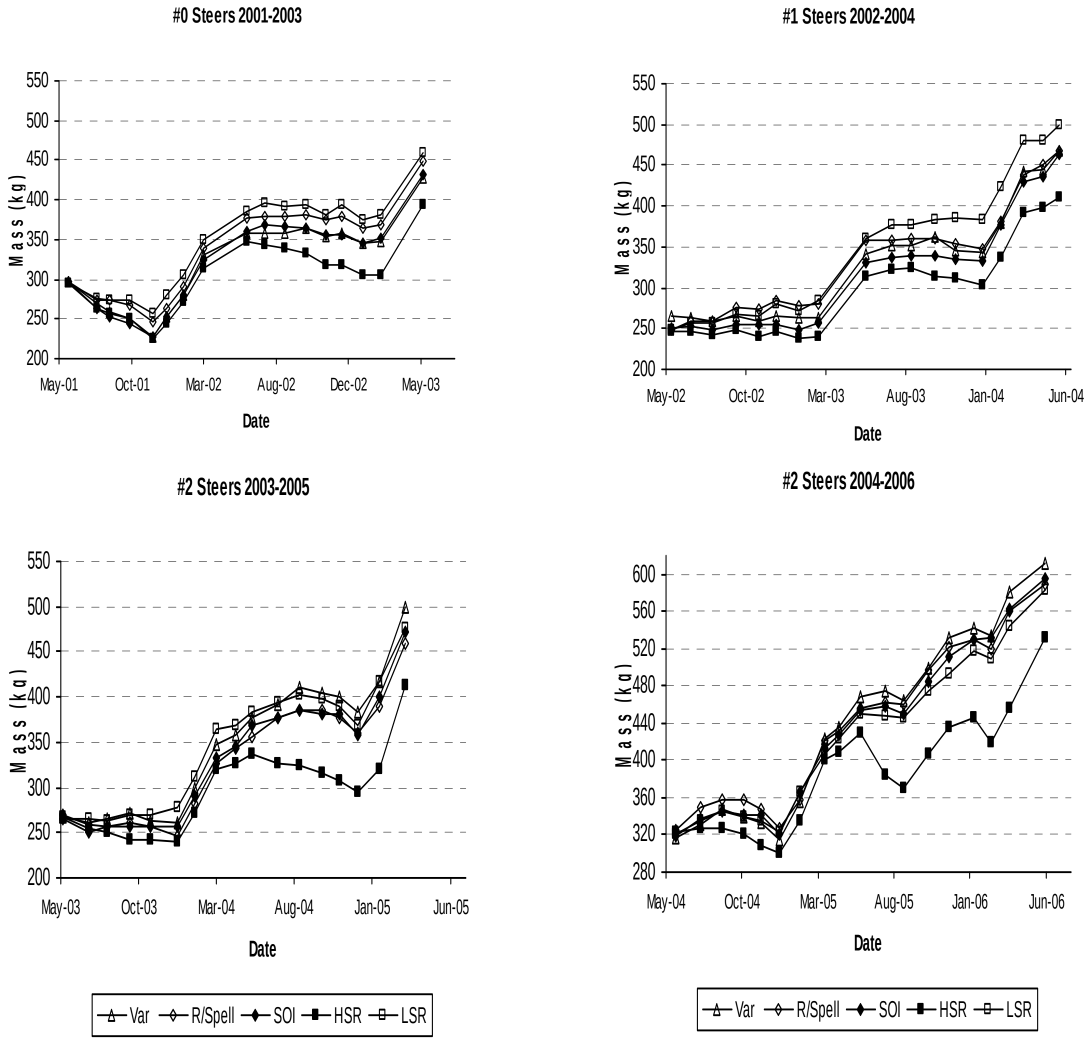


Figure 7.2b*:* Mean live weights (unfasted) of steers in different grazing strategies over consecutive two year grazing cycles at Wambiana. Note differences in scale between graphs

Effect of treatment on individual LWG

Treatment had a significant *(P<0.001*) impact upon LWG with large differences in individual animal production occurring between grazing strategies (Table 7.2). The effect was not consistent across years however, as indicated by the significance *(P<0.008*) of the treatment* year interaction. This inconsistency is not unexpected given that rainfall and, in some cases stocking rate (SOI and VAR), varied substantially between years.

For individual years, the effect of ‘treatment’ on LWG was significant (*P<0.05*) in five of the nine years of the trial (Table 7.2). Obvious, but statistically non-significant, differences in LWG were also apparent between grazing strategies in other years. The lack of significance in some years is surprising given the large differences in LWG recorded between strategies. For example in 2003/04, mean LWG was 121 kg in the LSR compared to only 76 kg in the HSR treatment. This non-significance largely reflects the low level of replication in the present trial (n=2) as well as the variation in LWG that sometimes occurred between replicates.

From a practical perspective, grazing strategy had a clear and consistent impact upon LWG: in seven out of nine years, individual LWG was highest under light stocking (mean: 123 kg) and least under heavy stocking (mean: 96 kg). Live weight gain in the R/Spell (mean: 112 kg), VAR (mean: 113 kg) and SOI (mean: 111 kg) strategies, was intermediate between the HSR and LSR and largely depended upon the stocking rate applied in a particular year. For example in 2000/01, animals gained 180 kg under light stocking, compared to 138 kg and 152 kg under the heavily stocked SOI and HSR strategies, respectively. In 2004/05 however, LWGs in the lightly stocked SOI and LSR were almost identical (119 vs. 118 kg) but both were significantly (P<*0.008)* greater than LWG in the HSR treatment (81 kg).

Table 7.2: Mean annual live weight gain (LWG) per animal for cattle in five different grazing strategies between 1997 and 2006 at Wambiana. Weights within the same column followed by the same letter are not significantly different. F-probabilities are for treatment differences in the same year. SED=standard error of a difference. Treatment abbreviations as before

	LWG per animal per year (kg/hd/yr)								
Treat.	97/98	98/99	99/00	00/01	01/02	02/03	03/04	04/05	05/06
VAR	70.2	148.4	113.3	153.5*c*	51.1	68.5*ab*	110.1	131.7*b*	151.7*ab*
R/Spell	63.2	144.0	113.3	144.5*b*	74.0	86.9*b*	97.1	120.2*b*	149.4*ab*
SOI	65.3	142.0	115.6	138.0*a*	69.4	69.5*ab*	104.6	119.5*b*	152.6*a*
HSR	58.5	133.5	117.4	152.2*c*	50.5	52.7*a*	76.5	81.3*a*	130.5*b*
LSR	71.8	159.4	130.0	180.1*d*	79.5	90.1*b*	121.3	118.8*b*	139.1*ab*
F-prob	*0.543*	*0.260*	*0.416*	***<0.001***	0.181	***0.037***	*0.134*	***0.008***	***0.003***
SED	*8.46*	*9.90*	*8.19*	*0.89*	12.09	*8.18*	*15.09*	*7.75*	7.83

The relative impact of the different grazing strategies on animal performance was particularly noticeable in the dry season. Accordingly while animals tended to at least maintain or even gain mass over the dry season under lighter stocking, loss of body mass frequently occurred in the heavier stocked regimes, even with urea supplementation e.g. 2003\04. Mass loss was sometimes so severe that drought feeding was required to arrest mass loss and prevent mortality, as happened in the HSR treatment in three consecutive dry seasons from 2003 to 2005.

Although cattle did gain (1998/99 and 2005/06) or at least maintain (1999/00) live weight under heavy stocking in the dry season on certain occasions, these seasons were exceptional given their above average rainfall (Fig. 7.1). The relative lack of any treatment effects upon pasture yield and composition in these early years (Chapter 12) and the necessity for drought feeding in 2005/06, suggests that under most conditions, animals will lose weight in the dry season under heavier stocking.

Treatment effects on wet season LWG were not apparent in most years with cattle appearing to perform equally well during the 'wet' irrespective of grazing strategy. Significantly, no compensatory growth occurred in treatments where animals had lost mass in the dry season (Fig. 7.2). Despite rapid gains in the wet, these animals never fully recovered and usually finished the season 30 - 50 kg behind their lighter stocked contempories.

Effect of age on individual LWG

The treatment*branding-year interaction was not significant *(P>0.005)* in any of the four years in which both 18 and 30 month old steers were used, indicating that treatments had similar effects on steers of both ages. Within individual years there were however significant differences in LWG between different cohorts (Table 7.3). These differences were not consistent with the younger, 2 year old steers having significantly *(P<0.001)* better *LWGs* in 2002/03 but the older 3-year old steers performing significantly better in the following two seasons. In contrast, there was no difference between cohorts in LWG in 2005/06. This inconsistency is difficult to explain as younger animals might, at least on an *a priori* basis, be expected to perform better than older steers, as recorded elsewhere by (Jones, McIvor *et al.* 1997) at Lansdowne.

Table 7.3: Mean live weight gain per head (LWG) for different aged steer cohorts across different years at Wambiana. Data meaned across all strategies for each cohort and season. Year branded and origin refer to the year in which the steer cohort was branded and property of origin respectively. (SLR=Swans Lagoon Research station; FVR=Fletcherview Research station).

Season	***Origin***	***Year branded***	***LWG/hd (kg)***
2002/03	SLR	2000	62.7
	SLR	2001	83.8
		F value	***0.001***
2003/04	SLR	2001	113.5
	SLR	2002	90.8
		F value	***0.002***
2004/05	SLR	2002	126.8
	FVR	2003	101.8
		F value	***0.005***
2005/06	FVR	2003	141.1
	FVR	2004	148.3
		F value	N/A

7.4.2 Effect of treatment and age on frame growth

Frame growth (height gain) was unaffected *($P<0.09$)* by treatment in 2003/04 (Table 7.4) although growth tended to be greatest under lightly stocked regimes like the LSR, VAR and SOI strategies (mean: 108 mm) and least in the HSR (88.7 mm). In 2004/05 the effect of treatment was significant *($P<0.05$)* with the smallest gain again occurring in the HSR (45.37 mm) and the largest growth occurring in the VAR and SOI strategies (mean: 66 mm). Frame growth in these latter strategies was greater ($P<0.05$) than in the LSR but this is not surprising given that the 'light stocking' treatment actually had the second heaviest stocking rate of all strategies in the 2004/05 season. A full comparison between treatments could not be conducted in 2005/06 because there was only a single cohort of steers in the HSR: nevertheless, comparison of the remaining four treatments indicated that frame growth was not affected by treatment (Table 7.4).

Table 7.4: Mean height gain per animal in different grazing strategies over three seasons at the Wambiana grazing trial. Heights within the same column followed by the same letter are not significantly different. Data meaned across both age cohorts for strategy and season. Treatment abbreviations as before.

	Height gain (mm/annum)		
Treatment	2003/04	2004/05	2005/06
Var	109.7	66.74*c*	78.00
R/Spell	97.3	63.11*bc*	59.09
SOI	105.4	67.48*c*	60.23
HSR	88.7	45.37*a*	(38.5)[1]
LSR	110.3	52.75*ab*	66.83
F-prob.	*0.09*	***0.012***	0.092[2]
SED	8.93	6.25	6.35[2]

[1] *Only 1 age cohort in the HSR in 2005/06 so treatment excluded from analysis.*
[2] *Analysis excludes HSR in 2005/06.*

Steer age had a significant *(P<0.001*) effect upon height gain in all years (Table 7.5). Again this effect was not consistent, with the younger cohort of steers growing more in 2003/04 and 2005/06 but the older steers growing more in 2004/05. This inconsistency is difficult to explain but may be confounded with genetics: in 2003/04 and 2005/06 both cohorts were drawn from the same properties (SLR and FVR, respectively). In contrast, in 2004/05 the older steers were from SLR while the younger steers were from FVR. Moreover, in 2004/05 the 'young' steers arrived in relatively better condition and were of markedly greater mass (mean: 340 kg) than those that arrived in 2003/04 (mean: 267 kg). The latter, lighter steers would presumably have grown more than the heavier cattle the following year.

Table 7.5: Mean annual height gain per animal for different cohorts of steers across three seasons at the Wambiana grazing trial. Data meaned across all strategies for each cohort and season. (SLR= Swans Lagoon Research station, FVR=Fletcherview Research station).

Season	*Origin*	*Year branded*	*Height gain (mm)*
2003/04	SLR	2001	83.6
	SLR	2002	113.2
		F value	***0.001***
2004/05	SLR	2002	64.7
	FVR	2003	46.3
		F value	***0.001***
2005/06	FVR	2003	38.7
	FVR	2004	98.2
		F-value	***0.001***

7.4.3 Effect of treatment on condition score

Treatment had a significant impact upon condition score (CS) with the 'condition*treatment' interaction being significant *(P<0.005*) in five out of the seven years of the trial where CS was recorded (Table 7.6).

Table 7.6: Effect of treatment on end-of-wet season condition score (May) at Wambiana between 1998 and 2006. Significance of the treatment*condition score (TR*CS) and treatment*condition score*branding (TR**CS*BR) interactions given in the bottom rows. NB: Condition scores were not recorded in 1997/98 and 2002/03.

	Condition score							
Treat.	**98/99**	**99/00**	**00/01**	**01/02**	**02/03**	**03/04**	**04/05**	**05/06**
Var	6.2	6.4	6.7	6.2	-	6.4	6.7	6.9
R/Spell	6.4	6.4	6.5	6.6	-	6.5	6.1	6.9
SOI	6.2	6.3	6.5	6.6	-	6.2	6.3	6.9
HSR	5.9	6.6	6.9	6.2	-	5.5	5.6	7
LSR	6.3	6.5	7.2	7.0	-	6.6	6.6	6.9
TR*CS	***0.003***	*0.456*	***0.008***	***0.001***	-	***0.001***	***0.001***	0.989
TR*CS*BR	-	-	-	-	-	*0.988*	*0.999*	*0.520*

The first exception occurred in 1999/00, when treatment differences were probably minimised by the fact that animals from all strategies were held in the same paddock between October 1999 and January 2000 to allow post-fire recovery of the trial. The second exception was in 2005/06 when the good distribution of rains through the year maintained animals in good condition in all treatments. 'Year of branding' i.e. cattle age, had no influence on the effect of treatment on CS (Table 7.6).

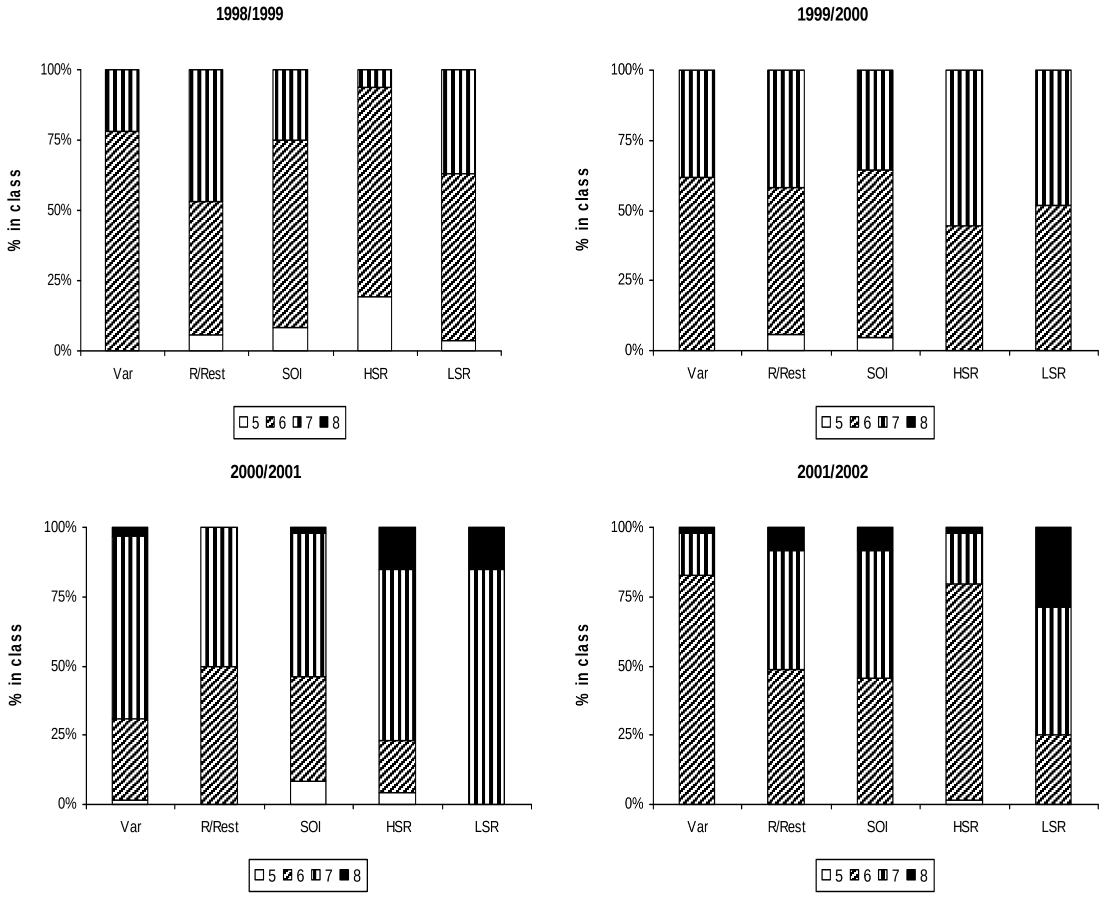


Figure 7.3a: Percentages of cattle in different condition score classes at the end of the wet season from 1998- to 2002 on different grazing strategies at the Wambiana grazing trial.

Mean CS tended to be highest in the LSR and/or in those strategies that happened to be lightly stocked in a particular season e.g. the VAR strategy in 2004/05. With the exception of 2005/06 which was an unusual year, lighter stocked strategies had relatively more animals in the higher CS classes than heavier stocked treatments (Fig. 7.3a & 7.3b). The effect of stocking rate on CS was most pronounced in the below average rainfall seasons of 2001-2005 with HSR animals having the lowest CS in these years (Fig. 7.3a & 7.3b) and having more animals in the lower CS classes relative to lightly stocked treatments. In 2004/05 for example, 50% and 75% of animals in the LSR and VAR strategies respectively, achieved a CS of 8. In contrast, none of the HSR animals achieved this score with over half achieving a CS of only 5 or 6. In 2000/01 HSR cattle had the second highest CS (6.9) after the LSR (7.2) but the HSR was more lightly stocked than either the SOI or VAR strategies in that year.

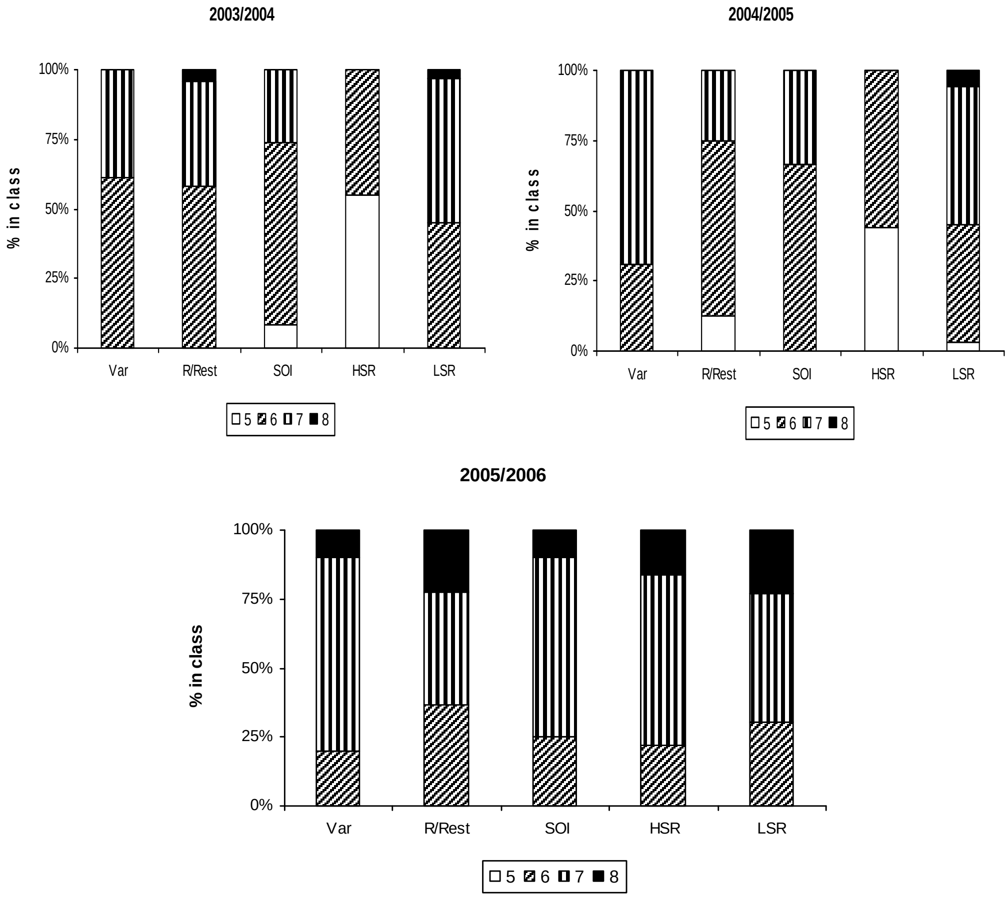


Figure 7.3b: Percentages of cattle in different condition score classes at the end of the wet season from 2003-2006 on different grazing strategies at the Wambiana grazing trial.

7.4.4 Animal Production per unit area

'Year' had a significant (*P<0.001*) effect upon live weight gain per unit area (LWG/ha) with major differences in production occurring between years (Table 7.7). Production was highest in the above-average rainfall years of 1997-2000 but dropped sharply thereafter in the subsequent, relatively dry (decile 20) seasons (Fig. 7.4). In the HSR for example, LWG/ha declined from 35 kg/ha in 2000/01 to only 14 kg/ha in 2001/02. These differences were largely driven by rainfall variability and its associated effects upon pasture growth and animal performance.

'Treatment' had a significant (*P<0.001*) effect upon LWG/ha but this effect was not consistent across years as is indicated by the significance (*P<0.001*) of the 'treatment*year' interaction. Again, this largely reflects variability in rainfall and, in some strategies, stocking rate between years. Thus while the VAR treatment stocked at 3.5 ha/LSU in 2000/01 produced 48 kg/ha, by 2003/04 the stocking rate had been reduced to *c.* 10 ha/LSU, and production dropped to only 10.98 kg/ha.

Significant differences in LWG/ha occurred between treatments in the first four years of the trial (1998-2001) as well as in 2002/03 and 2004/05 (Table 7.7). In eight of the nine years the highest LWG/ha occurred in the heaviest stocked strategies with the lowest LWG/ha occurred in the lightly stocked strategies. For example, in 1999/00 the HSR produced almost twice the LWG/ha (27 kg/ha) of that produced in the LSR strategy (14 kg/ha). Treatment differences were not significant in 2001/02 and 2003/04 but large differences in LWG/ha between strategies were still apparent. The lack of significance in 2003/04 probably reflects the within-treatment variability that resulted from spatial differences in rainfall distribution at the start of the wet season: in December 2003 an early storm delivered 70 mm to the second replicate of the HSR (P9) but only 35 mm to the first (P4). This apparently small difference resulted in a longer growing season in P9 and consequently, a far better LWG/ha (31 vs. 17 kg/ha) than in the first replicate (P4).

Table 7.7: Effect of treatment on mean live weight gain (LWG) per unit area (ha) over eight seasons between 1997 and 2006 at the Wambiana grazing trial. Figures within the same column followed by the same letter are not significantly different. Treatment abbreviations as before.

	LWG per ha								
Treat.	**97/98**	**98/99**	**99/00**	**00/01**	**01/02**	**02/03**	**03/04**	**04/05**	**05/06**
VAR	10.5	28.5 *a*	26.7 *a*	48.3 *a*	14.3	10.5 *c*	11.1	13.6 *c*	15.2
R/Spell	13.2	22.4 *b*	18.8 *b*	25.7 *c*	13.0	17.8 *a*	11.3	14.1 *c*	16.1
SOI	10.0	26.2 *ab*	28.1 *a*	39.5 *b*	11.5	10.6 *c*	12.7	15.6 *bc*	16.9
HSR	18.9	29.2 *a*	27.2 *a*	35.8 *b*	14.0	14.6 *ab*	24.4	24.9 *a*	20.4
LSR	10.5	17.5 *c*	14.8 *b*	20.4 *c*	9.7	12.2 *bc*	18.5	17.1 *b*	18.2
F-prob.	*0.055*	***0.010***	***0.004***	***0.001***	*0.338*	***0.026***	*0.116*	***<0.001***	*0.370*
SED	2.15	1.72	1.66	1.93	2.17	1.41	4.24	0.810	2.38

Importantly, differences in LWG/ha between treatments narrowed over time, so that by 2003/04, the production difference between the HSR (14 kg/ha) and the LSR (12 kg/ha) was relatively small (Fig. 7.4). This narrowing probably reflects the lower rainfall in later years as opposed to a general decline in production potential under heavy stocking. However, the relatively poor LWG/ha in the HSR in 2005/06 does suggest a reduction in productive potential, given the good season and the reduced stocking rate applied in the HSR in that year.

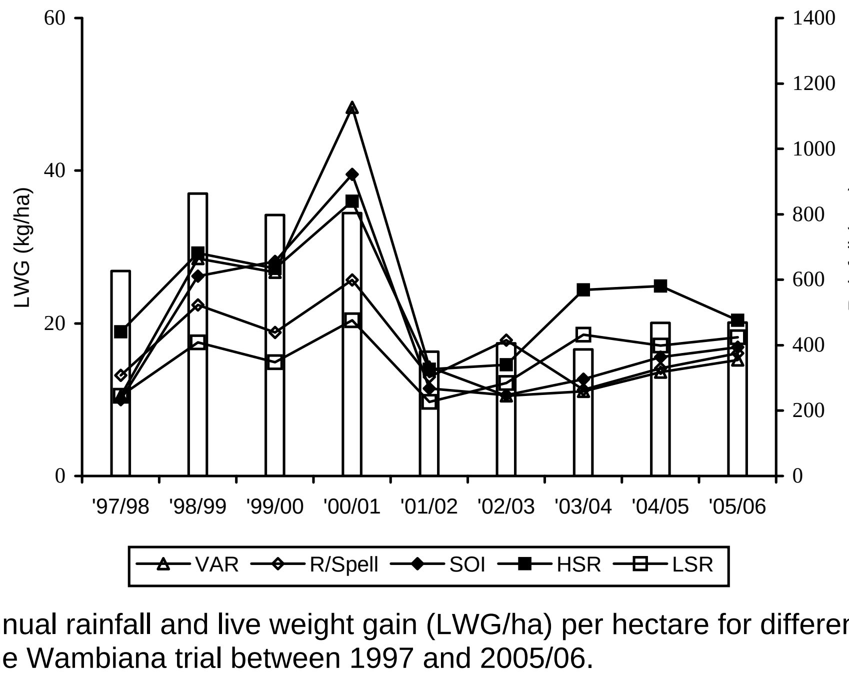


Figure 7.4: Annual rainfall and live weight gain (LWG/ha) per hectare for different grazing strategies at the Wambiana trial between 1997 and 2005/06.

7.4.5 Market performance

In May 2004 only the better condition animals were worth sending to the meatworks with the remainder being sold through the Charters Towers saleyards. The percentage of meat works animals was highest for the LSR (94%), moderately high in the SOI and R/Spell (67%), lower in the VAR (47%) but only 5% in the HSR. Although prices/kilogram were similar across all treatments, due to superior weight the returns per beast were well over $150 more in the LSR ($673) than in the HSR ($512). Returns/beast for the other treatments were approximately mid-way between these two extremes (Fig. 7.5)

The following year (May 2005) all older animals (#2002) went to the meatworks. The single exception was a small group (seven) of HSR steers sold at the local sale because of their relatively poor condition. Animals varied in grades and weights, returning a range of prices/kilogram and per carcass (Fig. 7.5). A clear treatment effect was evident with HSR animals returning a lower average price/kilogram ($2.77/kg) than remaining treatments (mean: $2.95/kg). This penalty, together with the lower carcass weights, resulted in the HSR receiving a far lower price/ beast ($560) than other treatments (mean: $680).

In 2006 all the older steers (#2003) leaving the trail went to the meatworks due to their good condition. All graded Japanese ox (AAA) but HSR animals received a lower price per kg (mean: $3.22/kg) than those from the other treatments (mean: $3.30/kg). HSR animals also only averaged $860/carcass due to their lower total weight. Carcass prices for the other treatments were appreciably higher with the VAR, SOI and R/Spell averaging about $1010 per beast. However, animal weights in the LSR were slightly lighter and accordingly carcass returns were marginally lower ($980) than in the latter treatments (Fig. 7.5).

Print 7: In the early wetter years grass was abundant in the heavy stocking rate but by 2004 cattle had to be supplemented with molasses and urea in the dry season.

Print 8: In lighter stocked treatments animals continued to perform in later years despite five successive seasons of below average rainfall.

7.5. Discussion

Marked inter-annual variability occurred in both LWG per animal (range: 30-180 kg/hd/yr) and LWG per unit area (range: 9-48 kg/ha/yr), reflecting variability in the amount and distribution of rainfall and, in the VAR and SOI treatments, variability in stocking rate between years. This variability was further compounded by the episodic occurrence of factors such as the outbreak of armyworm in 2003 and the 1999 fire. Changes in supplementation regime, genetics (cattle origin) and the introduction of HGPs through the trial would also partially account for the observed variability in LWG.

The seasonal pattern of LWG observed through the year is a characteristic of the northern savannas e.g. Gillard (1978), and is an obvious consequence of the marked seasonal rainfall of these regions. Comparison of LWG with NIRS data clearly indicate that LWG only occurs when forage quality is sufficient to satisfy the energy and protein levels required for animal growth (Chapter 12). Dry season mass loss results from the poor forage quality common at this time of the year when dietary CP levels frequently fall well below maintenance requirements. An exception to these seasonal trends occurred in 1998/99 and 2005/06 when unseasonable rains kept pastures green and allowed substantial LWG through the nominal ‘dry season’. However these seasons were exceptional and indeed, 1998/99 was rated by older graziers in the district as the best in sixty years (*J. Allingham, pers.comm, Fletchervale, Charters Towers*)

‘Treatment’ had a large impact upon LWG with consistent trends emerging between different grazing strategies in most years, despite extreme variability in seasonal conditions and rainfall. Differences between grazing strategies were largely driven by the effects of stocking rate upon animal production: overall, individual animal performance was best in lightly stocked- and poorest in heavily stocked- strategies.

Taken over all seasons, individual LWG was highest in the LSR and lowest in the HSR treatment (123 vs. 96 kg). The superior individual production under light stocking occurred in all years irrespective of rainfall or pasture availability. Individual LWGs were thus highest under light stocking in both 1998/99 (159 kg) and 2002/03 (90 kg) which were possibly the best and poorest rainfall years respectively, of the trial. LWG differences were cumulative so that after two years on the trial, cattle under light stocking were, depending upon the season, 50 to 100 kg heavier than those under heavy stocking (Fig. 7.2).

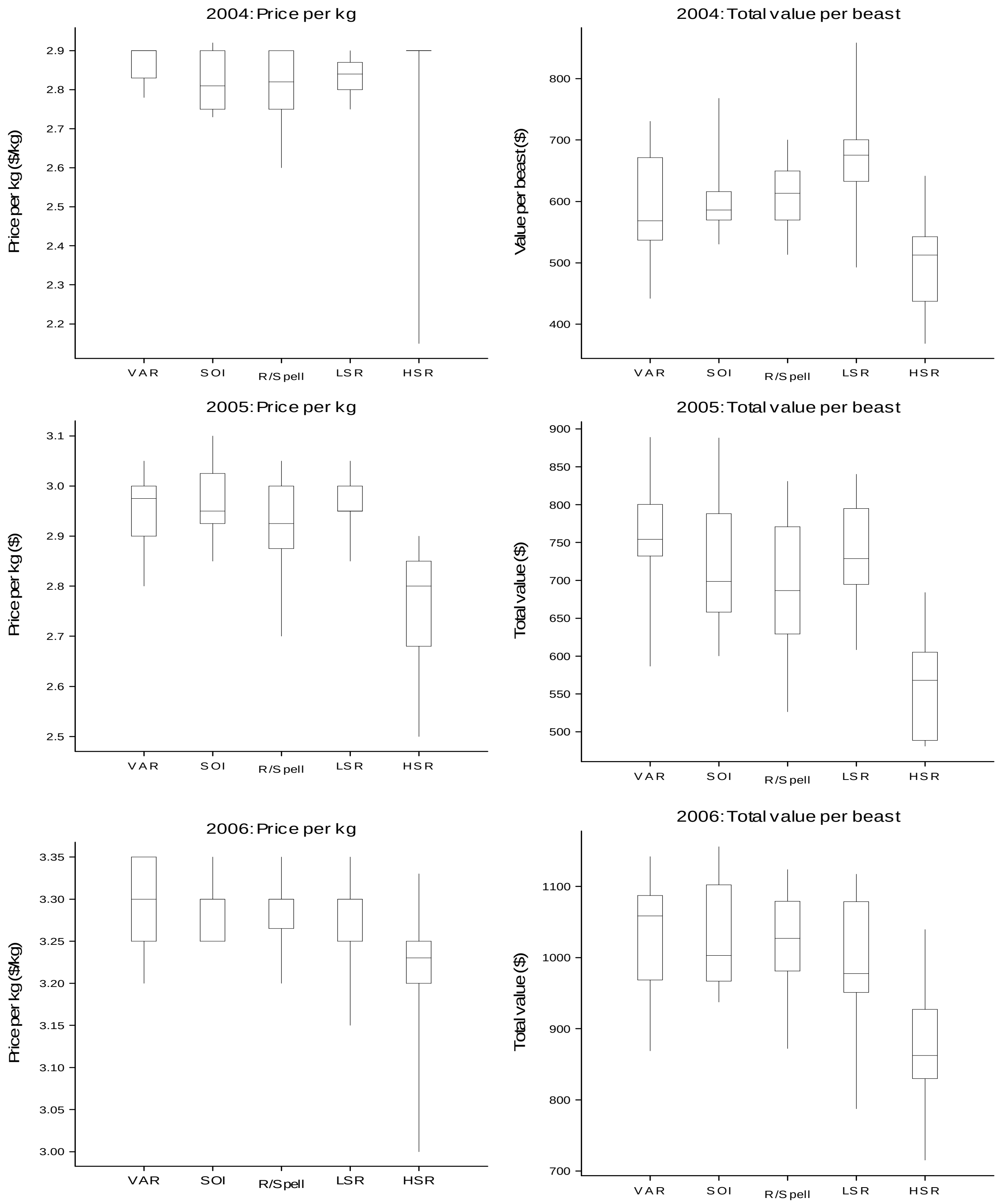


Figure 7.5: Box and whisker plot of price per kg and price per beast for animals marketed between 2004 and 2006 at the Wambiana trial.

Individual LWG in the R/Spell treatment (mean: 112 kg) varied but was intermediate between the HSR and LSR, as might be expected from it's generally 'intermediate' stocking rate. Unfortunately, production in the R/Spell was compromised by the 2001 fire and its subsequent impact upon pasture production and stocking rate in this strategy.

In the SOI and VAR strategies individual animal performance was very dependent upon the stocking rate applied in particular seasons. For example, in 2000/01 individual LWG was poor in the 'VAR' and SOI treatments relative to the LSR treatment, due to the heavy grazing pressures applied in the former treatments in that year. In contrast, because the SOI and VAR strategies were very lightly stocked in 2004/05 and 2005/06, individual LWGs were as good if not better than those in the LSR (Table 7.2).

Animal condition was also markedly better under light than under heavy stocking. Significantly, these differences were detected at the end of the wet season when body condition peaked and treatment differences would have been minimised. In the dry season, differences were far more pronounced with steers in lightly stocked strategies largely retaining condition whilst those in heavier stocked strategies rapidly lost condition, despite urea supplementation. Cattle in lighter stocked strategies also grew more in terms of frame size (height), than those in heavy stocked strategies. Frame size is an important determinant of weight-for-age, with larger framed animals generally reaching a given target weight at a younger age. A larger frame size is also required to finish steers for the higher returning Japanese and Korean export markets.

Cattle in the lighter stocked treatments thus finished heavier, taller and in better condition than those in heavily stocked treatments. On leaving the trial these steers consequently received better meatworks grades, which combined with their superior weight, returned a markedly better carcass price than those from heavily stocked paddocks. A small but significant proportion of steers from heavily stocked paddocks were too light and/or lacked the condition required for the meatworks: those steers that did go to the works received on average, poorer grades and a markedly lower carcass price than those from lightly stocked strategies. Although all steers were good enough to go to the meatworks in 2005/06, cattle from the HSR still received lower prices due to lower carcass weights and poorer weight-for age.

Differences in individual animal production between grazing strategies largely reflect the impact of stocking rate on diet quality and pasture availability. In the early, wetter years of the trial when pasture total standing dry matter (TSDM) was high in all treatments, differences in LWG largely arose from differences in diet quality as evidenced by the higher crude protein percentage and digestibility of diets selected under lighter stocking (Chapter 12). This reflects reduced competition for higher quality pasture components like green leaf, forbs and legumes. The impact of stocking rate on diet quality and LWG was almost immediate: for example, LWG (Fig. 7.2) and diet quality in the different strategies diverged within weeks of animals being returned to paddocks in January 2000 following the 1999 fire.

In later years LWG would also have been restricted by low intake in heavily stocked paddocks as TSDM dropped to very low levels (< 300 kg/ha), particularly in the dry season (Chapter 10). Although early wet season dietary quality was often very high at these low yields due to the availability of short, high quality regrowth, in the dry season diet quality dropped precipitously as animals consumed low quality stubble and leaf litter to survive.

In contrast to individual animal production, production/area was highest in the HSR but least in the LSR (mean: 23 vs. 14 kg/ha). However, inter-annual variability in production/ha was also greater than in the LSR (C.V.: 31 vs. 24%). Treatment differences were initially large in the wetter, first half of the trial with LWG/ha under heavy stocking sometimes being twice that under light stocking (Fig. 7.4). However, these treatment differences narrowed in later years due to reduced rainfall and, possibly, a reduction in the inherent production potential of the HSR paddocks arising from declining pasture composition and land condition in this treatment.

The relatively high LWG/ha achieved in the HSR in 2004/05 does suggest that the productive potential of this treatment is largely intact. However, production both in that and the previous (2003/04) dry seasons was dependent upon the standard industry practice of feeding M8U to maintain animals when feed is scarce. Animals on lighter stocked treatments in contrast, coped very well through this period, despite only having access to dry pasture and urea supplementation. The forced reduction in stock numbers in HSR paddocks in May 2005 is further cause for concern and suggests that these high stocking rates cannot be sustained indefinitely. Moreover, it gives ample illustration of how constant heavy stocking necessitates more reactive management such as forced destocking and drought feeding.

Production/ha in the VAR and SOI treatments was again dependent upon the stocking rate applied in particular seasons. LWG/ha was relatively high in these treatments in 2000/01 (mean: 41 kg/ha) due partly to good rainfall but also due to the heavy stocking rates (*c.* 3.8 ha/LSU) applied in these paddocks. However, mean LWG/ha in these treatments in 2004/05 was far lower (mean: 13 kg/ha) due to the extremely light stocking rates (*c.* 10 ha/LSU) applied at this stage. Inter-annual variability in production was particularly high in the VAR (C.V. = 62%) and SOI (C.V. =51%) treatments, although this is probably more a reflection of stocking rate fluctuations rather than any inherent susceptibility to climate variability *per se.* Production/ha in the R/Spell treatment was also variable and again depended on the season. LWG/ha was also affected by the decline in stocking rate implemented in 2003 due to the after effects of the 2001 fire in this strategy. Overall, mean LWG/ha in the R/Spell treatment (16.93 kg/ha) was only marginally better than that obtained in the LSR strategy (mean: 15.42 kg/ha).

The LWGs and stocking rate effects reported here are in agreement with those from other studies. For example, (Gillard 1979) reported significantly ($P<0.05$) better individual LWGs under light stocking compared to heavy stocking (mean: 122 vs. 104 kg/hd) in 5 out of 10 years: the reduced LWGs under heavy stocking typically occurred in drought years due to feed shortages. LWGs on sown and native pastures at 'Lansdown' also declined with increasing stocking rate with these effects being most obvious in the dry season when feed was scarce: conversely LWG/ha generally increased with stocking rate (Jones 2003). On native pasture oversown with Indian couch, LWG/ha also increased with stocking rate from 0.3 to 0.6 steers/ha but the heaviest stocking rate at 0.9 steers/ha was unsustainable *(Jones 1997)*. In contrast, at the 'Thalanga' demonstration site, stocking rate had no clear effect on LWG, possibly due to soil differences between unreplicated paddocks: at two other sites, steer LWG/hd were markedly higher under conservative stocking than under heavy stocking ((Smith 2000)D. Smith, *QDPI&F, pers. comm.*).

Ultimately, the definitive test for any grazing strategy is not simply individual or total animal production but relates to its relative economic performance and impact upon land and pasture condition. These issues are explored in detail in later sections of this report.

7.6. Summary

1. Individual live weight gain (LWG) varied sharply between years depending upon rainfall, rainfall distribution and treatment. For example, LWG in the LSR ranged from a high of 180 kg/hd in 2000/01 to just 70 kg/hd in 2001/02.

2. Live weight change generally followed a typical seasonal pattern with maximum LWG occurring in the wet season and relatively small gains or mass loss occurring in the dry season. However in years with unseasonable rains in winter and spring e.g. 2005/06, good LWGs were recorded in the dry season.

3. Treatment had a significant effect upon production with individual LWGs being consistently higher in the lighter than in the heavier stocked strategies. After two years, cattle were 50 to 100 kg heavier under light than under heavier stocked regimes. Frame growth and condition score were also significantly better under light than under heavy stocking.

4. Taken over all years mean LWG was highest in the LSR (126 kg/yr), lowest in the HSR (96 kg/yr) and intermediate between these levels in the VAR (113 kg/yr), R/Spell (112 kg/yr) and SOI (111 kg/yr) strategies. However, for individual years, relative animal performance in the VAR, R/Spell and SOI varied strongly according to the stocking rate applied.

5. Treatment differences in LWG were most marked in the dry season when weight loss tended to occur under heavy stocking. In contrast, animals in lighter stocked treatments maintained or even gained weight through the dry season.

6. When marketed, animals from lighter stocked strategies attracted a price premium per kg due to superior body condition and better weight for age, and also realised a better total price due to greater carcass weight, than animals from heavier stocked strategies.

7. Steer age had a significant effect upon frame growth in all three years when data was collected with the younger cohort growing more than the older animals. However, differences between cohorts in LWG were inconsistent and varied between years.

8. Production per unit area (LWG/ha) varied markedly between years with this variability being largely driven by rainfall and, to a lesser extent, changes in stocking rate within the two variable treatments (VAR and SOI). For example, LWG/ha in the VAR ranged from a maximum of 48 kg/ha in 2000/01 to only 11 kg/ha in 2003/04.

9. Treatment had a strong effect upon production per unit area with LWG/ha being greatest under heavy stocking but least under light stocking. However, the HSR required drought feeding (M8U) in three of the nine seasons. Stocking rates also had to be reduced by about a third in this treatment in June 2005 due to the extreme shortage of pasture.

8. Effects of utilisation rate, rainfall and pasture composition on LWG

8.1. Introduction

In Chapter 7 the effects of different grazing strategies on animal production over the eight years of the trial were investigated in detail. In the present chapter, this LWG data in combination with a range of management and environmental data is explored further. This is done to elucidate the major factors determining LWG and allow prediction of animal production under a range of conditions in the semi-arid savannas of the tertiary sediments. Management factors investigated include stocking rate, utilisation rate and urea supplementation, while the environmental factors considered include rainfall, Growth Index days, pasture mass and species composition.

8.2. Objectives

1. Explain the variability in LWG observed between different years and treatments in terms of management factors like stocking rate and/or environmental factors like rainfall or length of the growing season.
2. Develop empirical equations that allow prediction of the effects of these management and/or environmental factors on animal production.
3. Develop management guidelines and indices to assist managers in achieving target levels of animal production under different seasonal and environmental conditions.

8.3. Procedure

8.3.1 Methods

Regression and multiple regression analysis of live weight gain (LWG) per hectare and per individual animal were conducted using GENSTAT. Models were run relating both LWG/ha and LWG per head to a range of variables including stocking rate, growth index (GI) days from GRASP (Chapter 6) and annual rainfall. Different combinations of these variables were also assessed with and without the term ‘year’.

For individual LWG\hd the influence of previous or cumulative stocking rate and rainfall effects were investigated using rainfall or stocking rate from the previous year or a two year running mean of either variable. The effects of rainfall and GI days on LWG gain in the dry and wet seasons were also determined by partitioning both rainfall and GI days into wet- and dry-season components.

8.4. Results

8.4.1 Effects of stocking rate and utilisation rate on animal production

Production per unit area

Total LWG/ha was positively related *($P<0.001$)* to annual rainfall and Growth Index (GI) days with these variables explaining 39 % and 24 % of the variability in the data, respectively. LWG/ha could be predicted from these two variables using the equations:

LWG/ha=5.13+0.290*GI Days ($P<0.001$; R^2=24)

LWG/ha=2.17+0.0289*Rainfall ($P<0.001$; R^2=39)

Rainfall was appreciably better (*c.* 15%) than GI days in explaining variability in LWG/ha. This is logical given that rainfall is the primary determinant of pasture yield and in strategies where stocking rates were varied like the VAR and SOI, stocking rate adjustments were based on pasture yield, not GI days. The relatively wide variation in rainfall experienced between seasons during the trial would also have ensured that yield was more closely correlated with total rainfall than with GI days. In years with more consistent rainfall e.g. a run of consistently dry seasons, GI days might possibly be a better predictor of LWG/ha than total rainfall.

As expected, stocking rate (ha/LSU) was also a significant ($P<0.001$) determinant of LWG/ha, accounting for 39% of the variation in LWG per unit area.

$$LWG/ha=36.19-2.28*SR\ (P<0.001;\ R^2=39)$$

Stocking rate was thus of similar importance to rainfall in determining total LWG/ha. However, autocorrelation between these variables is probable as in the VAR and SOI the heaviest stocking rates were applied in high rainfall years and the lightest stocking rates in low rainfall years.

The best predictive equations for LWG/ha were obtained using a combination of stocking rate and either rainfall or GI Days i.e.

$$LWG/ha=19.43+0.0268*Rainfall - 2.12*SR\ (P<0.001;\ R^2=74)$$
$$LWG/ha=22.78+0.260*GI\ Days – 2.14*SR\ (P<0.001;\ R^2=59)$$

Addition of the factor ‘Year’ to these equations improved R^2 values to 86% (all models $P<0.001$) with this variable explaining an extra 12 – 27% of the variability in the data. Although models with ‘year’ included are of limited predictive value, they nevertheless have explanatory power and indicate that the large variation in animal production between years was influenced by factors other than stocking rate and rainfall or GI Days. Potential factors and their effects include differences between years in terms of weather (positive/negative), the 1999 fire (positive), the 2003 armyworm outbreak (negative), the use of HGPs and wet season P from 2004 onwards (positive) and the provision of dry season supplementation from 2003 onwards (positive).

When analysed on the basis of individual years, stocking rate explained a significant ($P<0.001$) proportion of the variability in LWG/ha in seven out of the nine years of the trial (Table 8.1; Fig. 8.1). The weaker relationship observed ($P<0.081$) in 2001/02 appears to reflect the combination of low rainfall and the carry-over effects of the very high stocking rates imposed in previous seasons on the VAR paddocks and it’s subsequent impact upon animal performance.

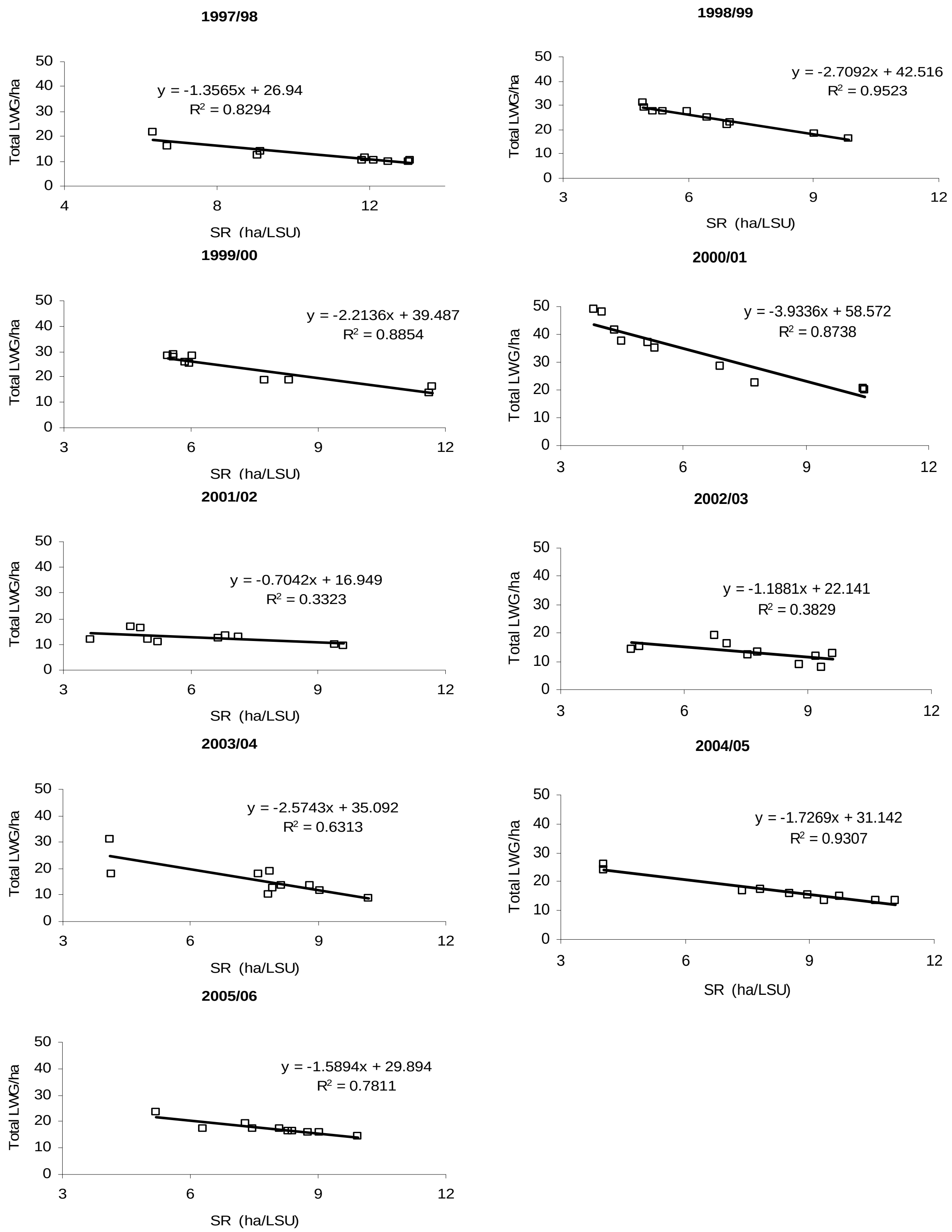


Figure 8.1: Relationship between total LWG per ha and stocking rate (ha/LSU) for individual years at Wambiana.

The positive overall relationship between stocking rate and LWG/ha is logical given that total production per unit area should increase with increasing cattle numbers, at least within certain limits. In classic stocking rate models the relationship is curvilinear with total production/ha initially increasing to a peak but thereafter declining at very heavy stocking rates due to depressed individual animal production e.g. Jones & Sandland (1974).

Superficially, this does not appear to have occurred in the present data suggesting that stocking rates were not heavy enough to depress production per unit area, at least during the first, relatively wet, half of the trial. In 2000/01 a concave relationship is even suggested with the increase in LWG/ha tending to accelerate with increasing stocking rate. However, in 2002/03 there is clear evidence of a decline in LWG/ha at higher stocking rates (Fig. 8.1). The apparently linear relation between LWG/ha and SR in 2003/04, 2004/05 and 2005/06 is also misleading: in these years production was only maintained in the HSR through substantial drought feeding in the dry season. Without feeding, production would have been severely depressed (2003/04) or might even have completely collapsed (2004/05 and 2005/06) at the heaviest stocking rates. Indeed, as reported earlier, SRs had to be cut by about a third in May 2005 in the HSR because of the extreme shortage of feed. As noted before, only time will ascertain whether this decline in carrying capacity reflects a drought induced feed shortage or a more permanent change in secondary production in this treatment.

Table 8.1: Linear regression equations relating total live weight gain per hectare (LWG/ha) to stocking rate (ha/LSU) for individual years between 1997 and 2006 at Wambiana.

Year	*a*	*b*	R^2	P-value
1997/98	26.95	-1.35	**80.9**	**0.001**
1998/99	42.52	-2.71	**94.7**	**0.001**
1999/00	39.48	-2.21	**94.7**	**0.001**
2000/01	58.55	-3.93	**85.8**	**0.001**
2001/02	16.95	-0.704	24.9	0.081
2002/03	22.14	-1.18	30.6	0.056
2003/04	35.09	-2.54	**58.6**	**0.006**
2004/05	31.13	-1.72	**92.2**	**0.001**
2005/06	29.89	-1.58	**75.2**	**0.001**

Total Live weight gain per animal

When analysed over all years, rainfall and GI days were the largest single determinants of total LWG per head over the grazing season i.e.:

$$LWG_{total}=36.40 + 0.132*Rain \qquad (P<0.001;\ R^2=39)$$
$$LWG_{total}=21.79 + 1.924*GIDays \qquad (P<0.001;\ R^2=52)$$

Interestingly, dry season rainfall (R^2=58.1; *P<0.001*) was a far more important determinant of total LWG than wet season rainfall (R^2=8.0; *P<0.004*).

Mean utilisation rate accounted for 25% (*P<0.001*) of the variation in LWG per head data, at least for the years 1998 to 2005, with LWG/hd declining as mean utilisation rate (%) increased:

$$LWG_{total}=138.24 - 1.14 *Utilisation \qquad (P<0.001;\ R^2=25)$$

For individual seasons, LWG/hd generally declined as pasture utilisation rate increased (R^2= 31-81%). The only exception to this occurred in the 1999-2000 season when animals spent two and a half months grazing together in a single paddock after the October 1999 fire (Table 8.2). Overall, there was no consistent threshold utilisation rate above which LWG declined, which largely reflects the wide range of utilisation rates observed over the course of the trial. As mentioned in Chapter 6, GRASP predictions of utilisation rate in 2006 were considered to be gross under estimates and were not used.

In contrast to utilisation rate, stocking rate had no effect on total LWG (P<0.948) when analysed over all years. This is unexpected given the significant differences in individual animal production recorded between treatments in most years (Chapter 7) and suggests that stocking rate effects were largely swamped by seasonal variability in rainfall and growing conditions. However, when analysed on the basis of individual years, LWG declined with increasing stocking rate in all seasons (Table 8.2). Thus total LWG was negatively related *(P<0.056)* to stocking rate in six of the nine years of the trial with a negative relation also being apparent in three of the remaining four years. The lack of a strong relationship in 1999/00 between SR and LWG may again be attributed to the post-fire management of the cattle in that year.

The lack of a relationship between LWG and SR in 2002/03 and 2003/04 is surprising given the dry nature of these years. Nevertheless, in both years the best individual LWG still occurred in the LSR with the worst occurring in the HSR treatment. Although the SOI, VAR and R/Spell were actually more lightly stocked than the LSR that year, individual LWGs in these former treatments were poorer than would be expected from their stocking rates. This reduced performance may be attributed to the effects of the heavy stocking rates applied in the SOI and VAR in earlier seasons (1999-2001) which appeared to have had a carry over effect on pasture yield and composition (Chapter 12), reducing LWG in drier, subsequent years. In the R/Spell treatment, LWG was probably depressed by the continued negative effects of the fire applied to sections of these paddocks in November 2001.

Table: 8.2 The percentage of variance and P-values for total, dry season and wet season live weight gain (LWG) explained by stocking rate in different years at Wambiana. NB: No dry season data were collected in 1997/98.

Year	Total LWG/hd		Wet season LWG/hd		Dry season LWG/hd	
	R^2	P-value	R^2	P-value	R^2	P-value
1997/98	30.6	***0.056***	30.6	*5.90*	-	-
1998/99	**47.5**	***0.016***	14.8	*0.148*	11.3	*0.181*
1999/00	0	*0.667*	0	*0.569*	20	*0.109*
2000/01	**46.4**	***0.018***	14	*0.155*	**54.3**	***0.009***
2001/02	**67.9**	***0.002***	0	*0.432*	**86.8**	***0.001***
2002/03	**15.4**	***0.143***	0	*0.991*	16.1	*0.137*
2003/04	16.4	*0.135*	**44.1**	***0.022***	0.7	*0.332*
2004/05	**83.9**	***0.001***	0	*0.947*	**71.3**	***0.001***
2005/06	**51.0**	***0.012***	**65.2**	***0.003***	**63.6**	***0.003***

Addition of the factor ‘Year’ to the regression equations outlined above dramatically improved R^2 values, with a combination of ‘rainfall’, ‘mean utilisation rate’ and ‘year’ accounting for 90% of the variability in total LWG data. These equations have significant explanatory power and indicate that a large part of the variability in annual LWG occurred due to factors other than seasonal variability in rainfall or GI days. Other possible sources of variability in the ‘year’ component include the use of dry season licks, the armyworm outbreak of March 2003, the effects of the October 1999 fire on subsequent pasture quality, the use of HGPs in 2004 as well as other unquantified differences in weather patterns or seasonal conditions.

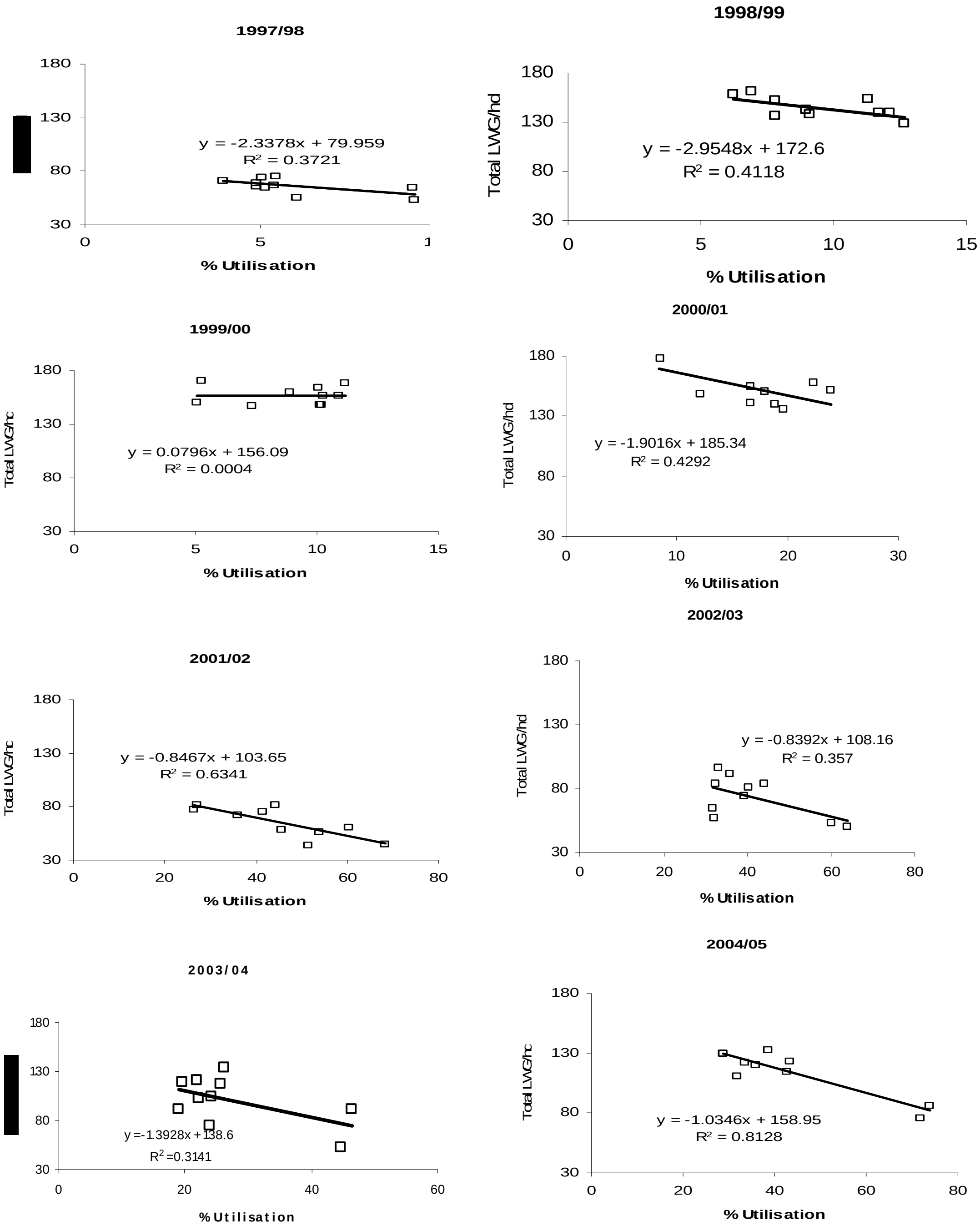


Figure 8.2: Relationship between total LWG per animal and percentage pasture utilisation rate for individual years at Wambiana.

Dry season (DS) live weight gain

Dry season LWG was strongly related to dry season GI days and rainfall:

LWG_{DS}*=-26.99 +1.659* GI Days*$_{DS}$ (R^2=61 %; *P<0.001)*

LWG_{DS}*=-22.35+0.2243*Rain*$_{DS}$ (R^2=43 %; *P<0.001)*

Dry season LWG was negatively related to mean pasture utilisation rate:

LWG_{DS}*=55.5-1.637*Utilisation* (R^2=57 %; *P<0.001)*

Although dry season LWG was not related to stocking rate it was related to the *previous* seasons stocking rate (R^2=20 %; *P<0.001).* This indicates a lag effect of stocking rate on animal performance in the subsequent dry season, probably through the depletion of available pasture for use in the DS. For individual years dry season LWG generally declined with increasing stocking rates, with the relation being significant *(P<0.003)* in four out of eight years (Table 8.2; Fig. 8.3).

Dry season LWG (LWG_{DS}) was best predicted from either (i) dry season GI days and stocking rate, (ii) dry season rainfall and utilisation rate or (iii) dry season growth days and utilisation rate:

$$LWG_{DS} = -58.7 + 1.697 * GI\ Days_{DS} + 4.27 * SR \quad (R^2 = 66\ \%;\ P<0.001)$$
$$LWG_{DS} = 18.0 + 0.1174 * Rain_{DS} - 1.011 * Utilisation\% \quad (R^2 = 63\ \%;\ P<0.001)$$
$$LWG_{DS} = 17.7 - 0.997 * Utilisation + 0.895 * GIDays_{DS} \quad (R^2 = 64\ \%;\ P<0.001)$$

Other equations are given in Table 8.3 below.

Table 8.3 Alternative predictive equations for LWG over the dry season*. (SR2Y=2 year running mean of stocking rate, other abbreviations as before).*

Variable	Equation	R^2	Significance
$\mathbf{LWG_{DS}}$	$-84.7+0.110*Rain + 5.01*SRPrev.Year$	48	***P<0.001***
$\mathbf{LWG_{DS}}$	$-63.5 + 0.240*Rain_{DS} +5.32*SR$	50	***P<0.001***
$\mathbf{LWG_{DS}}$	$-45.09+ 1.509*GI\ Days_{DS} +2.92*SRPrev.Year$	64	***P<0.001***
$\mathbf{LWG_{DS}}$	$-55.4+1.57* GI\ Days_{DS} +4.17*SR2Y$	66	***P<0.001***

As with total LWG/hd and LWG/ha, adding the factor 'Year' markedly increased the percentage of the variability accounted for in DS live weight gains to about 91%.

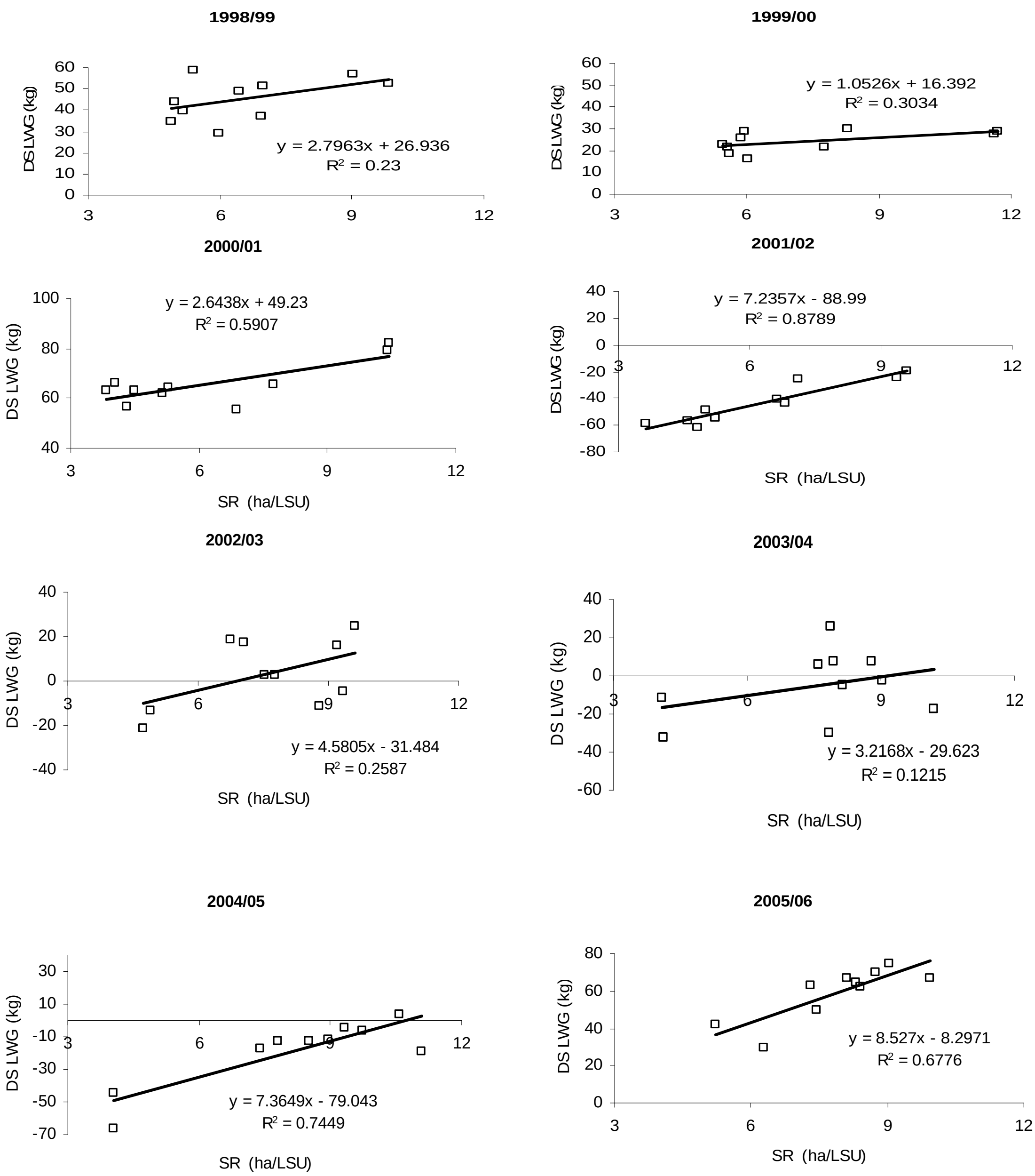


Figure 8.3: Relationship between dry season (DS) LWG per animal and stocking rate (ha/LSU) for individual years at Wambiana.

8.4.2 Effects of rainfall, TSDM and percentage DS pasture use on LWG

Rainfall, GI days

As described in above, dry season LWG was positively related to DS rainfall (*$P<0.001$*) with this single factor accounting for 43 % of the variability in the overall data. Inspection of the graph of this relationship suggests that a minimum of 100 mm of dry season rainfall is generally required to maintain body weight i.e. achieve a positive LWG, with every 10 mm of rainfall thereafter giving approximately 2.22 kg of dry season growth (Fig 8.4)

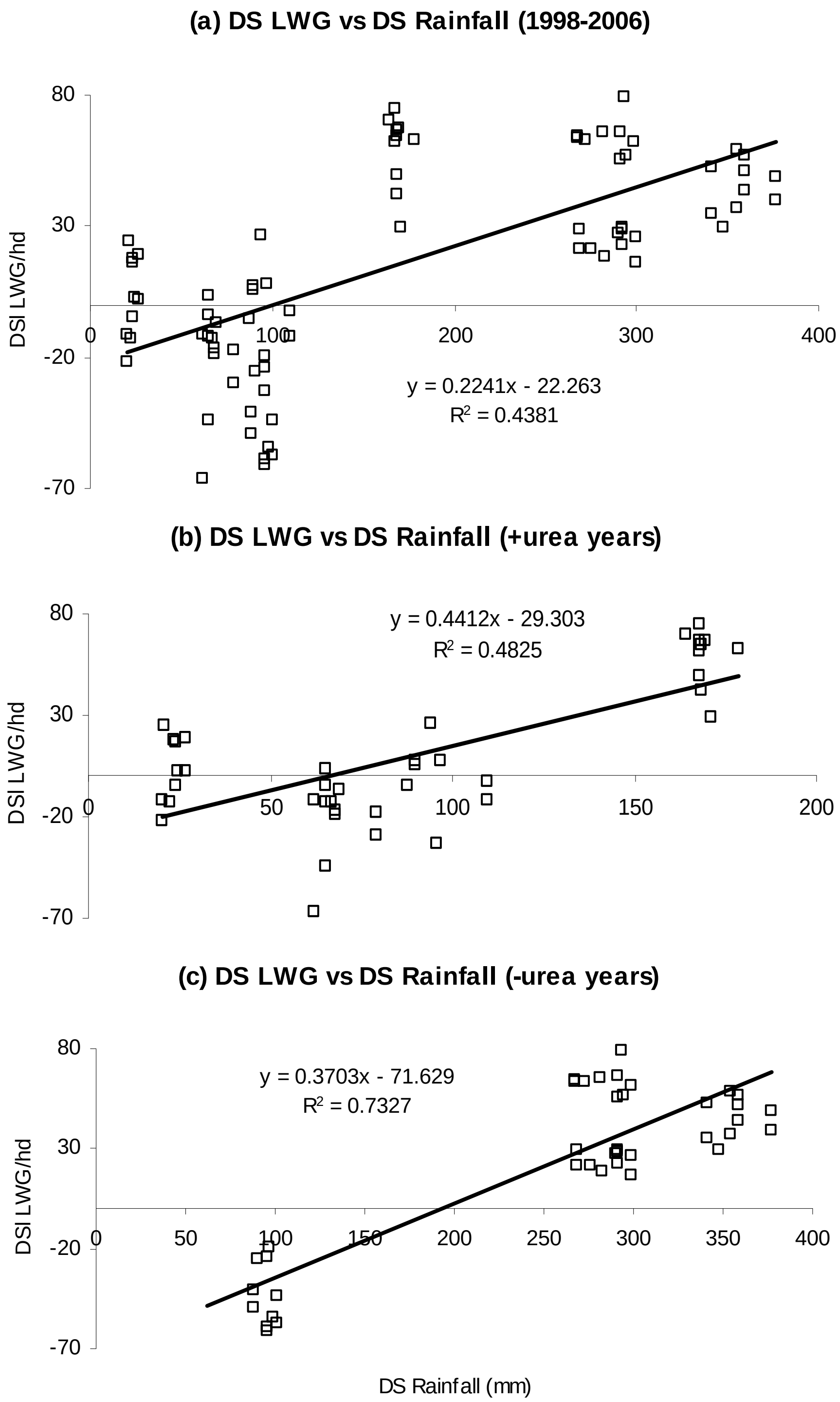


Figure 8.4: Relationship between dry season (DS) LWG and DS rainfall for (a) all years (b) urea supplemented years and (c) years without urea supplementation.

Regression analysis using urea supplementation as a grouping factor improved the LWG by rainfall relationship (R^2=63 %; *P<0.001*) and allowed separate equations to be developed for supplemented and un-supplemented years, i.e.:

No urea: $LWG_{DS} = -71.77+0.370* Rain_{DS}$ (R^2=72 %; *P<0.001)*

Urea: $LWG_{DS} = -29.42+0.442* Rain_{DS}$ (R^2=47 %; *P<0.001)*

The intercepts were significantly different (*$P<0.001$*) in supplemented and unsupplemented years, highlighting the positive effect of urea on DS animal performance (Fig. 8.4 b & c). With no dry season rainfall, body mass loss was thus minimised by supplementation with a predicted loss of -29 kg with urea compared to a loss of -71 kg for unsupplemented animals. The data also suggest that unsupplemented animals required a greater amount of total DS rainfall (190 mm vs. 60 mm) to at least maintain body mass compared to those on urea supplementation. Differences between slopes were significant (*$P<0.001$)* indicating that supplemented steers achieved about 4.4 kg of LWG and unsupplemented animals about 3.7 kg of LWG, for each 10 mm of DS rainfall.

Total LWG over the year was also positively related ($P<0.001$) to DS rainfall, with this variable alone accounting for 60 % of the variability in total LWG (Table 8.4). This is not unexpected given first the obvious effect of dry season LWG on total LWG and second, the effect of DS rain on factors such as GI days which, through its effect on the length of the growing season, directly influences dietary quality and, to a lesser extent, TSDM. Nevertheless, a big variation in total LWG was evident between different rainfall years, obviously reflecting differences in rainfall distribution, wet season rainfall, N uptake, stocking rate and supplementation etc (Fig. 8.1).

Table 8.4 Equations relating total and dry season LWG to rainfall and start-of-dry (SOD) and end-of-dry (EOD) pasture TSDM, for animals in years with or without urea.

Variable	Equation	R^2	Significance
LWG_{Tot}	$70.74 + 0.265*Rain_{DS}$	60	*$P<0.001$*
LWG_{Tot}	$33.14 + 0.1757*RainP – 0.00799*TSDM_{EOD}$	60	*$P<0.001$*
	All years		
LWG_{DS}	$-11.5 + 0.269*Rain_{DS} - 0.00708*TSDM_{SOD}$	51	*$P<0.001$*
	Years without Urea		
LWG_{DS}	$-52.8 + 0.3991* Rain_{DS} - 0.00908*TSDM_{EOD}$	78	*$P<0.001$*
	Years with Urea		
LWG_{DS}	$-90.3 + 0.715* Rain_{DS} – 0.02655* TSDM_{SOD}$	75	*$P<0.001$*
LWG_{DS}	$-84.6 + 0.727* Rain_{DS} – 0.0363* TSDM_{EOD}$	80	*$P<0.001$*
	Years with Urea but M8U data excluded		
LWG_{DS}	$-74.2 + 0.666* Rain_{DS} – 0.02088* TSDM_{SOD}$	78	*$P<0.001$*
LWG_{DS}	$-18.59 + 0.210* Rain_{DS}$	41	*$P<0.001$*

Effect of Pasture TSDM on LWG

Total LWG over all seasons was only weakly related (R^2 = 10.3%; *$P<0.001$*) to end-of-wet (EOW) total standing dry matter (TSDM) i.e. standing pasture at the end of May (Table 8.5). Results from other studies indicate that pasture mass is a poor predictor of both intake rate and diet quality, especially in heterogenous swards and extensive grazing situations e.g. (O'Reagain, Goetsch *et al.* 1996).

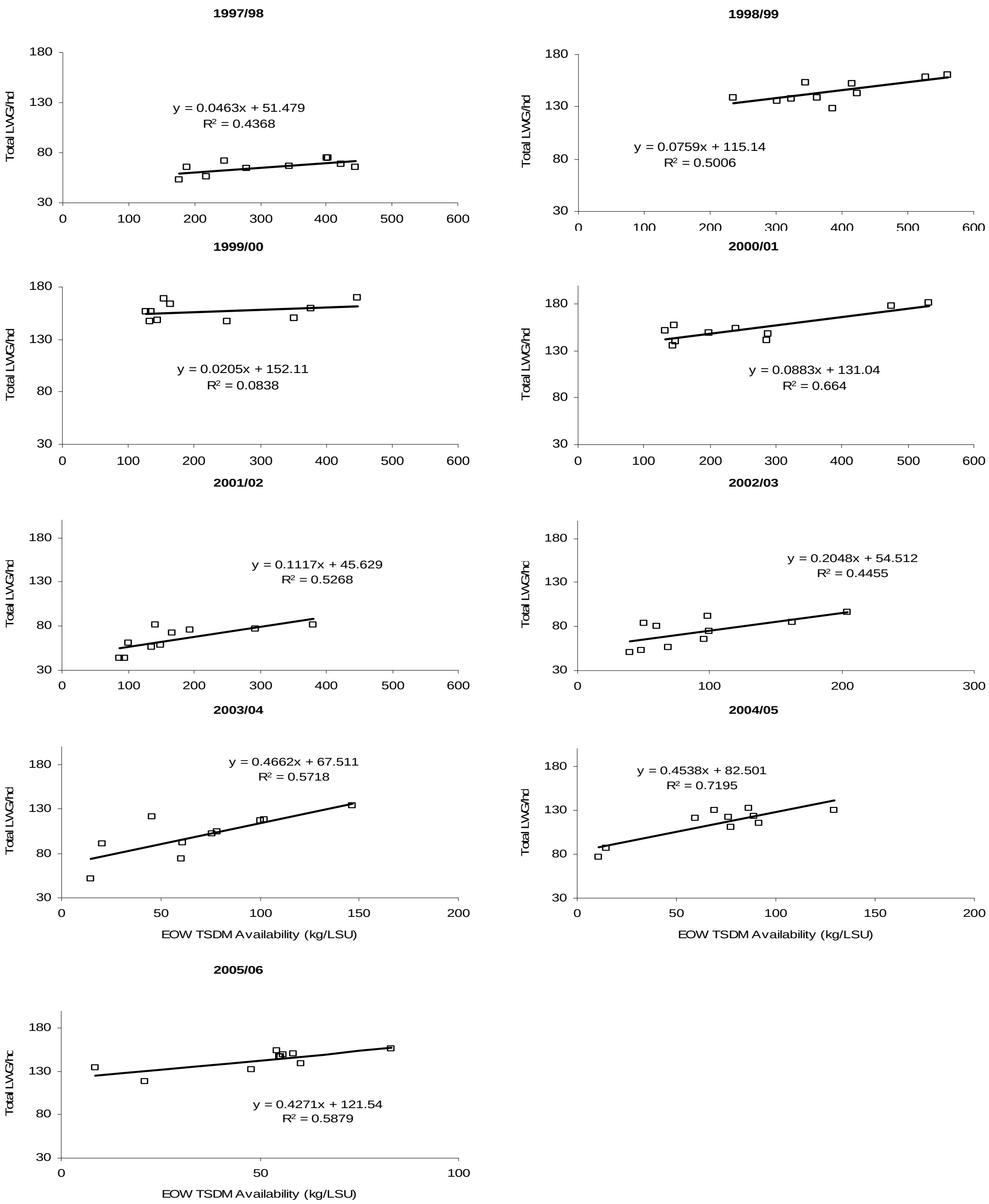


Figure 8.5: Relationship between total LWG and end of wet (EOW) TSDM 'availability' in kg/LSU/100 for individual years at Wambiana. Note different scales.

When TSDM was indexed as the *availability* of pasture per animal (kg/LSU), total LWG generally increased with increasing pasture availability per animal (Fig. 8.5) with this relationship being significant ($P<0.05$) in seven out of eight years (R^2 = 37 to 68%). Pasture availability is an index of the amount of pasture that each animal has available to consume and select from and is simply a function of TSDM by stocking rate. Pasture availability should have a direct, positive impact upon dietary quality and intake. In certain seasons LWG might however decline above a certain level of pasture availability due to a decrease in leaf: stem ratio and an associated decline in bite quality and intake rate.

Table 8.5: Definitions of some abbreviations used in Chapter 8

Definitions
SOD= start of dry (TSDM measurements from May) *EOD= end of dry (TSDM from mid-October of that season)* *EOW= TSDM from May measurements at the end of that season.* *TSDM availability per LSU= TSDM*SR (kg/LSU)* *TSDM allocation per LSU per day= TSDM*SR (kg/LSU)/ (length of dry/wet season)*
NB: EOW for season 1 = SOD for season 2 *3-P yield= EOW yield of 3-P species (kg/ha).* *3-P allocation: EOW yield of 3-P grasses/LSU/length of dry or wet season (kg/LSU/day)* *% Use of DS feed=* $TSDM_{EOD}$ *-* $TSDM_{SOD}/TSDM_{SOD}$

Dry season LWG

When analysed over all years, dry season LW change was not related to pasture TSDM at either the start (May) or end (October) of the dry season or with percentage use of DS forage. However, separate analysis of urea-supplemented and non-supplemented years indicated very different responses to dry season TSDM, with the nature of this response being strongly dependent upon dry season rainfall.

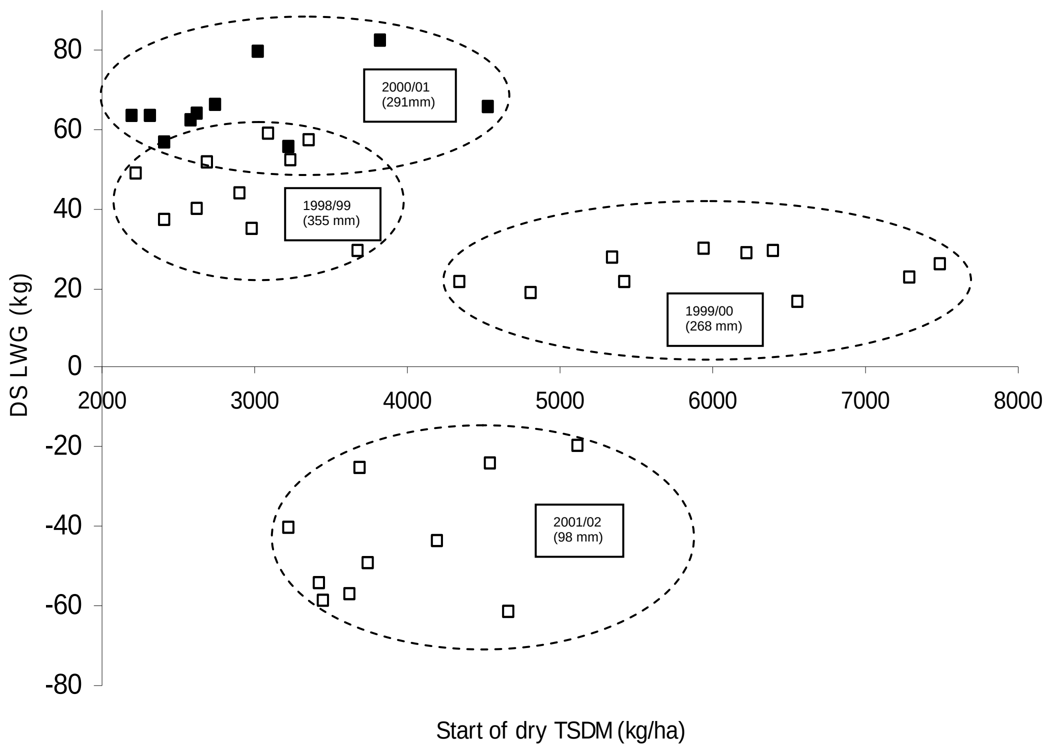


Figure 8.6: Relationship between dry season (DS) LWG and start-of-dry TSDM for the four years when animals were not supplemented with urea in the dry season. (Dry season rainfall in brackets).

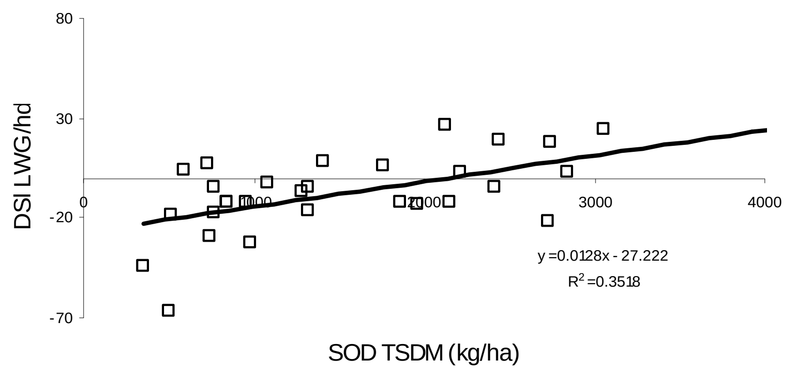
In years when animals were *not* supplemented but where significant (> 250 mm) DS rainfall occurred (1998/99, 1999/00 and 2000/01) dry season live weight gains of 16 to 82 kg/hd occurred (Fig. 8.6). Taken over all years, LWG_{DS} appeared to decline as start-of-dry pasture TSDM increased over a range from *c.* 1000 to 5000 kg/ha:

$$LWG_{DS}=75.57 - 0.00772*TSDM_{SOD} \quad (R^2= 42\ \%;\ P<0.001)$$

This presumably resulted from a decline in the availability and accessibility of high quality forage e.g. green leaf, as pasture mass increased. However, a large amount of unexplained variability occurred in LWG_{DS} both between and within seasons (Fig. 8.6). Equations incorporating variables such as SR or GI Days with TSDM did not improve this relationship although including DS rainfall did increase the R^2 – value by an extra 6%. This indicates the importance of other unquantified variables in determining dry season LWG for unsupplemented cattle in years with significant DS rainfall. For example, the exceptionally high LWGs recorded in 2000/01 (Fig. 8.6) possibly reflect both good dry season rainfall as well as the improved pasture quality resulting from the October 1999 fire.

In 2001/02, the only year with low DS rainfall when animals were *not* supplemented, animals lost LWG in all paddocks irrespective of TSDM, although there was some indication that weight loss accelerated as pasture mass declined (Fig. 8.6).

(a) DS LWG vs Start-Of-Dry TSDM (dry years + urea)



(b) DS LWG vs End-Of-Dry TSDM (dry years + urea)

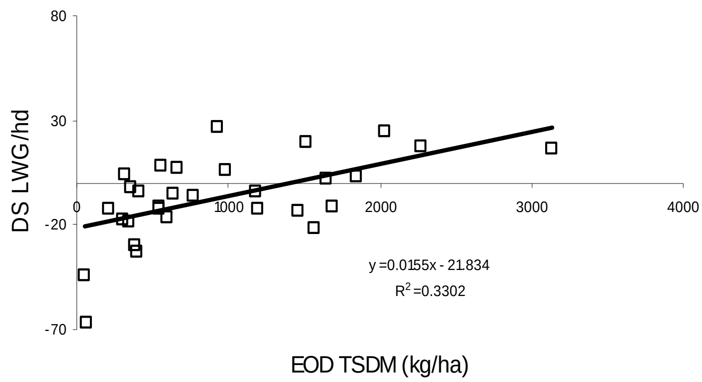


Figure 8.7: Relationship between dry season (DS) LWG and (a) Start of dry (SOD) TSDM and (b) End of dry TSDM, in 'dry' years, animals supplemented with urea. (See text for details)

In contrast, in relatively dry years *with* urea supplementation (2002-2005), dry season LWG showed a positive, curvilinear response (R^2 = 32 %; $P<0.001$) to TSDM at the start of the dry (SOD). This suggests that in years with little dry-season rainfall, supplemented animals require a minimum TSDM of *c.* 2000 kg/ha at the start of the dry in June to maintain or gain LW through the dry season (Fig. 8.7a). In such dry years, LWG in urea-supplemented animals was also positively correlated with end-of-dry (EOD) TSDM (R^2: 30.4; *P<0.001*) with a minimum pasture residue at the end of the dry season (October) of *c.* 1000 kg/ha required to prevent mass loss (Fig. 8.7b).

In practice, the minimum EOD pasture mass required at the end of the dry (EOD) to maintain LW is probably lower than indicated because DS LWG was calculated from 1 June to mid-December, whereas EOD pasture TSDM was measured in mid-October i.e. the *actual* TSDM in December would be markedly lower than the figure used here.

Importantly, the foregoing thresholds and relations did *not* hold in 2005/06, which was the only year when urea was provided and significant rainfall (> 160 mm) occurred through the dry season. In this year exceptional dry season LWGs were achieved despite possibly the lowest pasture yields in the history of the trial. Nevertheless, even in this year DS LWG showed a clear positive curvilinear relationship (R^2 = 73%) with start of dry TSDM (Not shown).

An important point from the above is that in drier years, supplemented animals were able to maintain LW at end-of-dry pasture yields of about 1000 kg/ha (Fig. 8.7b) i.e. provided animals have sufficient feed, dry season LW gains in steers are easily achievable under urea supplementation on these land types.

DS LWG vs. percentage use of DS pasture
Taken over all years, DS LWG was not related to the percentage use of DS feed, calculated as the disappearance of TSDM between the start and end of the dry i.e. ($TSDM_{EOD}$-$TSDM_{SOD}$/$TSDM_{SOD}$). This is not surprising given that significant dry season pasture growth occurred in some of the earlier, wetter years of the trial, resulting in a net gain in TSDM i.e. a negative percentage DS use, despite the effect of grazing.

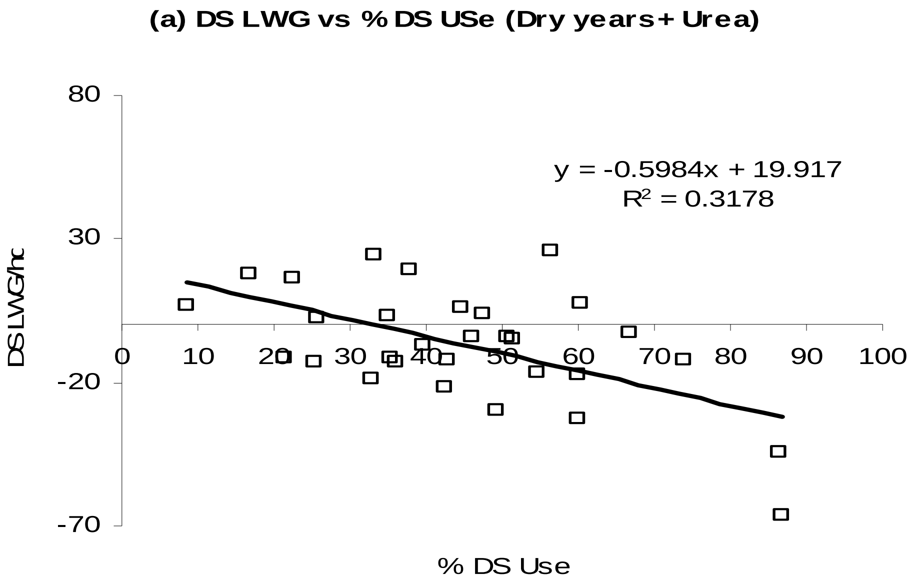


Figure 8.8a Relationship between dry season (DS) LWG and percentage use of DM in the DS. (See text for details)

However, in dry years with urea supplementation a negative relationship was evident (R^2= 29 %; *P<0.001*) with the x-intercept indicating DS mass loss above about 30 - 40% use of DS standing pasture (Fig. 8.8a). Note that percentage DS pasture use was calculated between May and

October while DS LW changes were calculated between June and December i.e. the level of DS use where LWG is maintained may be closer to 40 rather than 30%.

Mass losses above 60% utilisation were extreme despite urea supplementation and moreover, occurred despite feeding M8U late in the dry season i.e. in dry years without drought feeding LW losses will in fact be far greater than indicated above the 50 to 60% utilisation level, and could cause mortality.

As before, in the single year with appreciable DS rainfall and urea supplementation (2005/06), dry season LWG showed no relation with percentage DS use with very high LWGs apparently occurring at relatively high levels of DS forage use. This outcome partly reflects the difficulty of estimating actual DS forage use in years when DS pasture growth occurs but largely reflects the huge positive response of LWG to DS rainfall.

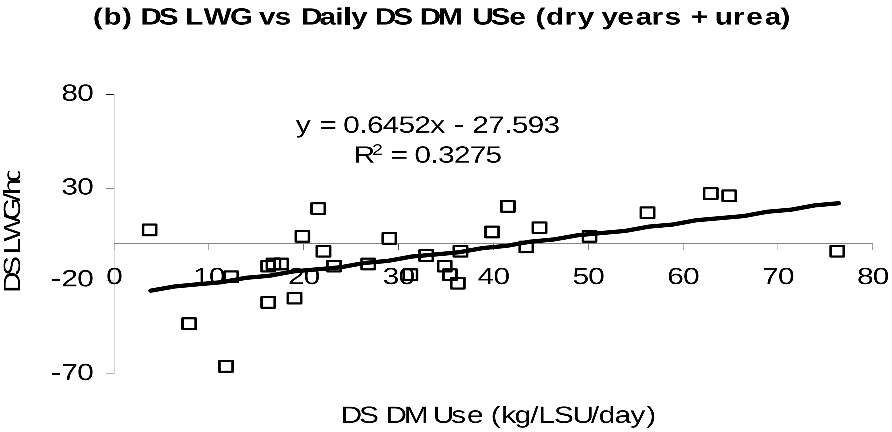


Figure 8.8b Relationship between dry season (DS) LWG and daily use of DM over the DS. (See text for details)

DS LWG vs. daily DM use

For animals in the wetter years when urea supplementation did not occur (1998-2002), there was no relation between dry season LWG and the DM 'used' per animal per day, expressed as kg.DM per large stock unit per day (kg.DM/LSU/day), [NB: This is calculated from the disappearance of DM over the dry season i.e. $TSDM_{EOD}$-$TSDM_{SOD}$ and does not assume that this feed was actually consumed]. As before, the lack of a relationship is largely attributable to the fact that DS growth occurred in some of the earlier years making it impossible to calculate the rate or extent of DM use.

For the drier years (2002-2005) when little dry season pasture growth occurred and animals were supplemented, DM 'use' over the DS ranged from between 10 to 80 kg.DM / LSU/day (Fig. 8.8b). Dry season LWG was thus positively related to daily DM 'use' i.e.

$$LWG_{DS} = 0.644 * Fuse\_DS - 27.61 \; (R^2: 30\ \%;\ P<0.001)$$

This indicates that dry season LW gain will occur where animals are individually able to 'use' or 'account for' more than about 40 – 50 kg.DM /LSU/day through the dry season. Assuming a daily intake of 10 kg per LSU, this suggests that at least 75% of standing pasture that 'disappears' over the dry season is lost through detachment, trampling, weathering etc and is not directly consumed by the cattle themselves. This is significant, and indicates that the wastage factors commonly used in DS fodder budgets should be considerably higher than previously assumed.

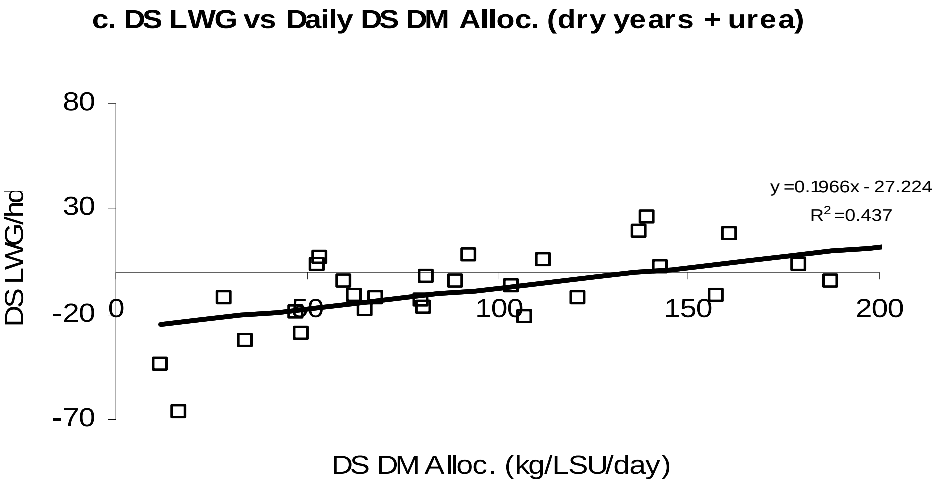


Figure 8.8c Relationship between dry season (DS) LWG and the daily 'allocation' (kg/ha/LSU) of DM over the DS. (See text for details)

In supplemented dry years, DS LWG was also positively related (Fig. 8.8c) to the 'allocation' of TSDM per LSU, simply calculated as the estimated availability of pasture per LSU per day through the dry season i.e.

$$LWG_{DS} = 0.195*SOD_{Alloc} - 27.19 \; (R^2 = 41\ \%;\ P<0.001)$$

Examination of Fig. 8.7c suggests that DS live weight gain will therefore occur where each LSU has a minimum 'allocation' of 140 – 150 kg/day available to select from through the dry season. In practice this simply means that the more forage an animal has to select from, the better its dry season performance is likely to be.

Pasture allocation is an index of both TSDM and stocking pressure and can accordingly be used to calculate DS stocking rates. For example, to ensure a positive LWG, a paddock with a TSDM of 2000 kg/ha would need to be stocked at 8ha/LSU to ensure a pasture availability of 140 kg.DM/LSU per day over the (180 day) dry season. As before this does not assume that each animal consumes 140 kg/day/LSU but indicates the amount of feed available that is required for animals to select a diet of sufficient quality to ensure a positive weight gain.

8.4.3 Effect of pasture composition on live weight gain

Effect of pasture composition on total LWG

Taken over all years, total LWG gain was positively related (*P<0.001*) to the total contribution to end-of-wet (EOW) yield (kg/ha) by both 3-P grasses (R^2 = 13 %) and 2-P grasses (R^2 = 13 %) i.e. LWG generally increased with the amount of 3-P and 2-P grasses available for grazing in the pasture. Total LWG was also related (*P<0.001*) to the contribution to EOW yield of forbs (R^2 = 14.7) and, more importantly, legumes (R^2 = 25 %). However, total LWG showed no relationship (R^2 = 1 %) with the amount of wiregrass present.

Total LWG was also positively related (*P<0.001*) to the *allocation* (kg/LSU/day) of 3-P grasses (R^2 = 8 %; *P<0.05*), forbs (R^2 = 13 %; *P<0.001*) and legumes (R^2 = 19 %; *P<0.001*) per animal over the wet season but showed no relation with the allocation of either wire - or 2-P grasses.

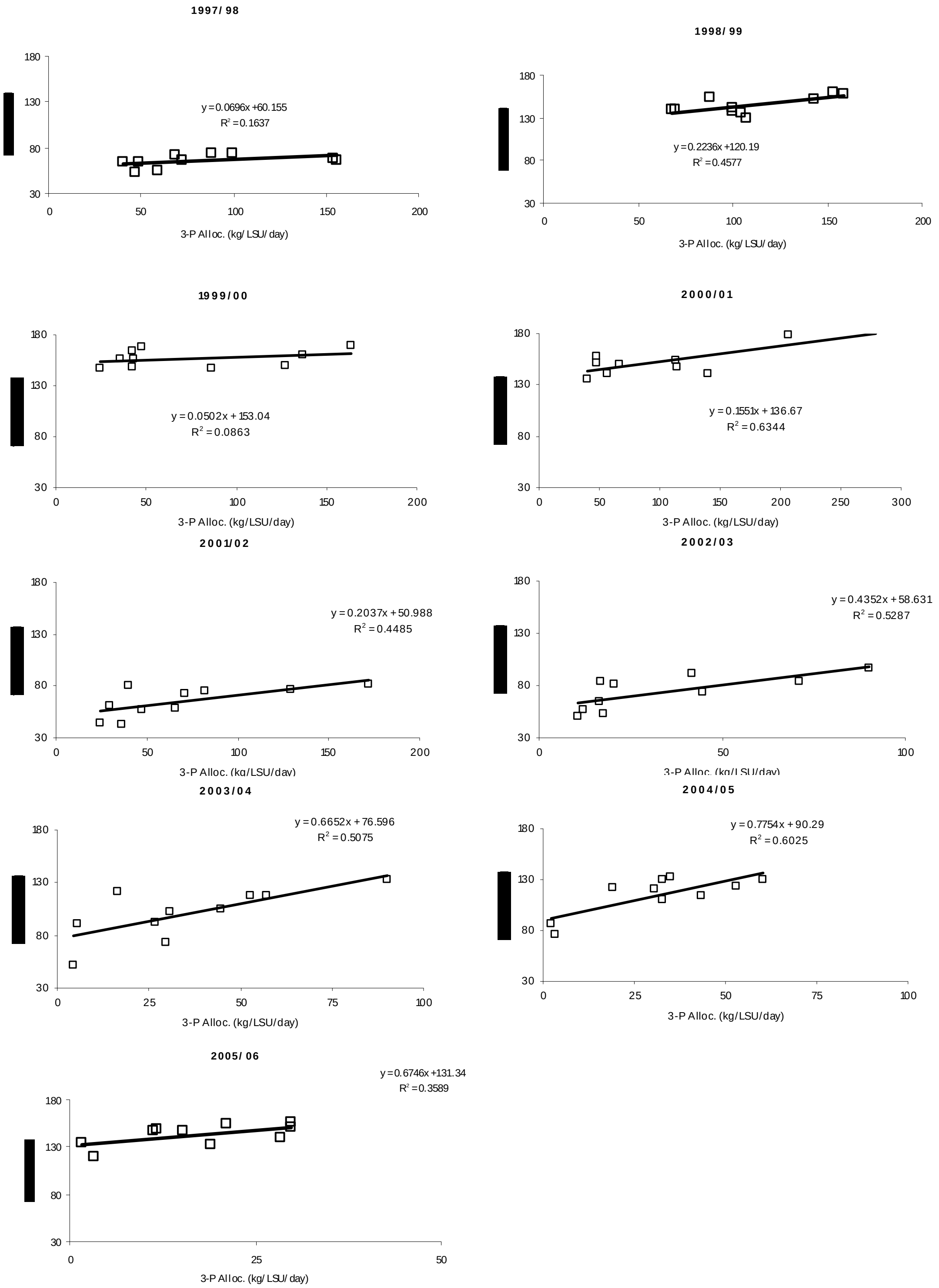


Figure 8.9 Relationship between total LWG per animal and 3-P allocation over the wet season (kg/ha/LSU) for individual years at Wambiana.

For individual years, total LWG showed a weak positive (R^2 = 29 to 61%) relationship with EOW 3-P allocation in 8 out of the 9 seasons studied (Fig. 8.9). In contrast, total LWG was generally negatively related or showed no relationship with the percentage contribution of wire grass to yield (Table 8.6).

Table 8. 6 R^2 values for the relationship between total individual LWG and the end of wet (EOW) 3-P contribution to yield, EOW 3-P percentage of yield, 3-P allocation and EOW wiregrass (WG) percentage yield. (See text for details).

Year	3-P Yield	3-P % Contribution	3-P Allocation	WG % Contribution
1997/98	3.77	- 0.12	15.1	- 25.6
1998/99	0.10	0.2	42.8	- 02.8
1999/00	20.0	17.6	36.9	- 11.7
2000/01	50.1	26.9	61.9	- 20.3
2001/02	26.7	13.7	44.3	- 11.6
2002/03	49.3	43.2	52.7	- 14.5
2003/04	47.2	38.8	51.8	- 64.6
2004/05	41.0	39.4	32.2	- 12.1
2005/06	15.4	3.0	29.8	0.0

These data provide support for the hypothesis that total LWG increases with the availability of 3-P grasses in the pasture. This is also shown by the significance of the multiple regression equation predicting LWG from the percentage contribution of 3-P grasses to EOW yield and rainfall:

$$LWG_{Tot} = -7.9+0.868*3P\_\%EOWYLD + 0.146*Rain \ (R^2=46\ \%;\ P<0.001)$$

LWG could also be predicted (R^2=47.7; *P<0.001)* from the percentage contribution of wire grasses to yield and paddock rainfall but with LWG decreasing with the percentage yield of wiregrass.

$$LWG_{Tot} = 48.0 - 1.09*WG\_\%EOWYLD + 0.150*Rain \ (R^2=47\ \%;\ P<0.001)$$

As noted before however, in both cases, most of the variability was accounted for by rainfall.

Effect of pasture composition on wet and dry season LWG
Wet season LWG showed little if any relationship with any indicator of the availability of any species group over either all years or for individual years and will not be discussed further.

Taken over all years, dry season LWG was not correlated with any of the variables of pasture composition, probably due to the overriding influence of rainfall and hence green leaf availability on animal performance.For individual years, dry season LWG was positively correlated with the percentage contribution of 3-P grasses to SOD yield in the 2002/03 (R^2= 43 %) and 2004/05 (R^2= 47 %) seasons, and with 3-P SOD allocation on 2005/06 (R^2=29 %) but not in other years. In contrast, dry season LWG showed a general negative relationship (R^2=20 to 64%) with the percentage contribution of wire grass to SOD yield, but this relationship was only significant in the years between 2002/03 and 2004/05.

In terms of the *availability* of these species per animal over the dry season, defined as the kg of grass available/LSU/hectare, there no relationship between DS LWG and 3-P availability when analysed over all years. Dry season LWG could be nevertheless be predicted from DS rainfall and 3-P SOD availability, although DS rainfall accounted for the majority of the variation in the data.:

$$LWG_{DS} = -10.51-0.0127*3P\_SODYLD+0.235*Rain_{DS} \quad (R^2=47\ \%;\ P<0.001)$$

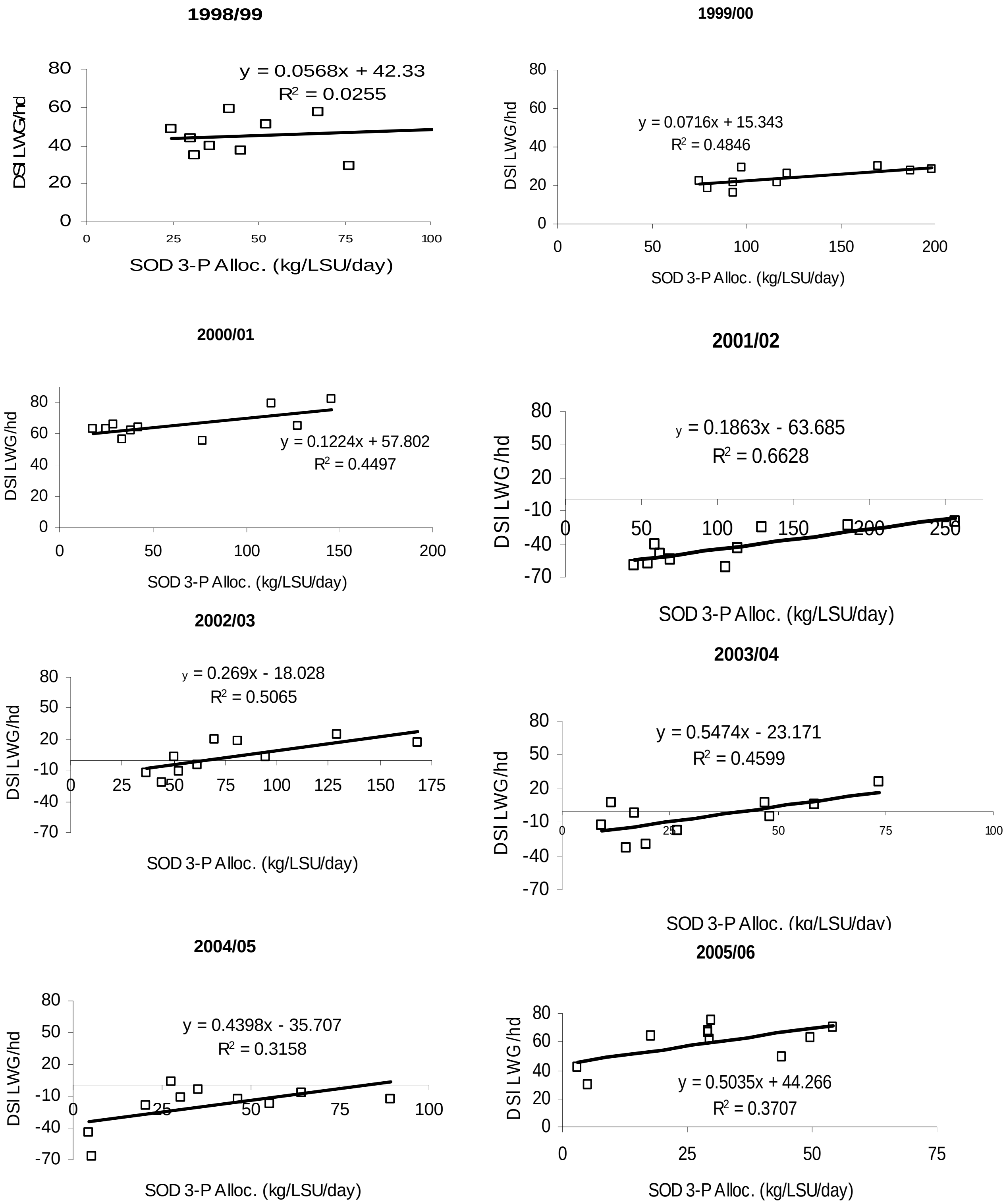


Figure 8.10 Relationship between dry season LWG per animal and the start-of-dry (SOD) 3-P forage allocation for individual years at Wambiana. Note different scales between graphs.

Dry season LWG was positively related to the allocation of 3-P grasses in most years (Fig. 8.10) with this variable explaining between 29 and 85% of the variability in DS LWG data. Although there was only a weak linear relation in 2004/05, a threshold effect is suggested with DS mass loss increasing sharply below an allocation of about 30 kg/DM/LSU per day (Fig. 8.10).

Comparing years, there was no consistent 3-P *allocation* level at which DS mass loss occurred but a clear effect of urea supplementation on the threshold 3-P allocation levels required for positive DS animal performance is suggested, at least in drier years. Thus in dry years with urea supplementation, maintenance or even mass gain occurred under 3P allocations as low as 50 kg/LSU/day e.g. 2002/03. Conversely, mass loss occurred at allocation levels far in excess of this in years e.g. 240 kg/LSU/day in 2001/02, when no supplementation was provided and no DS rainfall occurred i.e. a large amount of pasture bulk was present.

However, the effect of DS rainfall totally overrode these effects whether animals were supplemented or not : for example, in the relatively wet 2005/06 dry season, supplemented animals gained mass at DS 3-P allocation levels as low as 25/kg/LSU/day. Similarly, unsupplemented cattle performed well at 3-P allocation levels as low as 50 kg/LSU/day in 1998/99, again because of unseasonably good rains in the dry season.

8.5. Summary

1. Total production per unit area (LWG/ha) increased with rainfall and stocking rate with these variables accounting for 74% of the variability in the data. However, high stocking rates in later drier years were dependent upon M8U feeding to sustain animals through the dry season.

2. Individual animal production (LWG/hd) was positively related to total rainfall (R^2=39%) but was more strongly related to Growth Index (GI) days (R^2=52%), which indexes the length of the growing season. However, dry season rainfall (R^2=60%) was the single most important determinant of total LWG/hd.

3. LWG/hd decreased with increasing pasture utilisation rate both over all years (R^2=25%) and in individual seasons. Over all years LWG/hd was not related to stocking rate due to the overwhelming effect of other factors such as rainfall and GI days on production. However, for individual seasons, LWG/hd decreased with stocking rate in six of the nine years of the trial. Significant carryover effects from the previous years stocking rate were also apparent in the VAR and SOI treatments.

4. Taken over all years, dry season LWG (LWG_{DS}) was positively related to DS rainfall and DS Growth Index days but declined with increasing utilisation rate. LWG_{DS} also declined with stocking rate in most years. LWG_{DS} was negatively related to the previous years stocking rate, presumably through the negative effects of heavy stocking on carry-over feed into the dry season.

5. The effect of DS rainfall on LWG_{DS} was strongly mediated by urea supplementation: Urea supplementation firstly, reduced the predicted mass loss with no DS rainfall from – 71 kg/hd to – 29 kg/hd, secondly, decreased the predicted minimum DS rainfall required for maintenance of body weight from 190 mm to 60 mm and thirdly, increased the response to dry season rainfall from 3.7 kg to 4.4 kg of LWG/hd for every 10 mm of rainfall.

6. Over all years total LWG/hd was only weakly (R^2=10%) related to pasture TSDM (kg/ha). However, when indexed as the availability of pasture per LSU (kg /LSU), total LWG increased with increasing pasture availability in seven out of the nine years of the trial.

7. The response of LWG_{DS} to pasture TSDM at either the start of the dry (SOD) or the end of the dry (EOD) was complex and dependent upon DS rainfall and the provision or otherwise of urea supplementation.

8. In years with low DS rainfall where animals were supplemented with urea, LWG_{DS} was positively related to both start- and end-of-dry pasture TSDM**.** Threshold levels identified for positive LWG over the DS were approximately 2000 kg/ha and 1000 kg/ha for SOD and EOD pasture TSDM respectively. However, in 2005/06 when significant DS rainfall fell these thresholds did not hold and LWG occurred at TSDMs well below 1000 kg/ha. Nevertheless, even in this year LWG_{DS} was still positively related to SOD pasture TSDM.

9. The response of LWG_{DS} to pasture TSDM in years without urea supplementation was also dependent upon DS rainfall: in years with good DS rainfall, positive LWG_{DS} occurred but overall LWG decreased linearly with SOD pasture TSDM, presumably because of declining forage quality. In contrast, in the single season when animals were not supplemented and DS rainfall was low, all animals lost body mass with pasture TSDM having only an apparently minor effect on LW change.

10. Data from the three years with low DS rainfall and urea supplementation indicate that for positive LWG_{DS} utilisation rates should be limited to 30-40% of start-of-dry DS feed while forage disappearance (intake and wastage) should be about 40 – 50 kg/ha/LSU/day over this period. Animals also need a forage ‘allocation’ of about 140-150 kg/ha/LSU/day to select from to maintain a positive $LWG_{DS.}$ As before, these relations do not hold in years with good dry season rainfall.

11. Pasture species composition had a significant impact upon total LWG, although this effect was less than that of rainfall. Overall, total LWG/hd was positively related to the yield and availability (kg/LSU) of 3-P grasses, forbs and legumes in the pasture, but was not related to the yield or availability of wiregrass or annual species. For individual years, LWG/hd was generally positively related to the availability of 3-P grasses but negatively related to the availability of wiregrass in the pasture.

12. Dry season LWG was negatively related to the percentage contribution of wiregrass to SOD yield in later years but was positively related to the percentage contribution of 3-P grasses to yield, at least in some years. In dry years with urea supplementation, LWG_{DS} increased with increasing availability of 3-P grasses (kg/LSU) but no consistent threshold level of a minimum availability for LWG was evident.

9. Changes in species frequency

9.1. Introduction

How a grazing strategy copes with rainfall variability in terms of its effects on pasture species composition is of major importance. Species composition directly determines pasture productivity in terms of its rainfall use efficiency, the amount of feed produced and the quality of forage available to the grazing animal. Species composition is also a primary determinant of land condition, with obvious effects on soil health, infiltration rate and runoff. Faunal biodiversity will also be dependent upon species composition in terms of both habitat and food availability.

In this section data is presented on how the different grazing strategies applied at the trial affected species composition, and the interactions of these strategies with rainfall and soil type. Data on the effects of these strategies on pasture production and cover are presented in later chapters.

9.2. Objectives

The objectives of this section were to investigate:

1. Associations between the various soil types and different pasture species.
2. The effect of grazing strategy and rainfall on species frequency on three major soil types.

9.3. Procedure

9.3.1 Monitoring sites

Seventy one permanent monitoring sites, stratified by soil type, were established across the trial in 1998 (Appendix 2). Reference sites were also established in the paddock 8 exclosure as well in two adjacent commercial paddocks on 'Wambiana' ('Flohrs' and 'Brigalow' paddock). Two monitoring sites were randomly located in each soil type in each paddock. For the *E. brownii* (Box) communities, sites were further stratified with one site being close to (< 500 m), and the other site being far from, water. Each monitoring site consisted of five parallel 100 m transects marked with steel pickets at either end. Transects are 25 m apart and generally run S to N.

Sites were chosen as being typical of a particular soil type and were as uniform as possible. However, some areas were very heterogeneous so a few monitoring transects crossed transition zones extending into adjacent soil types. Monitoring sites were also established on the small soil anomalies (1-5 ha) that occurred in certain paddocks – these included a shallow grey sodosol (Sodic box) in paddock 1, a heavy grey earth (Coolibah flat) in paddock 10 and seasonally inundated areas (wet box) of heavy clay/grey earth in paddocks 3 to 6. There were 6 to 9 monitoring sites per paddock and a total of 71 across the entire trial.

9.3.2 Measurements

Sites are monitored annually for species frequency and ground cover in the mid-late wet season (March – May) using BOTANAL (Tothill *et al.* 1992). Sites were sampled by systematically placing a 0.25 m^2 quadrat at *c*. 5 m intervals along each transect i.e., 20 quadrats per transect, 100 quadrats per monitoring site. All grass, forb, sedge and juvenile woody species present in a quadrat were identified to the species level and recorded as being either present or absent.
Other variables recorded (but not presented in this report) include:

- *Carissa ovata*– present (1) or absent (0) above or in a quadrat.

- *Projected ground cover* -scored for each quadrat according to a 6-class scale i.e. 0- 5%; 5-15%; 15-30%; 30-50%; 50-90% and >90% cover. From 2002 onwards the 50-90% class was subdivided into 50 – 75% and 75-90% making this a 7-class scale.
- *Area of quadrat grazed*- from 2002 onwards, quadrats were also scored on a 0-4 scale according to the area of quadrat grazed.
- *Pig damage* – after extensive feral pig damage in 2000, quadrats were scored for either recent, old or no pig damage.

9.3.3 Statistical analysis

Data analysis largely focused on grasses as most forb and legume species were relatively transient and/or formed a relatively minor component of the pasture.

Repeated measures analysis (REML) on GENSTAT was conducted on 15 of the more important grass species to determine the effects of grazing strategy and, if applicable, soil type, on the change in species frequency over time. To account for baseline differences between sites, the 1998 species frequencies were used as a co-variate. The analysis used 'paddocks' as replicates, 'grazing strategy' as treatment and included the factors 'year', 'soil type' and 'year by soil type by treatment' interactions. Data was generally analysed at the species level. However for simplicity an '*Aristida benthamii complex'* was formed that included *A. benthamii, A. mucronata, A. queenslandicum* and *A. jerichoensis.* REML analysis using the 1998 data as a covariate was also conducted on the 2006 species frequency data to test for individual between treatment differences.

Multivariate ordination analysis was conducted to firstly, determine soil-type species associations and secondly, determine the relative effects of rainfall and grazing strategy on trends in species composition. For ease of interpretation, subsets of individual species were selected from the entire species list based on species abundance, expected value as an indicator species, life history and potential importance for grazing.

Data was generally analysed at the species level. However in some cases, species were grouped at the species group, genus and/or functional group level due to either their relatively rarity, perceived lack of importance or, in the case of certain *Aristida* spp., the difficulty in correctly distinguishing certain species in the field. Examples of some of these groups include '*Introduced legumes'*, '*Other annual grasses'*, '*Clay soil Aristidas*' and '*Fire grasses* ' (All *Schizachyrium* and *Rottboellia spp)*.'

PATN, a form of non-metric multi-dimensional scaling (Belbin 2004, www.patn.com.au), was used to identify major species-soil associations and interpret changes in species composition due to rainfall and grazing. The data were analysed in the following manner: (1) the data set was first reduced by deleting all species with a maximum frequency across all sites <10% for simplicity and ease of interpretation and because rare species often distort species ordinations. (2) Data was then log transformed ($\log_{10}$ + 1) as recommended in the PATN program to compensate for the zero or low frequencies recorded for certain species at different sites. (3) PATN was then run a number of times and the data set progressively reduced by discarding species with a low Kruskal-Wallis value until the stress value for the ordination failed to improve further.

To investigate species – soil associations only the 1999 species frequency data was used on the assumption that associations would be relatively permanent and change little between years. Analysis was first run for all 69 monitoring sites on the trial using the 1999 data set that included 42 species.

To identify the extent and direction of any changes in pasture composition, site by year species data for each soil-vegetation association were analysed across the eight years of the trial from 1998-2005. For simplicity, analyses were confined to data from four 'sentinel' years representing important points through the experiment i.e. 1998 (baseline), 2000 (very wet year), 2003 (drought year) and 2005 (end year). To minimize noise, analyses concentrated on relatively small groups of core perennial and some annual species.

9.4. Results

9.4.1 Species – soil type associations

PATN was initially run with the 1999 data using only species with a maximum frequency >10% which gave a stress value (SV) of 0.135. To improve the SV, species in the analysis with a low (<20) Kruskal-Wallis (KW) value i.e. a low discriminating power between groups, were discarded. Data from seven outlier sites with unusual soil variations e.g. Coolibah flat and sodic box, were also deleted giving an improved SV of 0.105.

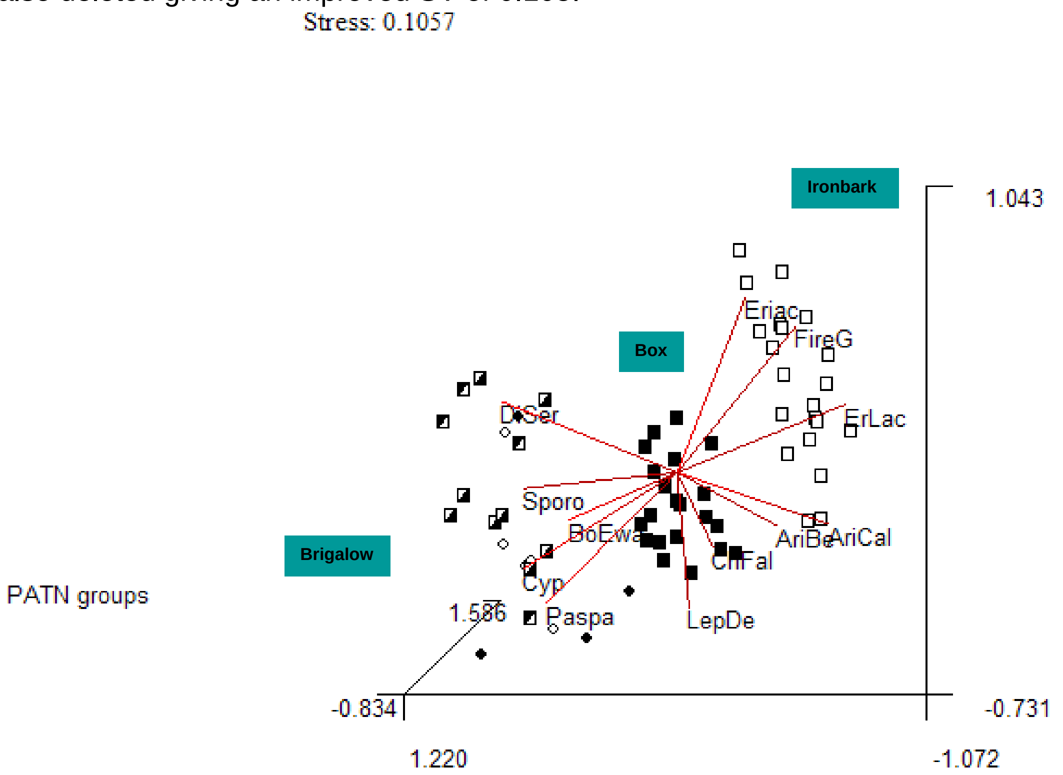


Figure 9.1: PATN biplot of sites and species for all monitoring sites across all soil types for 1999. (AriBen=*A. benthamii*, AriCal=*A. calycina*, BoEwa=*B. ewartiana*, ChFal=*C. fallax,* Cyp=*Cyperaceae* spp., DiSer=*D. sericeum*, ErLac=*Eragrostis lacunara,* Eriac=*E. mucronata*, FireG=*Firegrasses,* LepDe=*L. decipiens*, Paspa=*Paspalidium. caespitosum*, Sporo=*Sporobolus* spp.)

The site – species biplot (Fig. 9.1) and the associated two-way table (not shown) show clustering of sites into three distinct groups according to soil type - vegetation association (Table 9.1). Clustered at one extreme are the Ironbark sites on yellow/red kandosols characterized by species like *Eriachne mucronata, Eragrostis lacunaria, A. benthamii* and *Firegrasses.* The

‘Brigalow’ sites on heavy clays occur at the other extreme and are dominated by *Dicanthium sericeum, Cyperaceae spp. Paspalidium, Sporobolus and Bothriochloa ewartiana.* Box sites on texture contrast soils are clustered in the middle reflecting their intermediate status in terms of soil fertility, texture and species associations. Box sites are largely characterized by *Chrysopogon fallax* but also share certain species with both the Ironbark e.g. *A. calycina* and heavy clay sites e.g*. B. ewartiana,* respectively. Virtually no species overlaps occurred between clay and Ironbark soils (Table 9.1).

Table 9.1: General species associations across the different soil types at the Wambiana trial derived from PATN analysis of 1999 species frequency data.

Group and species	Description
1. *Stylosanthes spp*, *Tephrosia filipes,* annual *Digitaria spp,* annual grasses.	Occur almost exclusively on **Ironbark,** although annual *Digitaria spp.* may grow on Box.
2. *Digitaria brownii, Panicum effusum, Eragrostis lacunaria, Zornia spp., Enneapogon virens,* Native legumes*, H. contortus, Vigna lanceolata*	Largely on **Ironbark, but also on Box** to a certain extent. General species groups i.e. native legumes, more widespread and can also occur on clays.
3. *Eriachne mucronata*	Restricted to **Ironbark**
4. *Aristida benthamii, A. calycina, C. fallax, Fimbristylis, ‘Firegrass’, Forbs, B. ewartiana*	Mixed group occurring on **Box and Ironbark soils:** *B. ewartiana* mainly on Box but also on clays – rare on Ironbark.
5. *Chloris divaricata, Oxychloris scariosa, Enteropogon acicularis, Paspalidium caespitosum, Eriochloa crebra, Eulalia aurea*.	Occur almost exclusively on **clays** but also on **clay – box transition** zones. *Eulalia* confined to very heavy clays.
6. *Dicanthium sericeum, Iseilema. vaginiflorum, Sporobolus spp., Leptochloa decipiens*	Almost exclusively on **clay soils**, although some *Sporobolus* and *Cyperaceae* species may occur on box.
7. *Elytrophorus spicatus, Sesbania cannabina*	Confined to **seasonally wet clay sites**
8. *D. fecundum*	Largely confined to **Box** soils**,** not common on clays.

9.4.2 Changes in pasture composition with time

Ironbark sites

Initial analysis of Ironbark data revealed two distinct clusters of sites. These were firstly areas dominated by *Eriachne mucronata* on the red/yellow kandosols that occur on slightly elevated 'ridges', have relatively low cover and are in relatively poor condition, here termed '*Hard Ironbark' sites*. Secondly, areas on yellow/brown kandosols, that are slightly more fertile and have marginally higher organic matter content than the harder ridges, termed '*Soft Ironbark'* sites. These areas have a higher cover and are in marginally better condition than the harder ridges. The Soft Ironbark areas are dominated by a mixture of *Aristida* species along with *C. fallax* and *H. contortus,* various 2-P species like *Enneapogon,* and also contain native and introduced legumes. *E. mucronata* may be present but is not dominant. Small patches of relatively good condition pasture with a high density of *C. fallax* and *H. contortus* may also occur, particularly under trees.

'Hard Ironbark' sites

PATN analysis of hard Ironbark sites between 1998 and 2005 revealed marked changes in species composition with clear grouping of sites by year (Fig. 9.2). However, no treatment effects were evident and these groupings largely reflected rainfall-driven shifts in pasture composition, particularly in the frequencies of the weaker perennial grasses like *E. lacunaria* and *A. benthamii*. This is evidenced by the relatively high KW values (range: 20-26) of the latter species. In contrast, *Eriachne* was very stable across years and made little, if any, contribution to group separations *(KW=7).* The four major year groupings were:

- **1998**: *E mucronata* dominant but also moderate to high levels of annuals as well as weaker perennials like *E. lacunaria, Enneapogon, P. effusum, A. benthamii* and *A. calycina.* Overall*,* low levels of *Cassia absus, Alloteropsis cimicina, H. contortus* and forbs.
- **2000:** As for 1998, but with big increases in forbs, fire grasses and *Zornia,* moderate increase in *H. contortus* and *C. absus.* However*, E. lacunaria* and 'other' annual grasses starting to decline.
- **2003:** *Eriachne* stays largely constant and forbs remain at high levels. Massive decline in weaker perennials *E. lacunaria, P. effusum, Enneapogon*, *A. benthamii* and *A. calycina* etc due to drought. An increase in annual *Aristida* species like *A. holathera* and *A. hygrometrica. C. absus* stays *constant,* but *A. cimicina,* and annual grasses also increase.
- **2005:** Composition similar to 2003 but forbs, *A. cimicina* and *C. absus* decline and annual *Aristida spp* increase further*.*

The analysis suggests that the 'hard' Ironbark sites are an apparently stable matrix of long lived *E. mucronata* tussocks adapted to the low fertility, aridified environment on these ridges. Within this matrix, populations of annual grasses, legumes, forbs and weaker perennials fluctuate with the amount and distribution of rainfall. The general stability of *E. mucronata* suggests that any grazing induced changes in composition may only occur in the longer term.

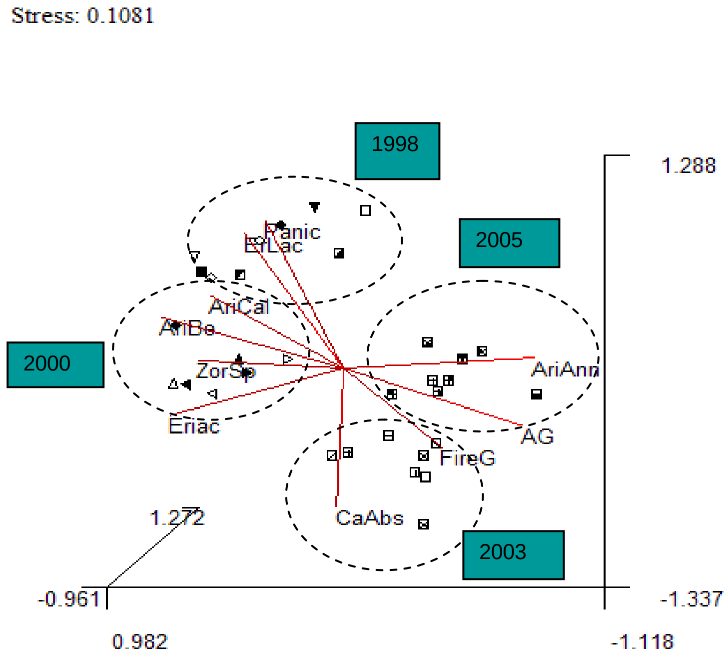


Figure 9.2: PATN biplot of sites and species for the 'hard' (*Eriachne* dominated) Ironbark soil-vegetation association for 1998, 2000, 2003 and 2005. (AG=Annual grasses; AriAnn= *Aristida* annuals, AriBen=*A. benthamii*, AriCal=*A. calycina*, CaAbs=*C. absus*, ErLac=*Eragrostis lacunara,* Eriac=*E. mucronata*, FireG=*Firegrasses,* Panic= *P. effusum*, Zor=*Zornia* spp.)

'Soft Ironbark' sites

Strong seasonal effects were also evident in the soft Ironbark sites with large shifts in the frequencies of weaker perennials and 2-P species occurring between years (Fig. 9.3). Complete turnover of *H. contortus* tussocks also occurred due to drought. Again, little or no treatment effects were apparent with any grazing effects appearing to be swamped by the influence of rainfall. Using 15 core species, PATN site by year groupings were as follows (SV=0.135).

- **1998:** Moderate levels of *C. fallax.* Moderate to high levels of weaker perennial species like *E. lacunaria, Enneapogon, P. effusum, Aristida benthamii, A. calycina* and low levels of *H. contortus* and *fire grasses. Cassia absus, A. cimicina, Vigna* and *Malvastrum spp.* largely absent.
- **2000:** Little change in species composition relative to 1998 but emergence and slight increases in *C. absus, Zornia, Vigna etc.* Big increases in *Firegrass,* some increase in *H. contortus,* but decline in species like *Enneapogon* and *E. lacunaria*.
- **2003/05:** Disappearance of the weaker perennials *E. lacunaria, Enneapogon, P. effusum, A. benthamii*, and the legume *Zornia.* Major decline in *A. calycina,* and some decline in *C. fallax.* Increases in the frequency of *A. cimicina, C. absus, Vigna,* annual *Aristida spp* and especially *Firegrass.* *H. contortus* appears unchanged but complete turnover of tussocks occurred (*pers. obs*.). Some increase in *Malvastrum spp.*

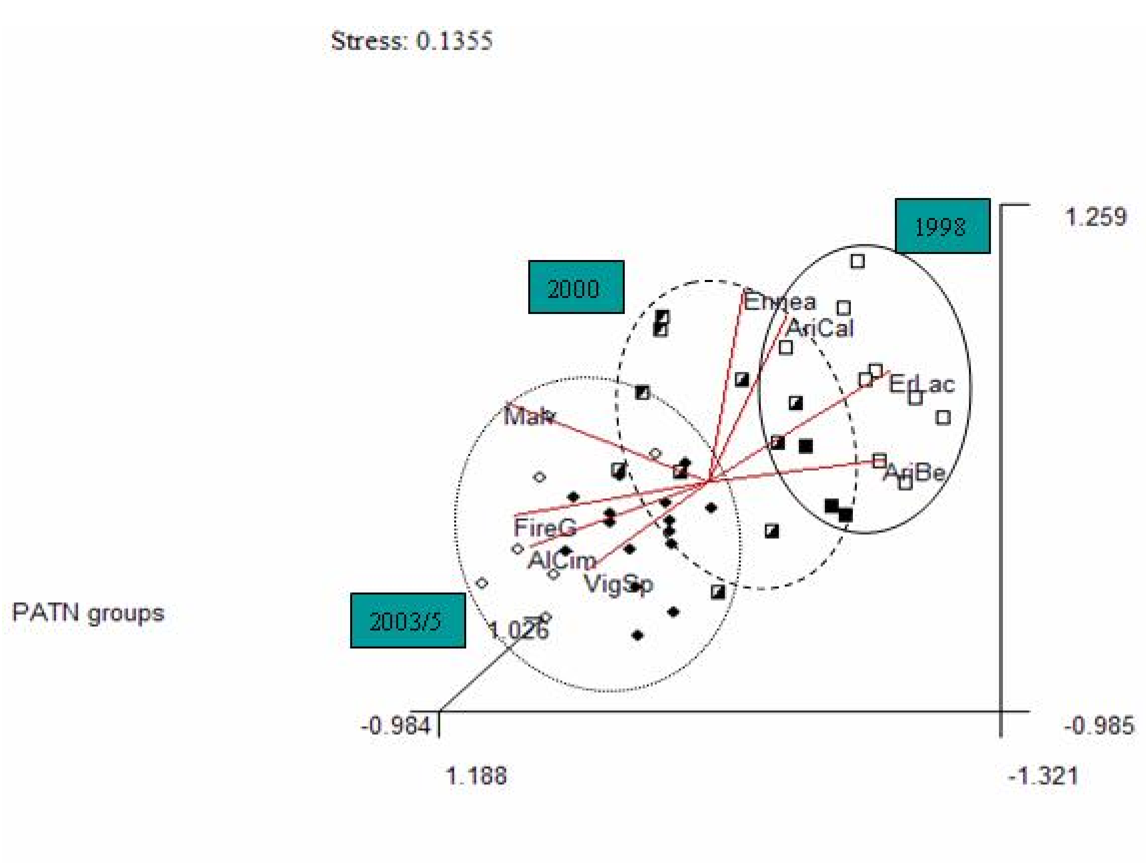


Figure 9.3: PATN biplot of sites and species for 'soft' Ironbark soil-vegetation association for 1998, 2000, 2003 and 2005. (AlCim=*A. cimicina*, AriBen=*A. benthamii*, AriCal=*A. calycina*, ErLac=*Eragrostis lacunara*, Ennea=Enneapogon spp, FireG=*Firegrasses*, Malv=*Malvastrum* spp. VigSp=*Vigna* spp.)

This analysis suggests…….

Box sites

PATN analysis of box sites was conducted with 8 of the most important perennial species and again highlighted strong seasonal effects. However, after 2000, treatment effects clearly emerged with five of the eight LSR site by year combinations being grouped separately in 2003/05 due to higher levels of *B. ewartiana* and, to a certain extent, lower levels of *fire grasses* and *A. cimicina* (Fig. 9.4). Overall five groups of site by year combinations were identified (SV= 0.104):

- **1998 - all sites:** Moderate to high levels of *A. calycina, E. lacunaria, C. fallax*, *A. benthamii,* low to moderate levels of B*. ewartiana*, very low levels of Forbs, while *A. cimicina* and Firegrasses almost absent.
- **2000-all sites:** Major increase in forbs to high levels, *C. fallax* increased slightly, increased to moderate levels of *A. cimicina* and fire grasses. *A. benthamii* at medium-high levels, *B. ewartiana* stays at moderate levels. Lower levels of *A. calycina* and large drop in *E. lacunaria.*
- ***2003 (plus some 2005 sites):*** High levels of fire grasses, *A. cimicina* and forbs. *A. benthamii* low, but *A. calycina* and *E. lacunaria* absent and *C. fallax* declined to moderate levels. *B. ewartiana* still at moderate levels.
- ***2005 sites plus exclosure***: Low to moderate levels of *B. ewartiana, C. fallax* and *forbs* but *A. calycina* almost absent. Moderate to high levels of Firegrass and *A. cimicina*.
- **2005/03 LSR sites.** High levels of *B. ewartiana*, low to moderate levels of *C. fallax*, forbs and Firegrasses but *A. cimicina* almost absent*.*

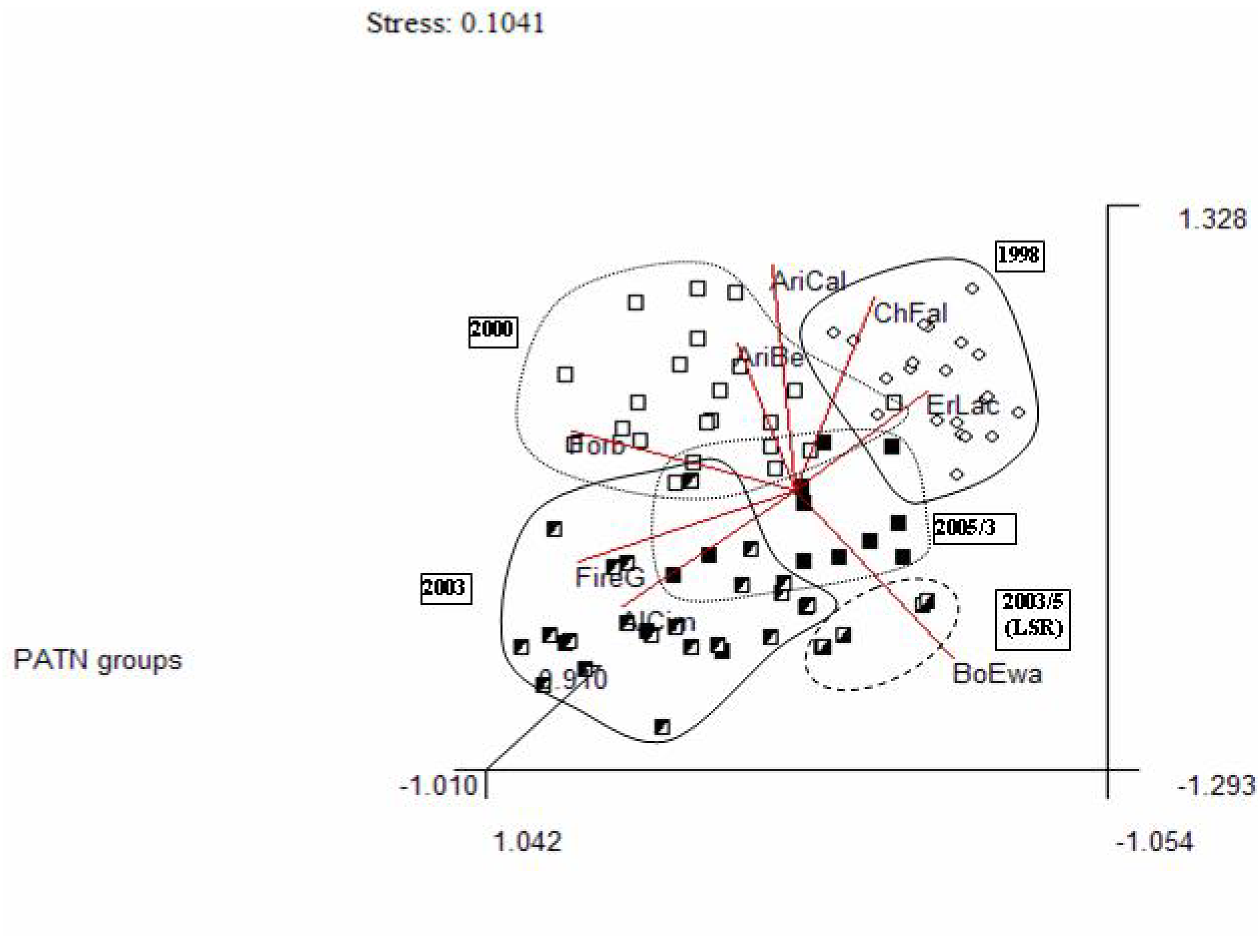


Figure 9.4: PATN biplot of sites and species for box monitoring sites 1998, 2000, 2003 and 2005. (AlCim=*A. cimicina*, AriBen=*A. benthamii*, AriCal=*A. calycina*, BoEwa=*B. ewartiana*, ChFal=*C. fallax*, ErLac=*Eragrostis lacunara*, FireG=Firegrasses, LSR=Light stocking rate)

This analysis suggests….

Heavy Clay sites

The clay soils at Wambiana are diverse and cover a range of extremes from well developed gilgais to level cracking clays. Wide variation in species composition was accordingly noted both between and within sites generically classified as 'clays'. Even within a site, significant variation can also occur within individual transects due to spatial heterogeneity in soils and drainage etc. Initial PATN classification of the data from all clay sites accordingly revealed 5 distinct sub-groups i.e.:

1. **Melon hole Brigalow:** sites with strong Gilgai development and mature Brigalow trees on mounds. Depressions are characterized by aquatic plants e.g. *Nymphoides indica* in water holes and wetter grasses like *Leptochloa decipiens* on the margins. Mounds carry assorted species like *P. caespitosum, Enteropogon acicularis*, *Sporobolus spp., B. ewartiana, Brachyachne decipiens,* legumes like *Rhynchosia minima* as well as various forb species.
2. **Cracking clays**: sometimes self mulching, usually dominated by *Dicanthium sericeum*, *Iseilema vaginiflorum*, *Sporobolus spp.* and sometimes *B. ewartiana*, forbs and native legumes like *Sesbania cannabina*. May contain scattered *E. brownii* and/or *A. harpophylla* trees etc
3. **Open clay lenses**: often on grey earths or cracking clays, frequently waterlogged in very wet seasons. May be dominated by thick stands of *Eulalia aurea* and small to moderate amounts of *B. ewartiana* and *D. sericeum* on drier phases. In wet years various *Cyperaceae*

spp and grasses like *Eriochloa crebra* are common. These lenses are sometimes treeless but can contain very open *E. brownii* or *E. Coolibah.*

4. **Scrubby sodic/clay sites:** these are slightly elevated areas and may have a pinkish surface layer. Usually characterized by *Fimbristylis, Chloris spp, E. acicularis, P. caespitosum* and *B. ewartiana.* The tree-shrub layer is diverse and can include *Carissa ovata, Eremophila mitchelli, Flindersia dissosperma and Lysiphyllum caronii* as well as taller trees like *A. harpophylla and E. cambageana.*
5. **Wet box sites:** grey clays, often with standing water in the wet season, with grasses like *Eriachne glauca, L. decipiens, Elytrophorus spicatus,* some *B. ewartiana* or *D. fecundum* and various *Cyperaceae spp*. The *E. brownii* tree layer is usually very open.

To avoid the effects of between-site variation on ordinations, frequency data from each clay soil group was analysed separately. These analyses all highlighted strong seasonal responses with the period from 1999 to 2005 being characterized by a species shift associated with the change from wet to relatively dry years. However, no treatment effects emerged and the biplots for individual groups are accordingly not presented. Generalised seasonal trends across all groups are summarized as follows:

Between 1999 and 2005 there was a marked decline, and in some cases, complete disappearance, of shorter lived, less drought tolerant, species at all sites. These included *L. decipiens, Cyperaceae spp.*, *Eragrostis, E. crebra, E. acicularis, P. caespitosum* and *Sporobolus* spp. as well as the aquatic species commonly found in melonholes. Over the same period the annual grasses *Brachyachne convergens* and *D. radulans* emerged and increased strongly in later, drier years*.* Of the perennials, *B. ewartiana* declined moderately over this time due to drought, but no treatment differences were evident. *Dicanthium sericeum* and *E. aurea* remained fairly stable over the whole period and showed no consistent trend in either direction.

This analysis suggests:

9.4.3 Effect of year and treatment on species frequencies

Overall effects of year and treatment on species frequency

Repeated measures analysis of the effects of year, treatment and soil type on species frequency, with 1998 data as a covariate are presented in Table 9.2. 'Year' had a highly significant effect (*P<0.001)* on all species frequencies reflecting the marked inter-annual differences that resulted from rainfall variability. The 'year' effect varied with soil as would be expected given the obvious landtype differences. 'Treatment' significantly affected (*P<0.05)* the frequencies of most 3-P species, the 2-P species *C. fallax,* the unpalatable wiregrasses *A. calycina, A. benthamii* and *E. mucronata,* and the annual grass *S. fragile.* For *C. fallax, A. calycina, B. ewartiana* and *S. fragile* treatment effects also varied with soil.

The '*Treatment*Year'* interaction was also significant *(P<0.05)* for some species indicating a dependence of treatment effects on year. For *S. fragile* treatment effects were significant *(<0.049***)** only in some years on some soils.' Treatment' had no overall affect on *D. brownii, P. effusum, D. fecundum, E. acicularis* or *P. caespitosum* frequencies*,* which seemed to be largely driven by the effects of 'year'. However, for *D. brownii,* treatment effects were significant *(P<0.036)* in some years.

Table 9.2: P-values derived from REML covariance analysis for the effects of treatment, soil type and year on the change in percentage frequency of grass species between 1998 and 2006.

Species	Treat.	Soil	Year	Treat* Soil	Treat* Year	Soil* Year	Treat* Soil*date
3-P grasses							
Astrebla	**0.047***	-	**<0.001****	-	0.121	-	-
B. ewartiana	**0.005***	**<0.001****	**<0.001****	**<0.001****	**<0.001****	**<0.001****	0.067
D. fecundum	0.968	**<0.001****	**<0.001****	0.875	**<0.001****	**<0.001****	0.147
D. sericeum	**0.004***	-	**<0.004***	-	0.243	-	-
E. aurea	**<0.001****	-	**<0.001****	-	0.813	-	-
H. contortus	**<0.001****	-	**<0.001****	-	**<0.015***	-	-
Wiregrass							
A. benthamii	**<0.001****	**<0.007***	**<0.001****	0.061	**<0.001****	**<0.001****	**0.537**
A. calycina	**0.016***	**0.045***	**<0.001****	**<0.001****	0.065	**<0.001****	0.856
E. mucronata	**<0.001****	-	**<0.001****	-	0.347	-	-
2-P grasses							
C. fallax	**<0.001****	**<0.001****	**<0.001****	**0.005***	**0.031***	**0.046***	0.723
E. acicularis	0.722	**<0.002***	**<0.001****	0.800	0.703	**<0.001****	0.995
D. brownii	0.348	**<0.001****	**<0.001****	0.800	**0.036***	**<0.001****	0.236
P. effusum	0.954	0.206	**<0.001****	0.373	0.253	**<0.001****	0.464
Paspalidium	0.430	-	**<0.001****	-	0.840	-	-
Annuals							
S. fragile	**0.002***	**<0.001****	**<0.001****	**0.014***	0.754	**<0.001****	**0.049**

Effect of treatment and year on individual species

To investigate changes in species frequencies under the different treatments over time, species frequencies species were plotted against year and repeated measures analysis of the 2006 data was conducted using the 1998 data as a covariate. For brevity, results are presented for a reduced sub-set of species chosen for their importance for grazing, value as an indicator species and/or to represent a particular functional group.

9.4.4 3-P grass species

Bothriochloa ewartiana

B. ewartiana frequencies on clay soils peaked in 2002 but thereafter dropped by 10 - 20% points in all treatments due to drought effects, which were particularly pronounced on these soils (Fig. 9.5). Post 2003, some treatment effects emerged with the LSR and R/Spell showing clear trends of recovery while frequencies in the VAR, SOI and HSR treatments have largely remained constant. By 2006, *B. ewartiana* frequencies in the LSR (35%) were significantly greater *(P<0.05)* than in the VAR strategy (21%), but other differences were non-significant**.**

On Box soils, *B. ewartiana* frequencies tended to peak in 2001(Fig. 9.5). Although frequencies did decline in 2003, drought mortality was lower than on clay soils and appeared to be lower at lighter utilisation rates e.g. LSR and Exclosure. Post 2003, frequencies remained relatively constant in the LSR but tended to decline in the remaining strategies. Absolute change in *B. ewartiana* frequencies on Box soils between 1998 and 2006, varied from increases of 19% (LSR) and 15% (Exclosure) to a decline of 5.08% in the HSR. By 2006, frequencies of *B. ewartiana* in the LSR (47%) were significantly *(P<0.05)* higher than those in the VAR (25%) and HSR (22%).

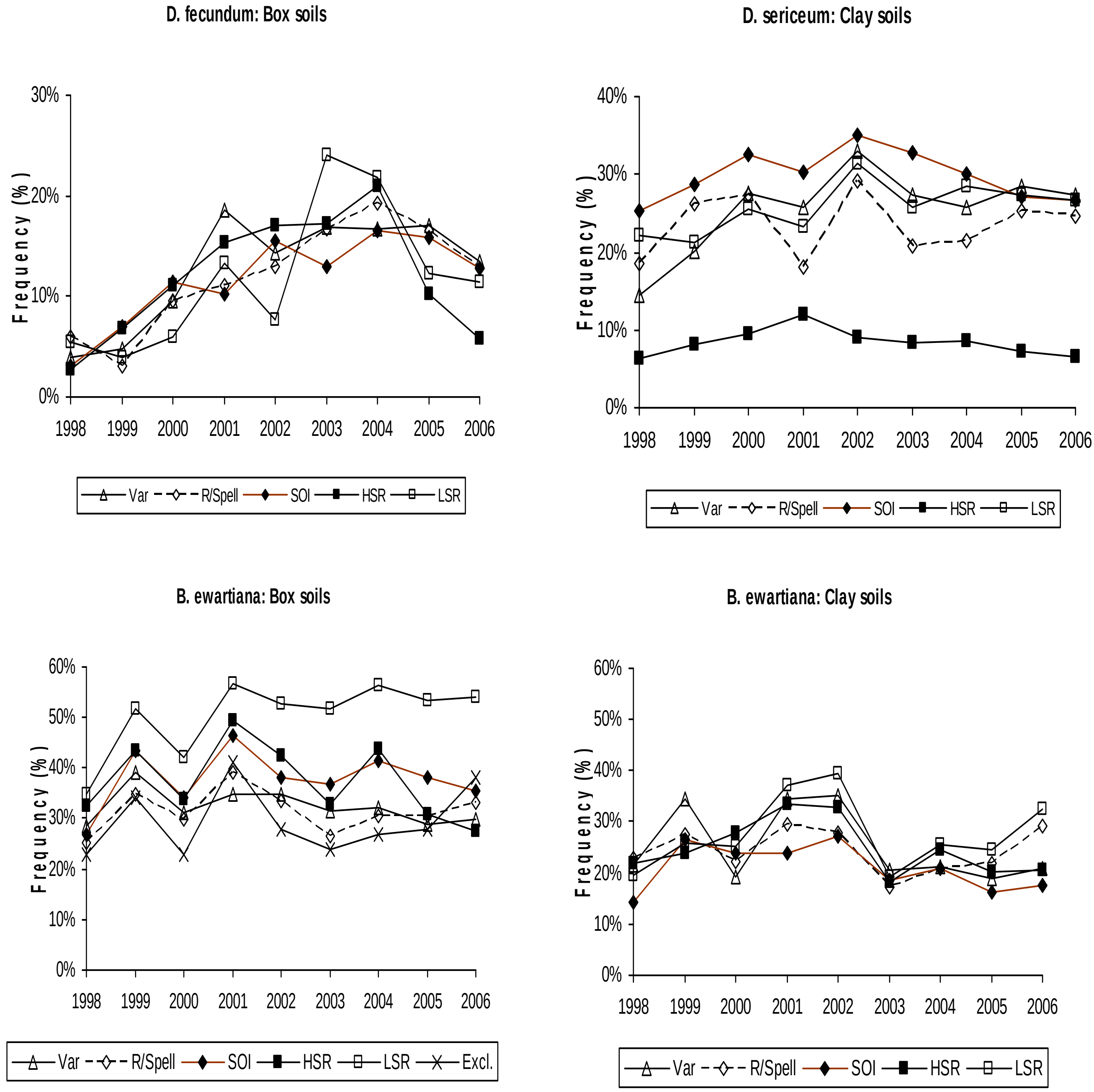


Figure 9.5: Change in mean percentage frequency of *D. sericeum* and *D. fecundum* (Top) and *B. ewartiana* (Bottom) between 1998 and 2006 under five grazing strategies at the Wambiana grazing trial. Note scale of vertical axis between species. (Excl.= exclosure, other abbreviations as before)

So, this infers that….

Dicanthium fecundum

D. fecundum was initially scarce in all paddocks (<5%) but increased 4-5 fold across all treatments to peak in 2004 (Fig. 9.5). Unlike other species, *D. fecundum* did not initially decline in 2003 due to drought. However, post-2004 frequencies declined in all treatments, due probably to continuing below average rainfall years. Although the largest drop in frequency has occurred in the HSR (20% to 5%), none of the 2006 treatment comparisons were significant.

So, this infers that…

Dicanthium sericeum
D. sericeum showed little change between 1998 and 2006 (Fig. 9.5). There appeared to be a slight increase in frequency to 2002 due to good rainfall: in these wetter years *D. sericeum* was often only grazed in the late dry season when dormant. Frequencies declined slightly (*c*. 5-10%) in 2003 due to drought but thereafter largely remained constant. Covariance analysis indicated that there were no significant differences between treatments in 2006.

D. sericeum at the trial site appears to be a stable, long lived species apparently tolerant of a range of grazing pressures. It will be interesting to observe whether these trends continue under the recent regime of wetter winters like 2005 where a general shortage of feed and out-of-season growth has ensured heavy, repeated grazing of *D. sericeum* tussocks throughout the year.

Eulalia aurea
E. aurea frequency generally increased from 1998 to 2002 in response to good rainfall (Fig. 9.6). *Eulalia* is confined to clay soils and in wet years animals avoid these areas allowing the grass to become tall and rank. The frequency of *Eulalia* dropped in 2003 due to drought, but then stayed stable (R/Spell, SOI, VAR) or gradually declined (LSR, HSR) until 2006. In the later drier years, *Eulalia* was grazed down and once short, was repeatedly grazed as fresh growth emerged. Overall, there has been little change in *Eulalia* frequencies over the 8 years of the trial with all treatment differences being non-significant in 2006.

Heteropogon contortus
H. contortus generally increased from 1998 to 2002, in response to good seasons and the 1999 fire (Fig. 9.6). Although the biggest response occurred in the LSR and R/Spell with *H. contortus* frequency doubling from 20 to 41% in the LSR. These trends emphasise the importance of light grazing, good rainfall, fire and/or spelling in promoting this species.

Post 2002 a general decline in *H. contortus* frequency apparently occurred (Fig. 9.6). In reality, 100% turnover of the population occurred due to extensive plant death in late 2002/03, followed by large scale seedling recruitment in March 2003. In later years, *H. contortus* frequency has generally declined across all treatments, in conjunction with continuing low rainfall. Overall, *H. contortus* is a useful 3-P grass but it should not be regarded as a key component of the *Aristida-Bothriochloa* community due to its relative vulnerability to drought.

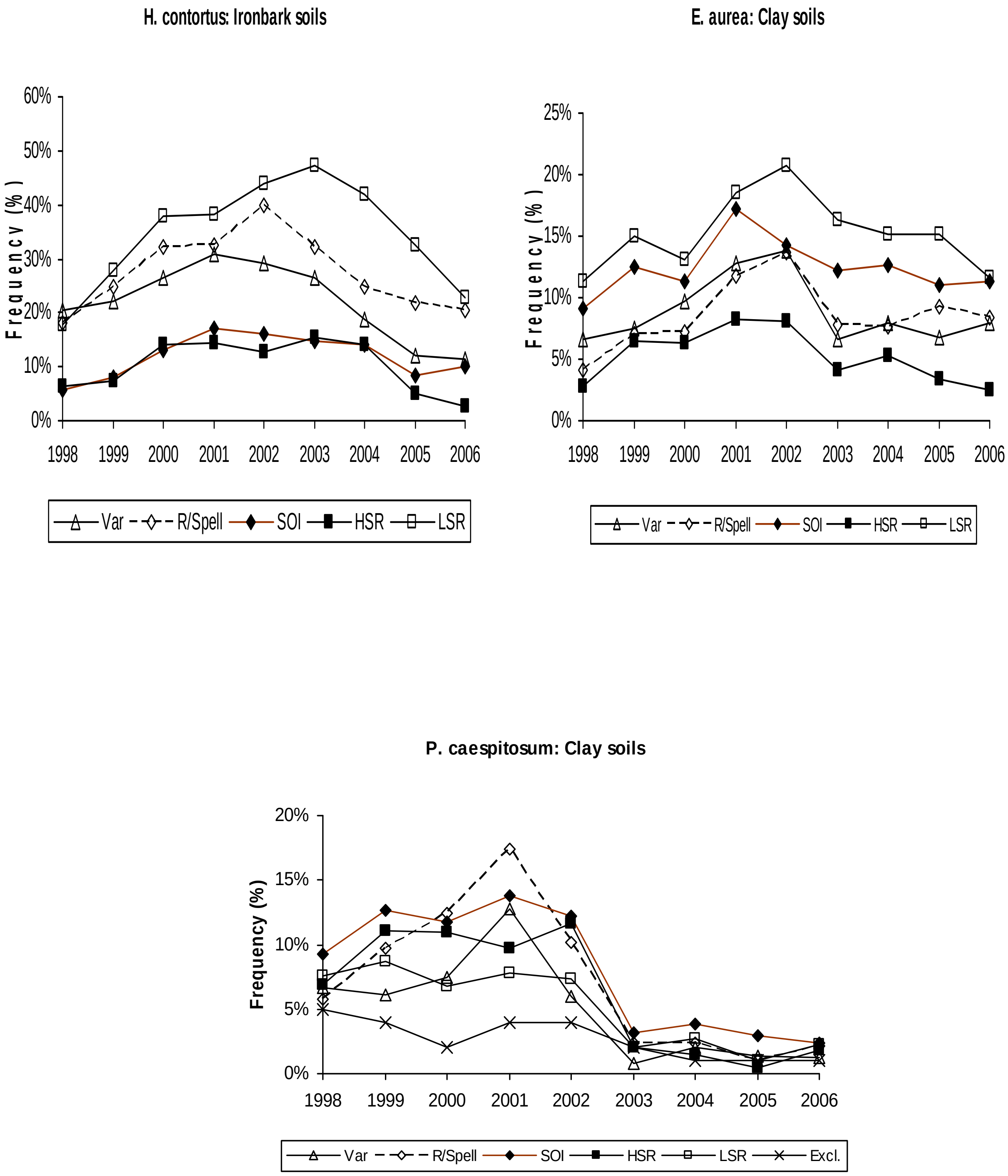


Figure 9.6: Change in mean percentage frequency of *H. contortus* and *E. aurea* (Top) and *P. caespitosum* (Bottom) between 1998 and 2006 under five grazing strategies at the Wambiana grazing trial. Note scale of vertical axis between species. (Excl.= exclosure, other abbreviations as before)

2-P grass species

Chrysopogon fallax

C. fallax was largely stable over the first 5 years of the trial but in 2003 frequencies dropped sharply across all treatments (Fig. 9.7). This decline was particularly pronounced on Box soils, and reflects the effects of drought and, in particular, armyworm on this species. The biggest declines appear to have occurred in treatments that were heavily stocked in 2000 like the VAR, SOI and HSR, as is evident from comparison of the changes in the LSR and Exclosure with other treatments.

In the R/Spell, the decline in *C. fallax* frequency in 2003 was particularly sharp and subsequent recovery on the Box soils has been relatively poor compared to the other strategies. This is almost certainly a response to the heavy grazing pressure applied to these sections while the Ironbark areas in the paddock were spelled (Chapter 5). Interestingly, the fire of November 2001 had little apparent impact upon *C. fallax* frequency in the Ironbark with the major drop in frequency only occurring in 2003.

Since 2003 *C. fallax* frequencies have largely recovered across the site, although recovery has varied between treatments on the Box soils. In 2006 there were no significant differences between treatments on the Ironbark but on Box soils, *C. fallax* frequencies were higher *($P<0.05$)* in the HSR (45%) than in the R/Spell (31%). This is a surprising trend considering that the R/Spell sites would have received at least one (section 2), if not two (section 3) wet-season spells over this time.

So,….

Digitaria brownii

D. brownii was also strongly driven by rainfall with its frequency on the Ironbark almost doubling from 1998 to 2002, dropping sharply in 2003, and declining gradually thereafter (Fig 9.7). Similar trends also occurred on the Box soils. Overall, treatment effects were non-significant, although this effect depended ($P<0.036$) upon year (Table 9.2). The data also suggest a response to spelling: first, *D. brownii* in the exclosure initially increased to very high levels on Box soils in 2000, although these frequencies subsequently dropped sharply. Second, *D. brownii* frequencies on the R/Spell remained relatively high on the Ironbark post-2002, possibly due to wet season spelling of these sections.

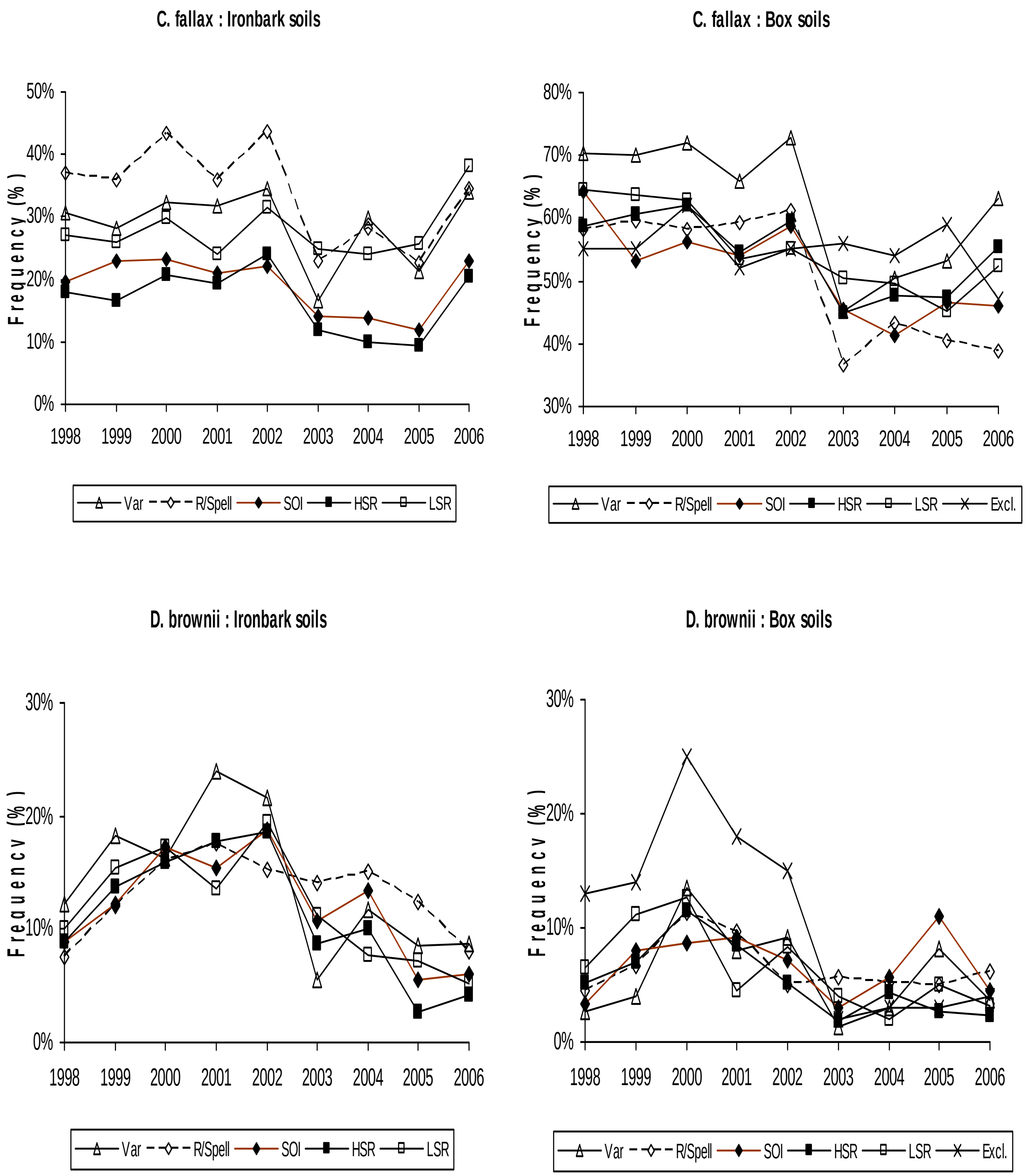


Figure 9.7: Change in mean percentage frequency of *C. fallax* (Top) and *D. brownii* (Bottom) between 1998 and 2006 under five grazing strategies at the Wambiana grazing trial. Note scale of vertical axis between species. (Excl.= exclosure, other abbreviations as before)

So,….

Enteropogon acicularis

E. acicularis increased in the good years, but then dropped rapidly in 2003 in the SOI, VAR and R/Spell treatments (Fig. 9.8). In contrast, frequencies were generally low (<7%) in the HSR and LSR treatments with no clear temporal trend apparent. Treatment had no effect on *E. acicularis* frequencies (Table 9.2). Like *P. caespitosum*, *Enteropogon* is palatable but is a minor component of the pasture and not particularly drought tolerant.

Eragrostis spp

The *Eragrostis* group showed a unique response over time with a consistent decline in frequency from *c.* 25% in 1998 to about 5% in 2002, with frequencies remaining low thereafter. This trend suggests an earlier peak in *Eragrostis* frequency pre-1998 (Fig 9.8). The trend is difficult to explain as the decline occurred during good years and was then maintained through subsequent drier years. *Eragrostis* possibly responds rapidly to the first good seasons post-drought when inter-specific competition is low. Frequency then probably declines as other species recover and competition increases. Wambiana was severely droughted in 1991-1994, but subsequent wetter years may have allowed *Eragrostis* frequencies to peak before the trial began. Numbers may then have declined post-1998 as competition from perennials increased with the better seasons. The *Eragrostis* data was not analysed statistically but no treatment effects were apparent. However, *Eragrostis* frequencies post 2003 does seem to be lowest in the exclosure, possibly due to shading and/or excessive competition.

Panicum effusum

Grazing treatment had no apparent effect on *P. effusum* frequencies with changes largely driven by rainfall (Fig. 9.8). On the Ironbark, frequencies were relatively high (*c.* 15%) between 1998 and 2002 but dropped to low levels (*c.* 4%) in 2003 – 2005, with some recovery taking place in 2006. Changes on Box soils were similar but were far less consistent in later years than those on the Ironbark (Fig 9.8). In 2006, frequency of *P. effusum* meaned over both soil types was significantly ($P<0.05$) higher in the VAR (13%) than in the R/Spell (6%) but other comparisons were non-significant.

Paspalidium caespitosum

Paspalidium frequencies were originally low (<10%) in all strategies but later increased due to good rainfall, particularly in the R/Spell in 2001 (Fig. 9.6). This response may be partly attributable to the wet season spell received by parts of these paddocks in 2000/01. As with other weakly perennial species like *P. effusum* and *E. acicularis*, *P. caespitosum* frequencies dropped sharply in 2003 due to drought and have since remained consistently low (<5%) across all treatments.

In general, *P. caespitosum* is very palatable and heavily grazed. Tussocks are often found only in small, protected refuges such as under *Carissa* bushes or between logs. Treatment appears to have had little effect on this grass but this is possibly because it was heavily grazed in all strategies, irrespective of stocking rate.

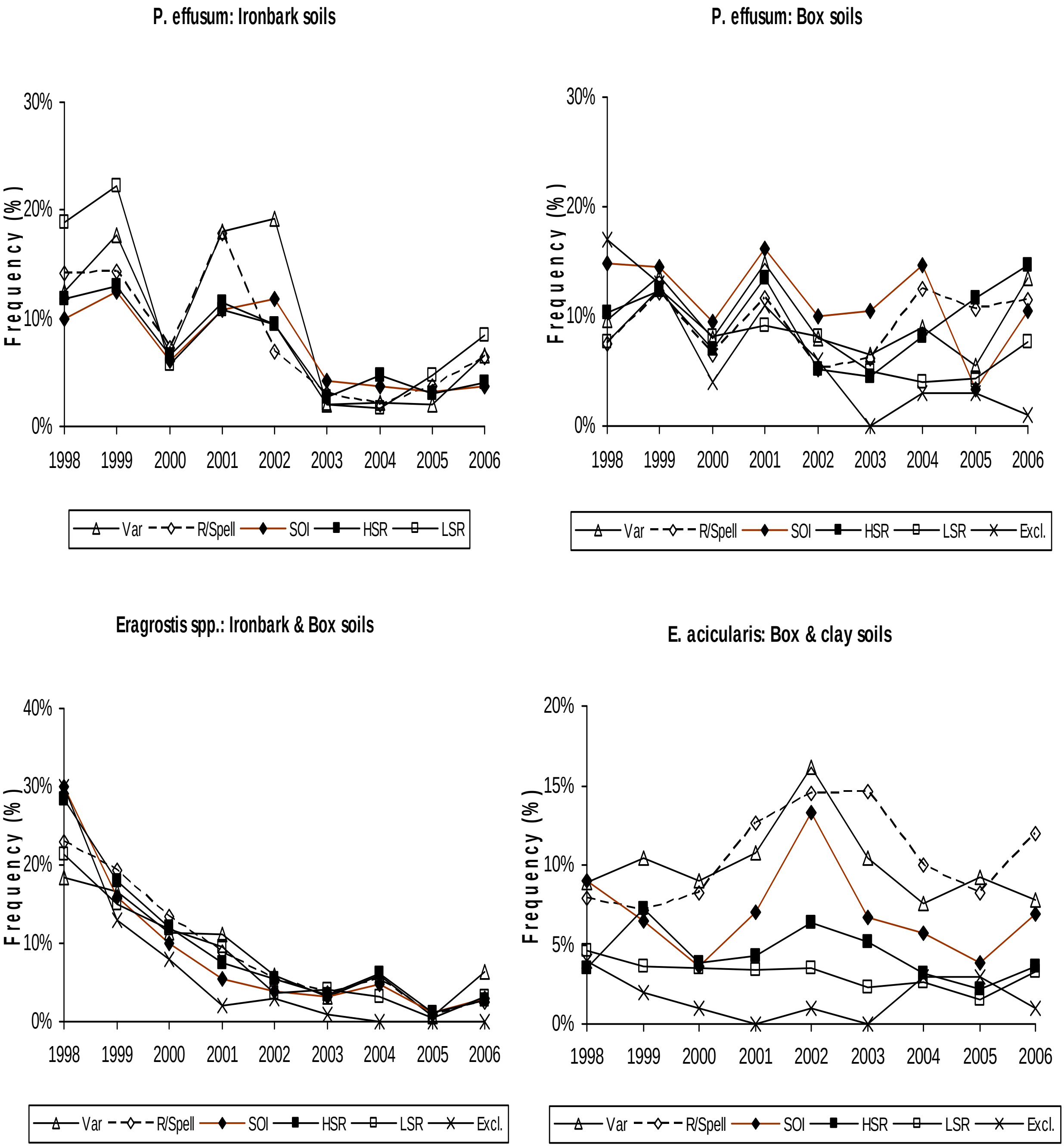


Figure 9.8: Change in mean percentage frequency of *P. effusum* (Top) and *Eragrostis* spp. and *E. acicularis* (Bottom) between 1998 and 2006 under five grazing strategies at the Wambiana grazing trial. Note scale of vertical axis between species.

9.4.5 Wiregrasses

Aristida benthamii spp. Complex

A. benthamii showed a similar response on both Box and Ironbark soils with a general, gradual decline between 1998 and 2002, followed by a massive crash and almost complete disappearance in 2003 (Fig 9.9). Frequencies thereafter gradually recovered to varying extents into 2006. On the Box soils some treatment effects appear to be emerging in recent years with overall recovery being greatest in the VAR treatment but least in the exclosure and LSR.

When meaned over both soil types, *A. benthamii* frequencies in 2006 were significantly *(P<0.05)* higher in the VAR (26%) than in either the LSR (8.45%) or HSR (10.88%). Frequencies were also higher *(P<0.05)* in the R/Spell (21.8%) than in the LSR. The low frequencies in the HSR are counter-intuitive as *Aristida* is usually classified as an Increaser species that increases under heavy stocking. However, utilisation rates were possibly so extreme in the HSR that animals were forced to graze the normally unpalatable species, causing a decline in its frequency.

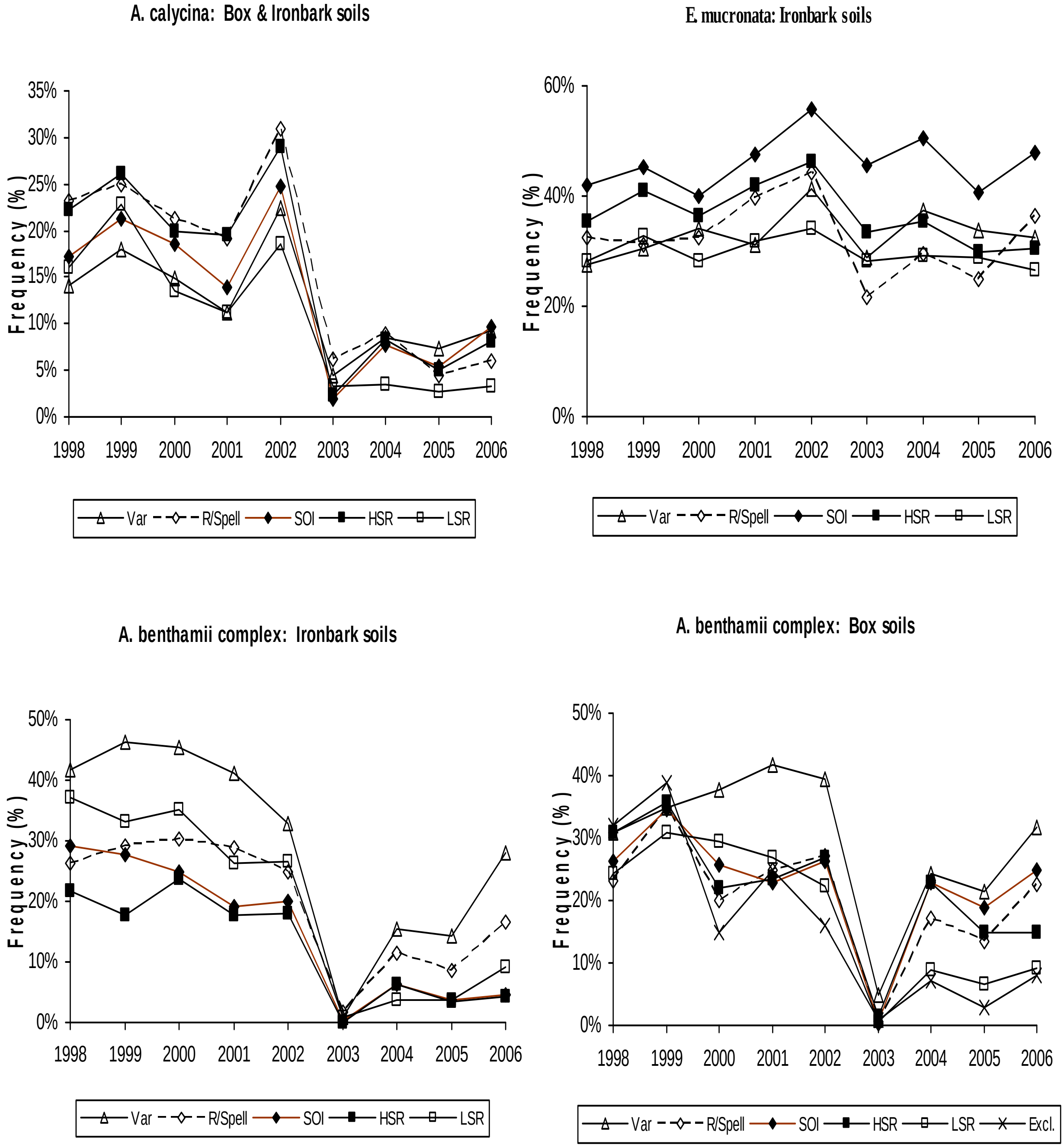


Figure 9.9: Change in mean percentage frequency of *A. calycina* and *E. mucronata* (Top) and *A. benthamii* (Bottom) between 1998 and 2006 under five grazing strategies at the Wambiana grazing trial. Note scale of vertical axis between species.

Aristida calycina

A. calycina frequencies peaked in 2002 but then crashed sharply due to drought induced tussock mortality, with frequencies dropping six-fold from between 15 – 30% in 2002 to between 1-6% in 2003 (Fig. 9.9). Unlike *H. contortus*, subsequent seedling recruitment in *A. calycina* was minimal. With the exception of the LSR, some recovery has occurred since 2004 in most treatments. *A. calycina* frequencies in 2006 on Box soils were higher (*P<0.05*) in the SOI (17%) than in the LSR (4.9%) and R/Spell (7.84%). However, on the Ironbark, frequencies in 2006 were higher (*P<0.05*) in VAR (10.8%) than in HSR (0.44 %) and R/Spell (1.58%).

Eriachne mucronata
E. mucronata was relatively stable over the study period, with only relatively minor changes in frequency occurring (Fig 9.9). Some decline in frequency was evident across all treatments in 2003 but these effects were relatively short term. The decline in 2003 was particularly marked in the R/Spell where the 2001 fire appears to have exacerbated later drought effects, probably through the removal of ground cover.

E. mucronata has been particularly stable in the LSR which is not surprising given that the species was seldom grazed in this treatment. However, even in the HSR where tussocks have been heavily grazed in the last few years, little change has occurred. In 2006 the frequency of *E. mucronata* was *(P<0.05)* higher in the SOI (32%) than in the HSR (21%), but no other treatment differences were significant. *E. mucronata* appears to be a stable, long lived species and is well adapted to the harsh, infertile areas on which it grows as evidenced by it narrow, tough leaves and general longevity.

Print 9: Fence line contrast on the Ironbark between the heavy stocking rate (left) and the light stocking rate (right) in the late dry season in November 2004. Note how the unpalatable grass *Eriachne mucronata* has been grazed in the heavy paddock but is largely ungrazed in the adjacent paddock..

9.4.6 Annual grasses

Iseilema vaginiflorum
Iseilema frequencies fluctuated between years, with peaks in 2000 and 2003 followed by a general decline to 2006 (Fig. 9.10). The 2000 peak in *Iseilema* can possibly be attributed to good rains, but the 2003 peak is puzzling given the relatively poor amount and distribution of rainfall that year. Overall, no treatment effects were evident with fluctuations appearing to largely reflect rainfall variability and inherent between-site variability.

Schizachyrium fragile
Schizachyrium showed a clear response to rainfall and peaked in 2001, dropped to a low in 2003 and then recovered well to 2006 (Fig. 9.10). Treatment had a significant effect on *S. fragile* (Table 9.2) but this was soil and year dependent *(P<0.049*). In terms of overall change, the relative increases in *Schizachyrium* from 1998 to 2006 were + 29% and +29% for the HSR and VAR treatments respectively, compared to only + 12% for the SOI and R/Spell, with no increase in the LSR. In 2006, *S. fragile* frequencies on the Ironbark, were greater *(P<0.05)* in the HSR (53%) than in the LSR (31%). This suggests a relatively greater availability of bare or open patches for this annual species to colonise within the HSR. In contrast, recruitment within the LSR was possibly limited by competition from the greater tussock density (Chapter 11).

9.4.7 Native legumes

***Zornia spp*.**
Zornia frequencies fluctuated sharply and involved a 4 - 6 fold increase in frequency from 1998-2001, decline and disappearance of *Zornia* in 2002/03 due to drought, and slight recovery to

2006 (Fig. 9.10). Treatment had no apparent effect on *Zornia.* However, the species largely disappeared in later years from the Exclosure suggesting a possible adverse response to shading and competition under ungrazed conditions.

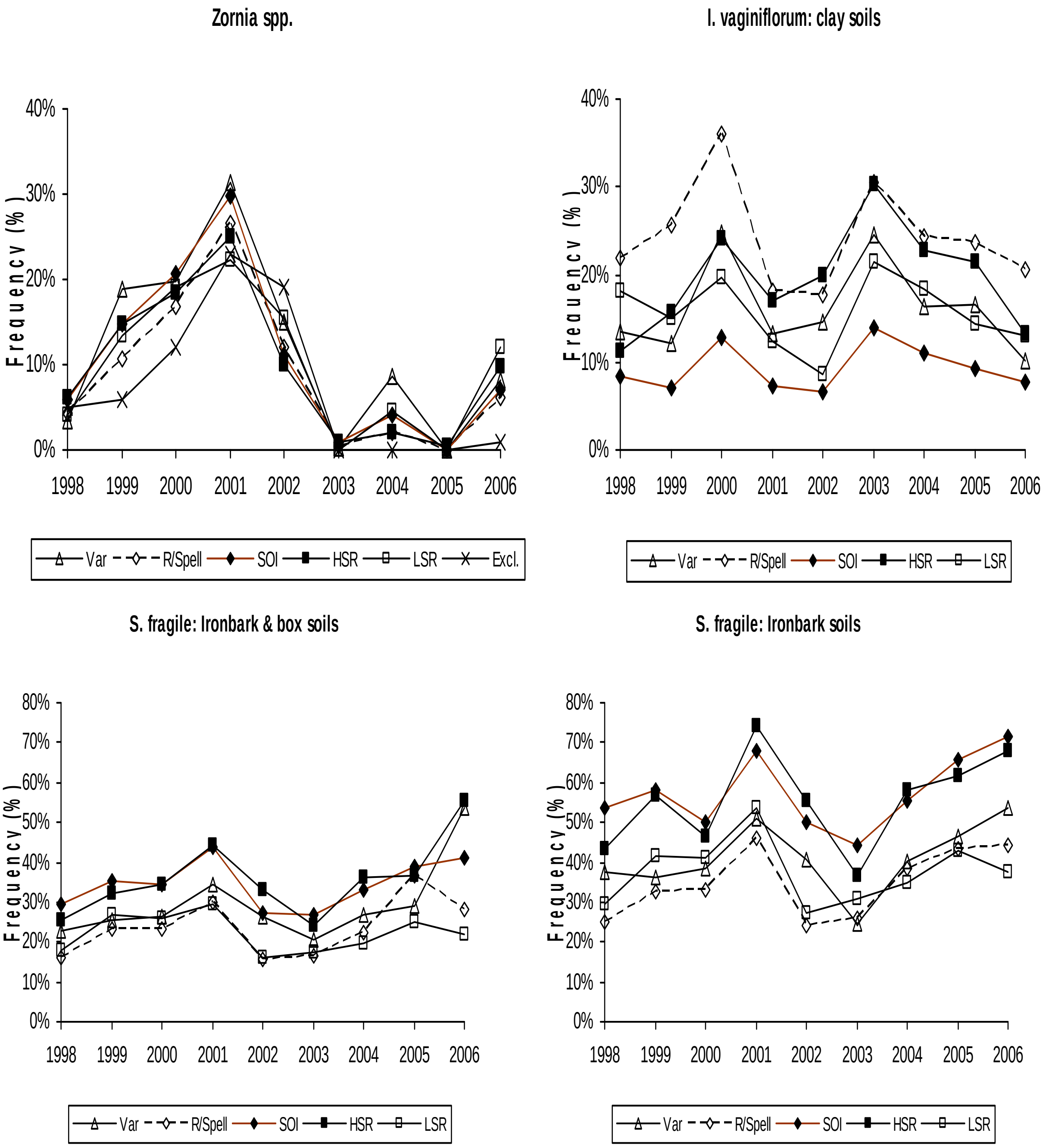


Figure 9.10: Change in mean percentage frequency of *Zornia* spp. and *I. vaginiflorum* (Top) and *S. fragile* (Bottom) between 1998 and 2006 under five grazing strategies at the Wambiana grazing trial. Note scale of vertical axis between species.

9.4.8 Species response to fire

While the present trial was not focussed on burning *per se* three different fires occurred through the study period (Table 9.3). These fires differed widely in nature and the conditions under which they were applied but some observations may be made on the response of certain grass species to fire.

Table 9.3: Summary of fires at the Wambiana trial between 1998 and 2006. (S1 and S3 refer to the sections (sub-paddocks) burnt, fire interval refers to years since area last burnt).

Date	Treatments	Soils	Fire interval	Fire intensity	Follow up rains
Oct 1999	All	All	*c.*25 years	V. Hot	V. Good
Oct 2000	R/Spell [S3]	Box	1 year	V. Cool	Good
Nov 2001	R/Spell [S1]	I/Bark, clay	2 years	Medium	V. Poor

Most species showed little response to the 1999 fire with grasses like *A. benthamii, C. fallax, D. sericeum, E. aurea* and *E. mucronata* remaining stable or increasing in the season immediately post-fire. A few species like A*. calycina* and *P. effusum* are obviously fire sensitive and decreased in frequency across all treatments following this fire. Importantly, *B. ewartiana* also showed a negative response to fire, at least in the short term, with frequencies on both Box and Heavy clay soils dropping in the season after the 1999 burn (Fig. 9.5).

No specific species response could be detected to the second fire in October 2000: this could reflect its cool nature, the good follow up rains that occurred post-fire and/or the soil type involved (Box). In contrast, the 2001 fire had an obvious negative effect on Ironbark areas with ground cover dropping at least 10% and pasture production being severely compromised in subsequent seasons (Chapter 10). Recovery on the clay soil areas following this fire was better with few apparent signs of degradation. In the Ironbark areas, the fire resulted in a sharp decline in *P. effusum* frequencies and an increase in *H. contortus* but its effects on the frequency of other species was unclear. As stated earlier, the effects of this fire on *E. mucronata* were not immediate but seemed to amplify the effect of the reduced rainfall on mortality the following season.

9.5. Summary

1. Multivariate analysis (MVA) of frequency data revealed three distinct soil type/vegetation groupings with characteristic species associations : (a) *Ironbark sites* on red/yellow kandosols dominated by *E. mucronata, Aristida* and a range of other weaker perennial or annual species, (b) *Box sites* on brown sodosols/chromosols dominated by *C. fallax, B. ewartiana* and *Aristida*, and (c) *Brigalow-box sites* on grey clays or vertosols dominated by *D. sericeum, E. aurea, B. ewartiana* and various *Cyperaceae* species.

2. MVA of Ironbark and Brigalow sites revealed strong shifts in species composition over time. These largely arose from rainfall driven changes in the populations of annuals and weaker perennials, with longer lived perennials like *E. mucronata* (Ironbark) or *E. aurea* (Brigalow) remaining relatively stable. No treatment effects on species composition were detected on these land types with most effects overridden by season.

3. Strong seasonal effects on species composition were also evident at the Box sites. After 2000 however, clear treatment effects emerged with LSR sites having higher frequencies of *B. ewartiana* and lower frequencies of the fire grasses (*Schizachyrium fragile* and *Rottboelia formosa*) relative to other treatments.

4. Univariate analysis of species frequency data confirmed strong changes in the frequency of individual species between 1998 and 2006 across all treatments. In general, the frequency of most species declined sharply with the advent of drier seasons in 2002. Recovery thereafter

was variable but most species frequencies slowly increased with improvements in the amount and distribution of rainfall.

5. The weaker perennials like *A. calycina* and *A. benthamii, P. caespitosum* and *P. effusum,* the 3-P grass *H. contortus* and the native legume *Zornia were* particularly sensitive to drought and dropped sharply in frequency in very dry years. *B. ewartiana*, *C. fallax* and *E. aurea* showed moderate drought sensitivity. In contrast, although some tussock mortality occurred, *D. sericeum* and *E. mucronata* showed only a minor response to drought.

6. Responses to fire were varied: Species that decreased slightly (*c.* 5-10%) with the 1999 fire were *A. calycina, B. ewartiana, P. effusum,* and to some extent, *E. acicularis*. In contrast *H. contortus* and *D. brownii* appeared to increase slightly with fire. Most other species showed no apparent response to fire.

7. Grazing treatment had no detectable effect on the frequency of *P. caespitosum, P. effusum, E. acicularis, D. brownii* and *D. fecundum* with species populations largely driven by climate. Treatment also had little effect on the frequency of the relatively unpalatable *E. mucronata*. However, palatable species like *E. acicularis* and *P. caespitosum* are likely to decline over time under heavy grazing.

8. Both *B. ewartiana* and *H. contortus* increased under lighter utilisation. In contrast, the annual grass *S. fragile* appeared to be favoured by heavy grazing and increased in the HSR. *A. benthamii* also appeared to be favoured by moderate to heavy grazing but declined under very heavy grazing pressure as occurred in the HSR in the later years of the trial.

9. Overall, constant light stocking led to an increase in the 3-P grasses *B. ewartiana* and *H. contortus*, and a decrease in the Increaser species *A. calycina* and *A. benthamii*. Constant heavy stocking led to a decrease in the frequency of *B. ewartiana* and *C. fallax*, but caused an increase in the annual grass *S. fragile*. The *Increaser* grasses *A. calycina* and *A. benthamii* also declined under heavy stocking because of over utilisation.

10. Despite varying stock numbers, the VAR and SOI strategies caused a decline in some of the better grasses like *C. fallax* and *B. ewartiana,* apparently through heavy stocking in critical years leading into the drought. Increases in *Aristida* species and *S. fragile* also occurred, despite a sharp reduction in stocking rates in later years.

11. The R/Spell treatment was partially compromised through the effects of an ill-timed fire and its subsequent effects on the spelling regime. However, spelling seems to have favoured *B. ewartiana* and *H. contortus,* although the frequency of *A. benthamii* also increased.

Print 10: A monitoring site on the Box soil in one of the heavy stocking rate paddocks in 1998 (left) and in 2006 (right). Cover has declined dramatically and the density and vigour of 3-P grasses is much reduced.

Print 11: A monitoring site on the Box soil in one of the *light stocking* rate paddocks in 2000 (left) and in 2006 (right). Although cover has declined, a healthy population of 3-P grasses is still evident.

10. Effect of different grazing strategies on pasture composition, yield and cover

10.1. Introduction

Pasture yield and species composition are obviously major determinants of animal production in the semi-arid savannas. Ground cover is also of importance as it directly determines runoff and infiltration rates and hence the rainfall use efficiency of the pasture. In this chapter, responses in pasture yield, cover and species composition over the eight years of the trail are presented.

10.2. Objectives

The objectives of the this section is to:

- Quantify the effects of different grazing strategies on pasture yield, composition and ground cover.
- Quantify the effects of rainfall and utilisation rate on pasture yield and ground cover.

10.3. Procedure

10.3.1 Measurements of pasture yield and composition

Pasture total standing dry matter (TSDM), species contribution to yield and ground cover were assessed annually at the end of the dry (October) and wet (May) seasons using BOTANAL (Tothill *et al.* 1992). One hundred quadrat placements were made at regular intervals along each of two permanent transects that ran the length of each paddock i.e. 200 quadrats per paddock. Depending upon the paddock transects ranged from 1.7 to 3.5 km in length. The length of the transect across each soil type was roughly proportional to the percentage of that soil type in a particular paddock. Assessments were conducted by experienced operators, with the same operators being used across most years.

Other variables recorded for each quadrat include:

- *Projected ground cover* - scored according to a 6-class scale i.e. 0- 5%; 5-15%; 15-30%; 30-50%; 50-90% and >90% cover. From 2002 onwards the 50-90% class was subdivided into 50 – 75% and 75-90% making this a 7-class scale.

Other data recorded during yield measurements but not presented in this report include*:*

- *Carissa ovata* – presence above or in a quadrat.
- *Defoliation area*- scored on a 0-4 scale where 1 = ¼ of the quadrat area grazed, 2= 2/4 grazed, 3= ¾ grazed etc
- *Defoliation intensity*- scored on a 0-4 scale where 1= lightly grazed, 2= moderately grazed, 3=moderately to heavily grazed and 4= heavily grazed.

For data analysis plant species were grouped into eight functional groups based on life history, palatability, productivity and perenniality. These groups were: 3-P grasses (palatable, productive and perennial), 2-P grasses (palatable, productive and/or perennial), wire grasses (*Aristida* and *Eriachne* spp.), annual grasses, ‘other’ grasses, forbs (i.e. all dicotyledons excluding legumes), legumes (native and introduced) and Sedges (*Fimbristylis* and *Cyperus* species). Main species groups are given in detail in Appendix 4.

10.3.2 Statistical analysis

Total standing dry matter (TSDM) and percentage groundcover data were tested for normality using GENSTAT. Utilisation rates were calculated as described in Chapter 6. Cover data was not transformed due to the relatively even distribution of data points between 20 and 80% cover. The effects of year (time), soil association and treatment on cover and TSDM were analysed using a repeated measures analysis of variance (REML) with grazing strategies as treatments and paddocks as replications. REML was used because treatment effects would accumulate over time and data from individual years was unlikely to be independent. The effects of various interactions between time, treatment and soil type on the data were also explored. The effect of treatment on the percentage contribution and absolute yield of plant groupings were also investigated using REML.

The effects of rainfall and pasture utilisation rate on TSDM were also explored using linear regression analysis in GENSTAT. Utilisation rates were derived from the model GRASP as described earlier (Chapter 6). Two indices of long term utilisation rate were also derived based on a progressive running mean over all years or over three years i.e. current year plus two previous years.

10.4. Results

10.4.1 Effect of year and treatment on TSDM and species contribution to yield

Total standing dry matter

Pasture TSDM changed profoundly over the course of the trial *(P<0.001)* from a high of 5000 kg/ha in 1999 to average less than 800 kg/ha in 2006 (Table 10.1; Fig. 10.1). This change was a direct result of reduced rainfall post-2001 combined with grazing pressure. The outbreak of armyworm *(Leucania separata)* in March 2003 also contributed to this decline. In comparison, the effects of fire were relatively transient: although TSDM was reduced in 2000 following the October 1999 fire, pasture yields recovered rapidly to average about 3000 kg/ha in 2001. Overall, soil type had little effect on TSDM (*P=0.732)*.

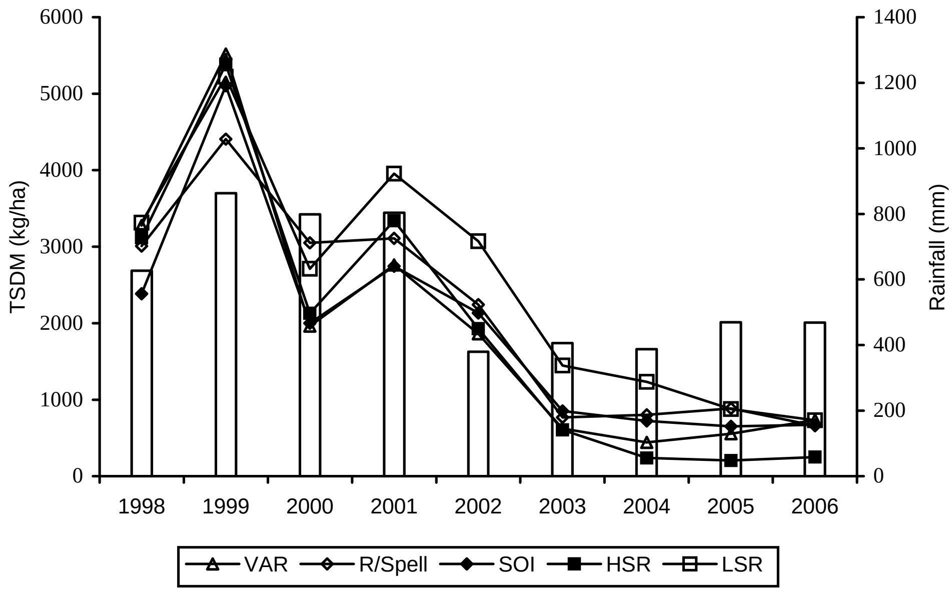


Figure 10.1: Change in total standing dry matter (TSDM) and annual rainfall between 1998 and 2006 under different grazing strategies at Wambiana. Data meaned across May and October TSDM estimates.

Treatment had a significant (*P=0.044)* effect on TSDM (Table 10.1) but was of secondary importance compared to 'time' i.e. rainfall. The effect of treatment varied with time (treatment*time interaction; *P=0.049)* but was independent of soil type *(P=0.813).*

Table 10.1: Repeated measures ANOVA for the effects of time (year), treatment and vegetation type on end-of-wet total standing dry matter (TSDM) from 1998-2006 .

Stratum	***DF***	***SS***	***MS***	***Variance ratio***	***F-Prob.***
Rep	1	1.917E+06	1.917E+06	2.16	
Treatment	4	**2.454E+07**	**6.135E+06**	**6.93**	**0.044**
Residual	4	3.543E+06	8.859E+05	1.02	
Veg	2	5.585E+05	2.793E+05	0.32	0.732
Treat.Veg	8	3.657E+06	4.571E+05	0.53	0.813
Residual	10	8.690E+06	8.690E+05	2.01	
Time	16	**1.222E+09**	**7.637E+07**	**176.90**	**<.001**
Treat.Time	64	**5.239E+07**	**8.185E+05**	**1.90**	**0.049**
Time.Veg	32	2.098E+07	6.558E+05	1.52	0.182
Treat.Time.Veg	128	1.741E+07	1.360E+05	0.32	0.999
Residual	240	1.036E+08	4.317E+05		
Total	509	1.459E+09			

Treatment effects on TSDM were relatively subtle in the early, wetter years (1998 to 2001) but emerged strongly thereafter as rainfall declined (Fig 10.1). Overall, TSDM tended to be highest in the LSR. Stark between-treatment differences in pasture TSDM were particularly evident in later dry years. For example, HSR paddocks were almost bare in the dry season in these later years and had 400 % to 600% less TSDM than the other, more lightly stocked strategies. Yields in the HSR remain low (< 300 kg/ha), but in May 2006 there was little difference in TSDM between the SOI, VAR, R/Spell and LSR strategies (range: 660 - 740 kg/ha). The similarity in TSDM between these latter strategies is surprising, given that stocking rates in the SOI, VAR and R/Spell paddocks have been lighter than those in the LSR since 2003/2004. This suggests that the heavy stocking rates previously applied to these former treatments, have had long-term effects on subsequent paddock yields. An extreme example is apparent in the HSR: despite having a stocking rate only 40 - 60% heavier, TSDM in the HSR is currently *c.* 400% lower than that in other strategies.

Effect of year and treatment on species contribution to yield

In 1998 all grazing strategies had similar proportions of 3-P grasses, 2-P grasses and wire grasses (Fig. 10.2). Pasture composition thereafter changed in a relatively consistent fashion until about 2003 with the percentage 3-P grasses tending to increase and 2-P grasses showing a slight decline in all strategies. Wire grasses declined temporarily due to the 1999 fire and the extreme dry season post-2002. Pasture composition changed after 2003 (HSR) or 2004 (other strategies), with the percentage of 3-P grasses declining, the percentage of annuals increasing sharply and wire grasses gradually increasing. Treatment differences were obvious with the largest changes occurring in the HSR (Fig. 10.2).

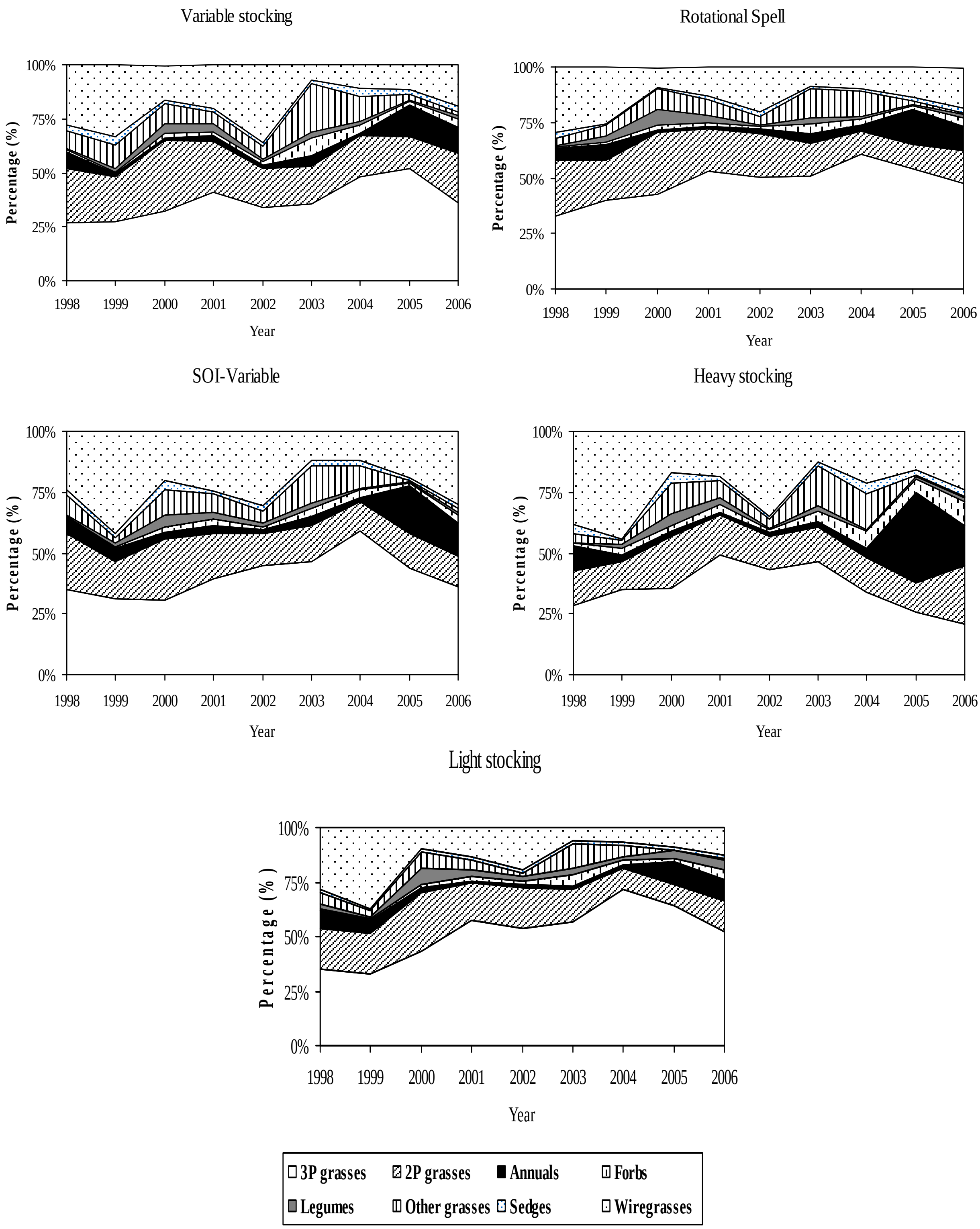


Figure 10.2: Change in the percentage contribution to yield of different species groups between 1998 and 2006 for five grazing treatments at Wambiana. Data meaned over treatment replicates (n=2).

In May 2006 big differences in yield and percentage species contribution to yield existed between the different grazing strategies (Fig. 10.3). Thus 3-P species made up 52% of the total yield in the LSR compared to only 21% in the HSR *($P<0.186$)*. In terms of weight, the yield of 3-P grasses were seven times greater under light (384 kg/ha) than under heavy stocking (51 kg/ha).

In contrast, the percentage yield of 3-P species in the LSR (52%) was similar to that in the R/Spell (47%), but both were higher than either the SOI (35%) or VAR (36%). However all these differences were not significant due to the limited treatment replication (*n=2*).

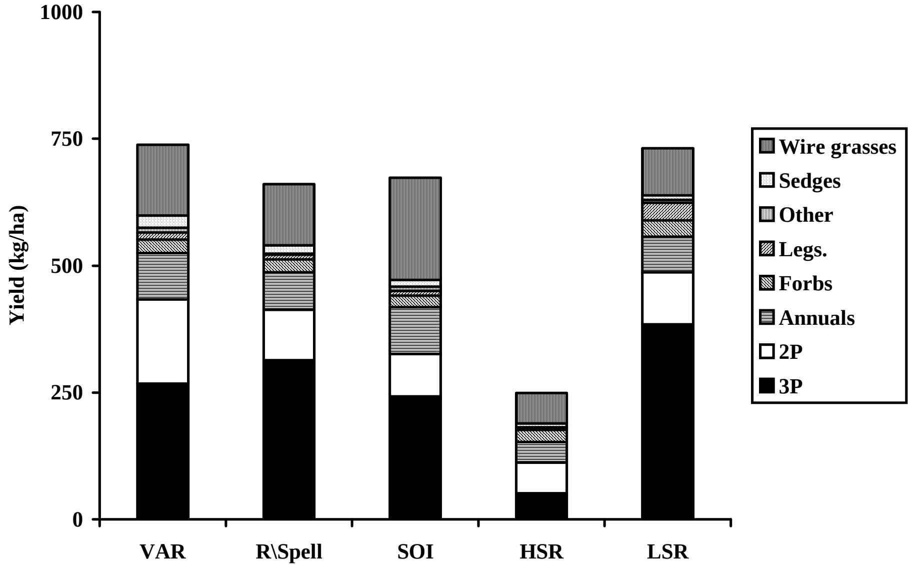


Figure 10.3: Contribution (kg/ha) of different species groups (see text) to total yield in May 2006 across five stocking strategies at Wambiana. Data meaned over both replicates.

Other species group comparisons are also of interest. For example, the percentage contribution of annual grasses to yield was greatest under heavy stocking (18%) but least under light stocking (9%) while the percentage contribution of wiregrasses in the HSR (22%) was twice that in the LSR (12%). Overall, pasture compositions for the SOI, VAR and R/Spell treatments were fairly similar and somewhat intermediate between the HSR and LSR. From a management perspective therefore, it is obvious that at present (2006) the total amount and proportion of grazeable forage is greatest in the LSR and R/Spell treatments, lowest in the HSR and intermediate in the VAR and SOI strategies.

10.4.2 Effect of year and treatment on TSDM and species contribution to yield

Rainfall was a significant (*P<0.001)* predictor of pasture TSDM and accounted for 59% of the variability in the data across all years:

TSDM=-1834+7.386* Rainfall *(P<0.001;* R^2*=59 %).*

However, TSDM was best predicted by a combination of rainfall and accumulated grazing pressure, expressed as long-term mean GRASP utilisation (LTU) rate i.e.

ln TSDM=8.30 +0.000723* Rainfall-0.0777*LTU rate *(P<0.001;* R^2*=79 %).*

End-of-wet yield of 3-P grasses was also positively related to rainfall i.e.:

3P_EOWYLD = - 492 + 2.566* Rainfall *(P<0.001;* R^2= *44 %).*

Adding LTU rate significantly improved the percentage of variability encountered for i.e.:

3P_EOWYLD = 860 + 1.298*Rainfall – 38.77*LTU (*P<0.001;* R^2= *55 %).*

Wiregrass yield was significantly related to rainfall (*P<0.001*; R^2= *32 %*), but negatively related to long term utilisation rate (*P<0.001*; R^2= *27 %)*. However, for annual grasses the relationship with both rainfall (*P<0.001;* R^2= *14 %*) and LTU rate *(P<0.001;* R^2= *15 %*) was weaker with neither variable accounting for much of the variability in the data.

10.4.3 Effect of year and treatment on ground cover

Projected ground cover also changed dramatically (*P<0.001*) with time through the course of the experiment, with the extent of this change varying with soil type and treatment (Table 10.2). Cover was initially high (50-80%) in the early years, but declined steadily from 2002 onwards due to reduced rainfall and, to a lesser extent, accumulated grazing pressure (Fig. 10.4). In contrast to TSDM, cover showed a slight lag response to rainfall, remaining relatively high (*c.* 60%) in 2002 across most treatments, despite reduced precipitation. This lag presumably occurs because of the initial maintenance of cover in dry years via litter-fall from trampling and detachment.

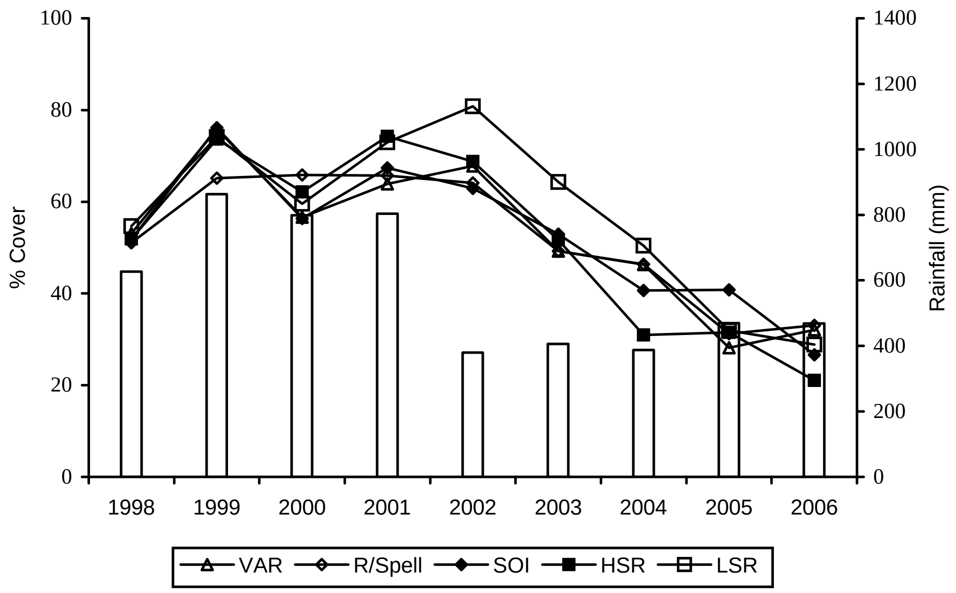


Figure 10.4: Change in percentage ground cover with annual rainfall between 1998 and 2006 under five grazing strategies at Wambiana. Data meaned across May and October cover estimates and over both replicates.

The change in cover over time was also affected (*P<0.001)* by treatment *(Table 10.2)*. Although there were initially only minor differences in ground cover between treatments, from 2002 to 2004 cover was consistently higher in the LSR than in the remaining strategies (Fig.10.4). Nevertheless by 2006, cover averaged only 28% across all strategies and had declined to as low as 21% in HSR paddocks. The change in cover varied between vegetation types and, in general, tended to be higher in the Box and Ironbark than on the Brigalow (data not shown). However, treatment effects were independent of vegetation type (Table 10.2).

Two further points are noteworthy. First, as with TSDM, in those treatments where stocking rates had been lowered in line with reduced rainfall (VAR, SOI and R/Spell), cover continued to decline after 2003 and 2004 indicating a strong carryover of treatment effects from earlier years. Second, the effects of the 1999 fire on cover were relatively minor: although cover initially declined with the fire, ground cover recovered quickly with the good seasons. However, the effects of a later fire in 2001 in the R/Spell on cover were devastating: these effects are discussed in more detail in Chapter 14.

Table 10.2: Repeated measures ANOVA for the effects of time, treatment and vegetation type on ground cover from 1998-2006.

Stratum	***DF***	***SS***	***MS***	***Variance ratio***	***F-Prob.***
Rep	1	380.64	380.64	0.75	
Treatment	4	2975.80	743.95	1.46	0.362
Residual	4	2039.89	509.97	12.49	
Veg	2	**2443.75**	**1221.87**	**29.92**	**<.001**
Treat.Veg	8	461.62	57.70	1.41	0.299
Residual	10	408.43	40.84	0.84	
Time	16	**104522.53**	**6532.66**	**134.35**	**<.001**
Treat.Time	64	**9388.79**	**146.70**	**3.02**	**<.001**
Time.Veg	32	**7123.97**	**222.62**	**4.58**	**<.001**
Treat.Time.Veg	128	5601.15	43.76	0.90	0.636
Residual	240	11669.93	48.62		
Total	**509**	**147016.50**			

Relation between ground cover and utilisation rate
Regression analysis showed that only 33% of the variation in cover data was explained by annual rainfall. A two year running rainfall mean and long term utilisation (LTU) rate explained 54% and 57% of the variability in cover data respectively, with a combination of both variables explaining 61% of the variability i.e.

Cover = 42.45 – 0.862 LTU + 0.3659 * 2YMeanRainfall (P<0.001:* R^2*=63 %)*

10.5. Summary

1. Pasture TSDM changed dramatically from a high of about 5000 kg/ha in the early, relatively wet years like 1999 to less than 1000 kg/ha in the drier years from 2003 to 2006. TSDM was largely determined by rainfall and, to a lesser extent, long term utilisation (LTU) rate with these variables accounting for 79% of the variability in data.

2. The October 1999 fire caused a transient drop in TSDM the following season (2000) but yields recovered quickly thereafter due to good rains. In contrast, recovery on Ironbark areas in the R/Spell from a fire in 2001 was extremely poor due to low rainfall, the soil type involved and the timing between fires.

3. TSDM was highest in the LSR and lowest in heavily stocked treatments from 2001 onwards. By May 2006, TSDM averaged 800 kg/ha across all treatments but had declined to less than 300 kg/ha in the HSR.

4. Pasture species composition also changed with rainfall: composition generally improved until 2003 but the % of 3-P species declined and the % of annuals increased thereafter. Overall, the yield of 3-P grasses was largely determined by rainfall and long term utilisation rate (R^2=55 %).

5. Strong treatment differences in pasture composition were also evident. By 2006 the % contribution of 3-P species to yield in the LSR was double that in the HSR. In contrast, the % contribution of annuals and wiregrasses to yield in the LSR was only half that in the HSR. By 2006, the amount of grazeable forage was highest in the R/Spell and LSR, lowest in the HSR and intermediate in the SOI and VAR treatments.

6. Ground cover also responded strongly to rainfall and declined from 60-70% cover in wetter years to only 20-30% cover in 2006. This response was lagged, with cover only declining in the second year of below average rainfall. Changes in ground cover were best explained through a combination of long term utilisation rate and rainfall meaned over the previous two years.

7. Treatment strongly affected cover in later dry years. From 2002 to 2004, ground cover was consistently higher in the LSR than in the heavier stocked strategies. By 2006 cover averaged <28% across all paddocks and was as low as 21% in the HSR treatment.

11. Effect of grazing strategy and utilisation rate on basal cover and plant demography

11.1. Introduction

Basal cover and tussock density of perennial grasses are two primary determinants of pasture health and productivity. Basal cover is a direct reflection of both the size and competitive ability of a plant as well as the number of tillers in a tussock and thus directly indexes tussock health and potential productivity. Seed production is also directly correlated with basal cover with larger tussocks producing more seed and of great viability.

Tussock density is a direct measure of the number of individuals per unit area and is thus a valuable index of population size and potential dominance of a species. Species density and basal cover can of course be inversely correlated but pastures in good condition are likely to have a good density of medium sized tussocks which optimises the relationship between plant size, competition and productivity.

Why was plant demography measured?

11.2. Objective

The objectives of this section are to report the effects of the different grazing strategies and utilisation rates on:

- Basal cover, tussock area and tussock density of 3-P grasses.
- Plant demography of major pasture species.

11.3. Procedure

11.3.1 Measurement of basal cover

Basal cover, tussock basal area and tussock linear density i.e. tussocks/metre of transect, were measured using the line intercept method (Bonham 1989). Measurements were conducted in each paddock in late 2004 but due to time constraints were restricted to one monitoring site on the Box soil. All sites were between 100 to 300m of a water point. Cover measurements were also conducted in the large exclosure located in paddock 8. Transects were approximately 200m long and covered the full variation in cover and species composition at each site. To reduce interference, transects were chosen with a minimum cover of *Carissa ovata.* A 100 m surveyors tape was stretched between the steel pickets marking individual transects and wooden pegs hammered at regular intervals along the tape for reference. The start and end length along the tape of every 3-P (perennial, palatable and productive) and *C. fallax* tussock that intercepted the tape was then recorded on palmtop computers. On the Box soils, 3-P species were largely restricted to *B. ewartiana* and *D. fecundum,* and to a lesser extent*, D. sericeum* and *H. contortus.* On rare occasions *T. triandra* and *T. avenacea* were also encountered. The tussock diameter perpendicular to the tape was also recorded and an estimate made of the percentage of the tussock alive. All cover data presented is corrected for percentage of the tussock alive at the time of measurement.

11.3.2 3-P tussock counts

3-P tussock counts were conducted across all monitoring sites in conjunction with frequency measurements in April 2006 (Chapter 9) by counting the number of tussocks per 0.25 m^2 quadrat. For the purposes of this survey 3-P grasses were defined as all native perennial, productive and palatable grasses and by definition excluded *Cenchrus cilliaris* and *Chrysopogon fallax*. Tussocks were defined as established plants and excluded seedlings or weak, recently established plants with only a few tillers.

11.3.3 Monitoring of plant demography *(Contributed by David Orr)*

Twenty permanent quadrats, each 50 x 50 cm, were established in the Box community in November 1998 in both replicates of the LSR, HSR and R/Spell treatments. In each paddock, 20 quadrats were arranged in 4 nests each of 5 quadrats. Quadrats within each nest were subjectively selected so that they contained 4, 3, 2, 1 or no *B. ewartiana* plants. The presence of the 4 other perennial grasses, *C. fallax*, *Aristida* spp., *H. contortus* and the weak perennial *P. effusum* were also noted. Accordingly, 40 *B. ewartiana* and variable numbers of the other perennial grasses were recorded when the permanent quadrats were established.

Commencing in November 1998, the position and size of tussocks of the selected perennial grasses were charted by recording their position and size in each quadrat within 4 grids each 25 x 25 cm ((Orr, Paton *et al.* 2004). Subsequent recordings were made annually in the late wet or early dry season when the survival and size of existing plants were recorded together with any seedling recruitment in each paddock.

Basal area of individual species was determined as the area occupied by all plants of individual species in the quadrat. Individual plant size was determined as the area covered by each plant and calculated as the total basal area per quadrat/the number of individual plants.

11.3.4 Statistical analysis

Line intercept data was either log (tuft basal area) or square root (% cover and tuft density) transformed. Treatment differences were tested using ANOVA in a randomized block design in GENSTAT using mean cover values from individual paddocks. Data from the single unreplicated exclosure in paddock 8 was not included in the analysis but is presented for comparison.

3-P tussock count data was square root transformed and treatment effects analysed using ANOVA with soil type as a factor, and paddock as a replication. Regression analyses were conducted by relating tuft basal area, linear tuft density, percentage cover and 3-P tussock density to GRASP estimates of utilisation rate meaned over all years or for individual years (Chapter 6).

Data from the permanent quadrats on plant density, recruitment, basal area and plant size were analysed as a one way ANOVA using GENSTAT. Plant survival was analysed using a proportional hazard survival model (Ash, O'Reagain *et al.* 2000)(Cox 1972).

11.4. Results

11.4.1 Effect of grazing treatment on grass basal cover

There was a strong treatment effect on cover: total perennial grass cover i.e. 3-P and *C. fallax* cover, was 3 to 4 times greater *($P<0.05$)* in the LSR than in the HSR, VAR or SOI strategies (Fig. 11.1). This was a direct reflection of the greater 3-P *($P<0.05$)* and *C. fallax* cover in the LSR relative to other treatments. Total cover in the R/Spell was intermediate *($P<0.05$)* between the LSR and other treatments but still only half that in the LSR. Total cover in the exclosure was greater than in the R/Spell but surprisingly, was less than in the LSR. Interestingly *C. fallax* cover in the exclosure was 2 to 3 times greater than in the other treatments suggesting that this species is relatively sensitive to grazing (Fig. 11.1).

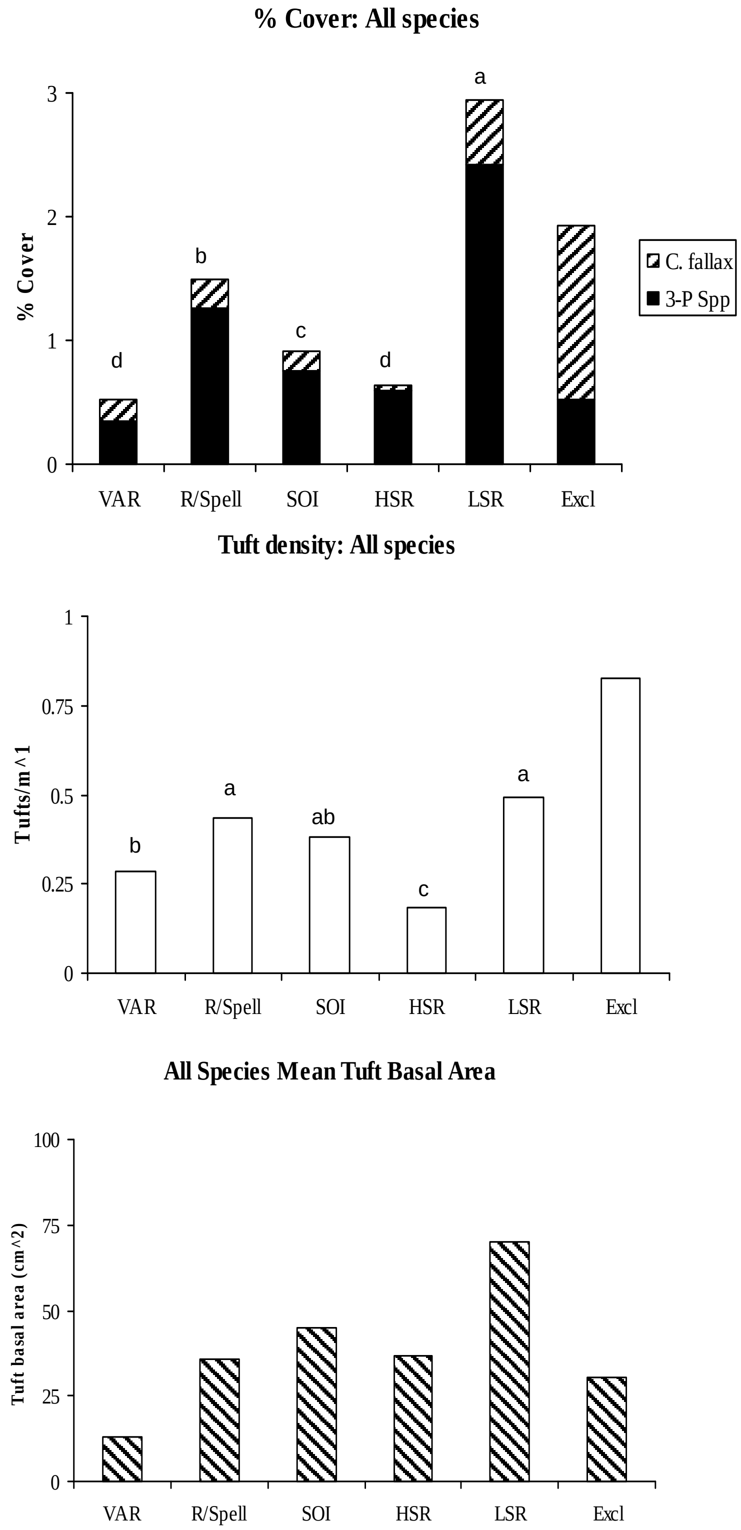


Figure 11.1: Mean percentage basal cover for 3-P species and *C. fallax* (top), tuft 'linear density' (middle) and tuft basal area for all species (bottom) across five treatments at Wambiana in late 2004. Exclosure data is included for comparison but was not statistically analysed. Bars with different letters are significantly different at the 5% level.

The greater perennial grass basal cover in the LSR reflected a combination of two factors. First, average tuft basal area (tuft size) was greatest in the LSR (mean: 70 cm^2) and markedly larger than in the VAR (12 cm^2) and HSR (36 cm^2) treatments, although these differences were not significant. Second, tuft linear density i.e. tufts per linear metre of transect, was significantly *(P<0.05)* greater in the LSR and R/Spell (mean: 0.464 tufts/m) than in either the VAR (0.283 tufts/m) or HSR (0.184 tufts/m) treatments. This equates to an average inter-tuft spacing of 2.02m and 5.43m for the LSR and HSR respectively. Perennial grass tussocks in the LSR were thus, in general, larger and spaced closer together than in the other treatments.

11.4.2 Relationship between basal cover and utilisation rate

There was no overall relationship between mean paddock utilisation rate (1998 – 2004) and 3-P tussock live basal area (LBA), tussock linear density or 3-P percentage basal cover measured in 2004. Similar results were obtained with *C. fallax*, although tussock linear density was negatively related to mean utilisation rate *(*R^2*= 42.0; P<0.025).*

However, 3-P tussock LBA, linear density and basal cover measured in 2004 were all negatively related *(P<0.05)* to the paddock utilisation rate for individual years between 1998/99 to 2001/02 (Fig. 11.2). For *C. fallax*, tussock LBA in 2004 was also negatively related *(*R^2*= 54.7 to 83.9)* to annual utilisation rate over the same period although tussock linear density was only negatively *(P<0.05)* related to utilisation rate in 2002/03 (R^2*= 43.9)* and 2003/04 (R^2*= 32.5).*

The results suggest that the utilisation rate in a particular year is of equal importance to the long-term average utilisation rate in determining 3-P cover. The results appear to suggest that high stocking rates have equally deleterious effects in wet e.g. 1998/99 and dry years e.g. 2001/02. However, utilisation rates in wetter years like 1999/00 (Fig. 6.3). were relatively low (<30%) and unlikely to have caused significant damage to basal cover In contrast, utilisation rates in 2001/02 were very high and exceeded 40% in the VAR, HSR and SOI strategies (Fig. 11.3). This suggests that the majority of damage occurred in 2001/02 when relatively high utilisation rates combined with low rainfall led to a sharp drop in 3-P cover in heavier stocked strategies like the VAR, SOI and HSR.

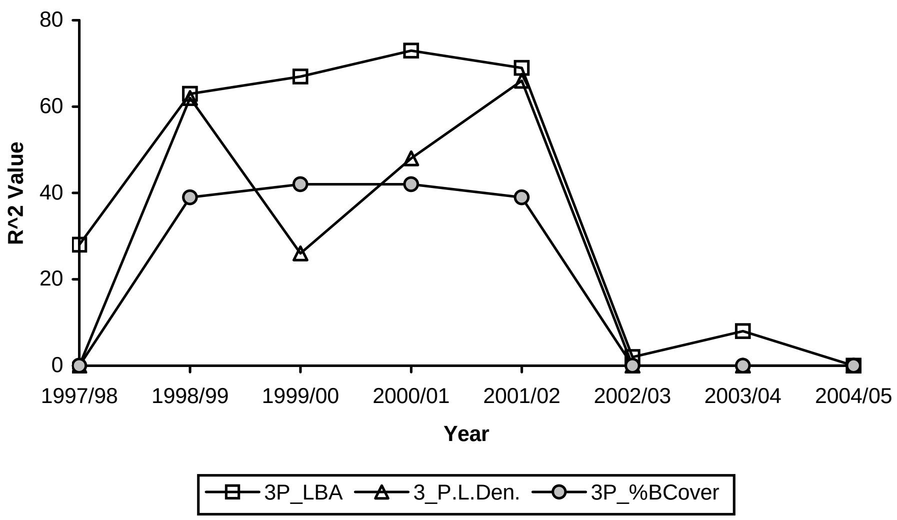


Figure 11.2: R^2 Values for the relation between 3-P tussock live basal area (LBA), 3-P linear density (L.Den) and 3-P percentage basal cover (% B.Cover) and GRASP predictions of annual utilisation rate in individual seasons from 1997/98 to 2004/05.

The fact that there was no relation between any of the 2004 basal cover variables and utilisation rates in the dry years following 2001/02 also suggests that treatment effects occurred in earlier years and utilisation rates in these later seasons had relatively little effect on pasture condition. Indeed, visual observations of the trial site were that much of the damage in the VAR and SOI strategies occurred in earlier years around 2001/02. The data supports this interpretation with a wide range in 3-P tussock LBAs, for example, occurring in later years over a relatively narrow range of utilisation rates.

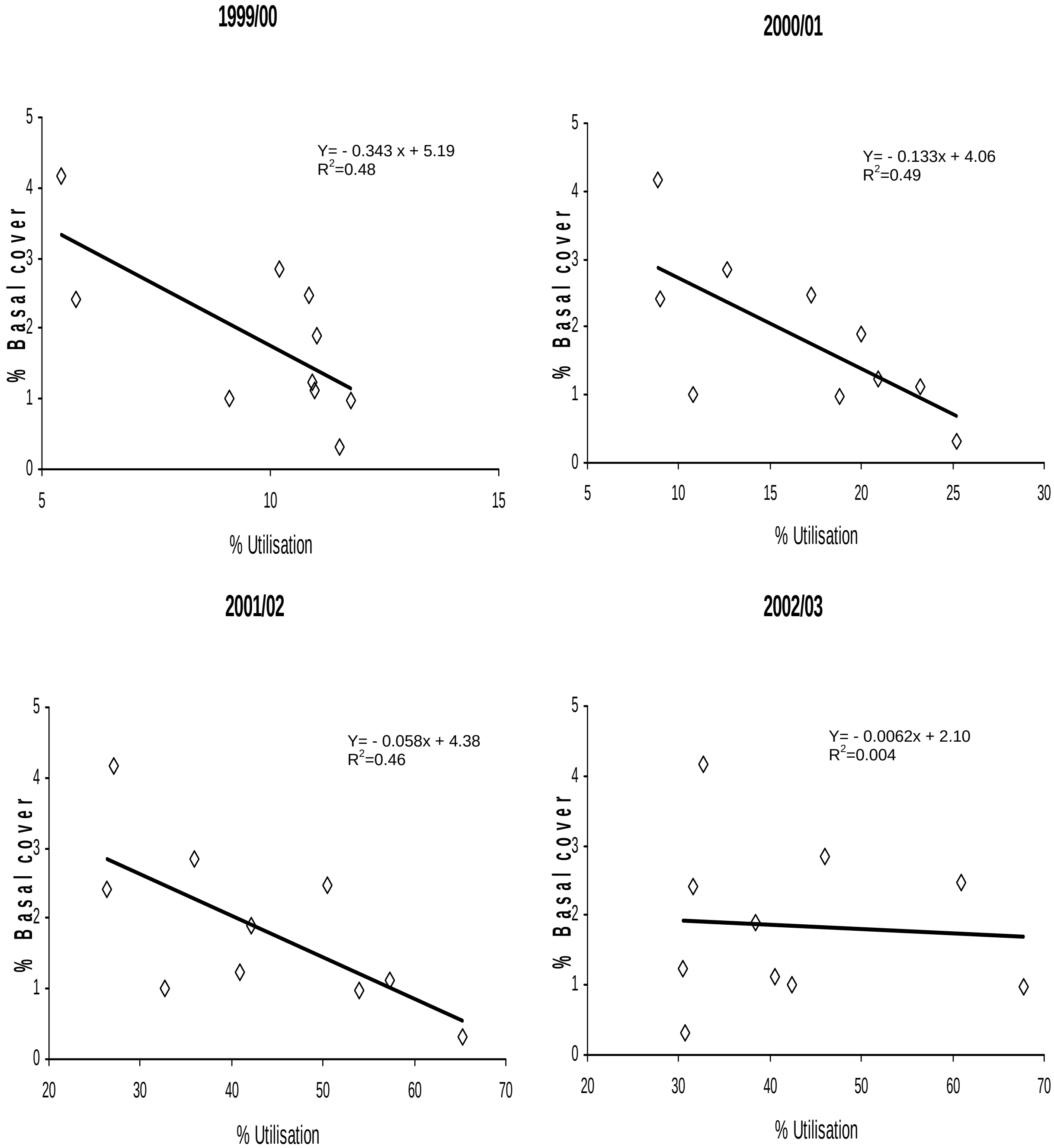


Figure 11.3: Relationship between 3-P percentage basal cover on Box soils in 2004 and GRASP predictions of pasture utilisation rate in a selection of different years. Note differences in scale of utilisation rate between years

In summary, these results suggest that it is not the *average* utilisation rate *per se* but rather the *timing* of a particular utilisation rate with regard to the season involved that is the primary determinant of pasture condition in terms of basal cover, tussock density and tussock LBA.

11.4.3 Effect of grazing strategy on 3-P tussock density

Grazing treatment had a significant (*P<0.05*) effect on mean tussock density: taken over all soil types, tussock density was greatest in the LSR (3.99/ m^2) and nearly three times greater than in the HSR (1.26/m^2). Tussock densities in the R/Spell, VAR and SOI were lower than in the LSR but still nearly two of more times greater (*P<0.05*) than in the HSR.

Table 11.1: Mean 3-P tussock density in April 2006 (meaned over all soil types) for five grazing strategies at Wambiana. Means not significantly different at the (P<0.05) level marked with the same letter.

Treatment	3-P Density (tussocks/m^2)
VAR	2.74 *ab*
R/Spell	3.25 *ab*
SOI	2.23 *b*
HSR	1.26 *c*
LSR	3.99 *a*

In terms of soil differences, mean 3-P tussock density was nearly three times greater *(P<0.001)* in the Box and heavy clays (mean: 3.68/m^2) than in the Ironbark (1.01/m^2). In the exclosure which is situated in the Box soil, 3-P tussock density (3.68/m^2) was similar to that measured in the R/Spell (3.69/m^2) but lower than that in the LSR (4.26/ m^2) for the same soil type.

11.4.4 Effect of utilisation rate on 3-P tussock density

3-P tussock density measured in 2006 declined as average utilisation rate (meaned over all years) increased for the Box (R^2= *62.9, P=0.004*) and to a lesser extent, the Ironbark soils (R^2= *36.7; P=0.037*). No relationship was apparent on the heavy clays (R^2= *31.0; P=0.055*) with a wide range of tussock densities occurring at similar mean utilisation rates below 25% (Fig. 11.4).

The variability in the relationship between utilisation rate and tussock density is not unexpected given that the utilisation rates are paddock averages and do not account for soil type differences. In practice, pasture utilisation varied markedly both between and within soil types and interacted strongly with rainfall and the year concerned (Chapter 6). Similarly, 3-P tussock densities *within* a single soil type varied markedly for similar utilisation rates according to the relative attractiveness and resilience of the monitoring site in question. These results confirm that average utilisation rates are not reliable predictors of grazing impact on or within individual soil types. Nevertheless, the results do show that high average rates of utilisation are likely to lead to a general decline in 3-P tussock density on most soils.

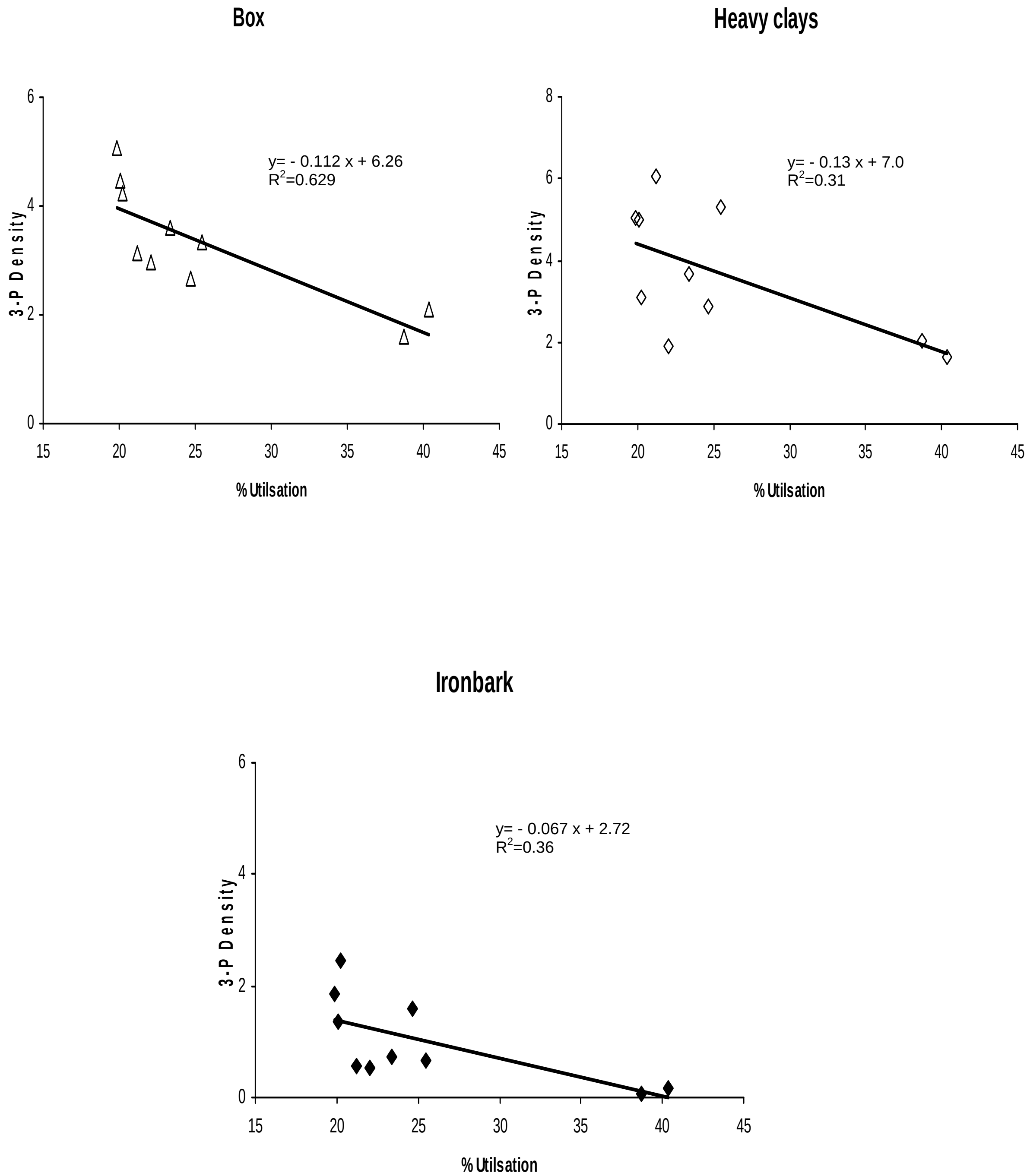


Figure 11.4: Relationship between 3-P tussock density (tussocks/m^2) in 2006 and average utilisation rate over all years for Box, heavy clays and Ironbark soils.

For individual years, 3-P density in the Box was more strongly correlated with annual utilisation rate in some seasons e.g. 1999/2000 and 2001/02 than in later years like 2003/04. This suggests that high utilisations have a greater impact in some years than in others and supports the contention that the *timing* of utilisation is possibly of equal importance to the *average* utilisation. As stated earlier, observations indicate that the decline in pasture condition in the VAR and SOI treatments occurred somewhat suddenly in 2001/02 rather than gradually over a longer period.

As with basal cover, the seasonal effects observed here are inconsistent: 1998-2000 was particularly wet while 2001/02 was characterized by an early start to the dry season in March 2002 and a subsequent 11 month drought. Superficially, this suggests that utilisation rates in wet years are of similar importance to those applied in dry years in determining pasture condition. However, scrutiny of the data shows that utilisation rates varied from 25 to 67% in 2001/02 but were restricted to a narrow range from 10 – 25% between 1998 and 2000. This lends support to the assertion that the 2001/02 high utilisation rates combined with below average rainfall had a major impact upon subsequent 3-P tussock density.

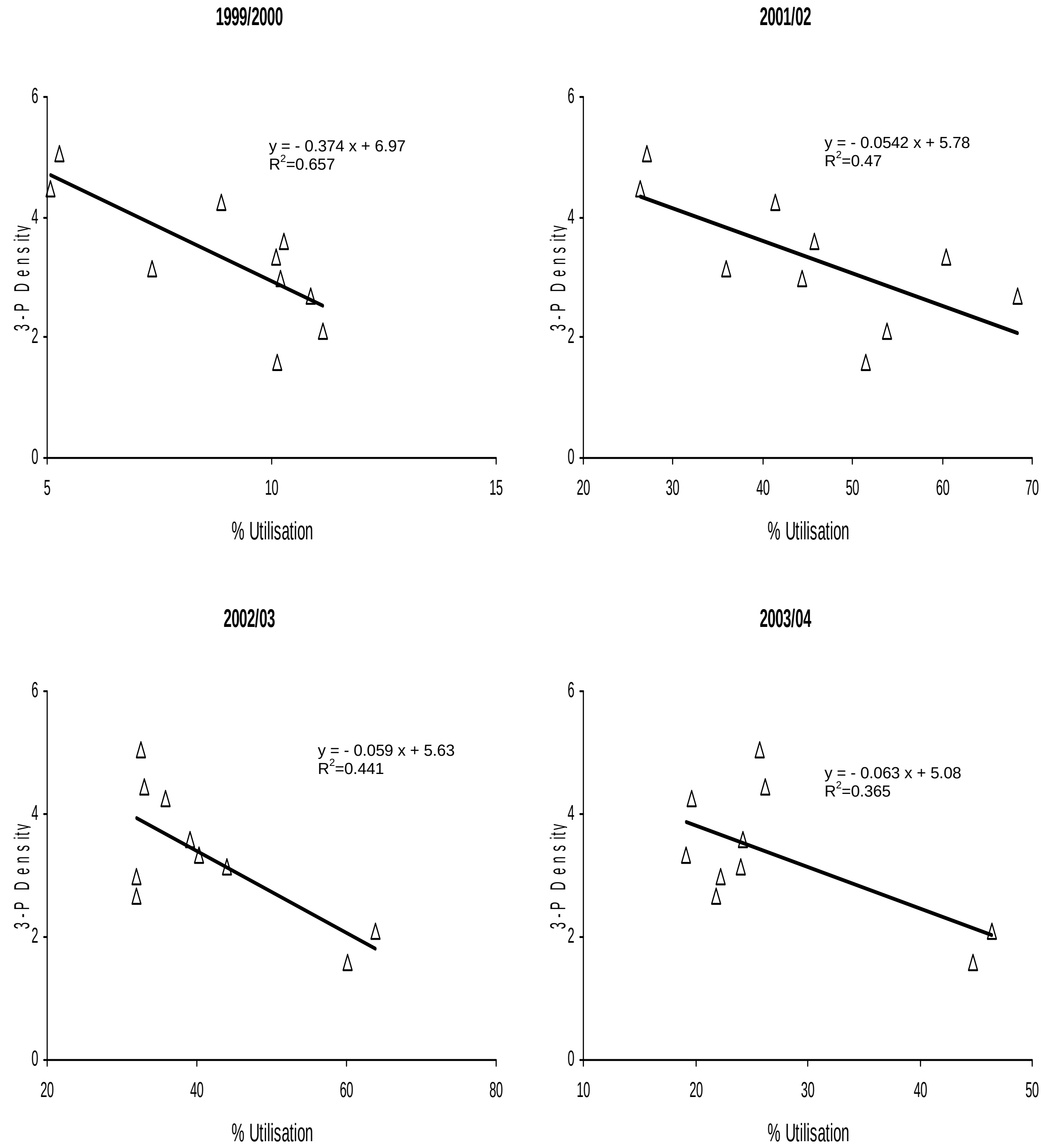


Figure 11.5: Relationship between 3-P tussock density (tussocks/m^2) in 2006 on the Box soil and average utilisation rate in a selection of four different years.

11.4.5 Plant demographics *(Contributed by David Orr)*

Plant density

There were no (*P>0.05*) treatment differences in plant density in the permanent quadrats between 1998 and 2006 for any of the 5 species considered (Fig 11.6). For *B. ewartiana*, density remained around 8 – 10 plants/m^2 from 1998 to 2003, before declining to *c.* 6 plants/m^2 in 2006. For *C. fallax*, density remained relatively constant at 4 – 5 plants/m^2 from 1998 to 2002 but thereafter declined to about 3 plants/m^2 in 2006.

In contrast, *Aristida, P. effusum* and *H. contortus* have all displayed large variations in density (Fig. 11.6). For example, *Aristida* density was 8 plants/m^2 in 1998 but declined gradually to 2004 and then dropped sharply from 2004 to 2005. Similarly, following the 1999 fire and good rains, *H. contortus* initially increased from < 1 plant/m^2 in 1998 to 5 plant/m^2 in 2000. Thereafter however, density declined to < 1 plant/m^2 in 2006. These changes in density in all species are largely related to changes in the survival of the original plants and to seedling recruitment.

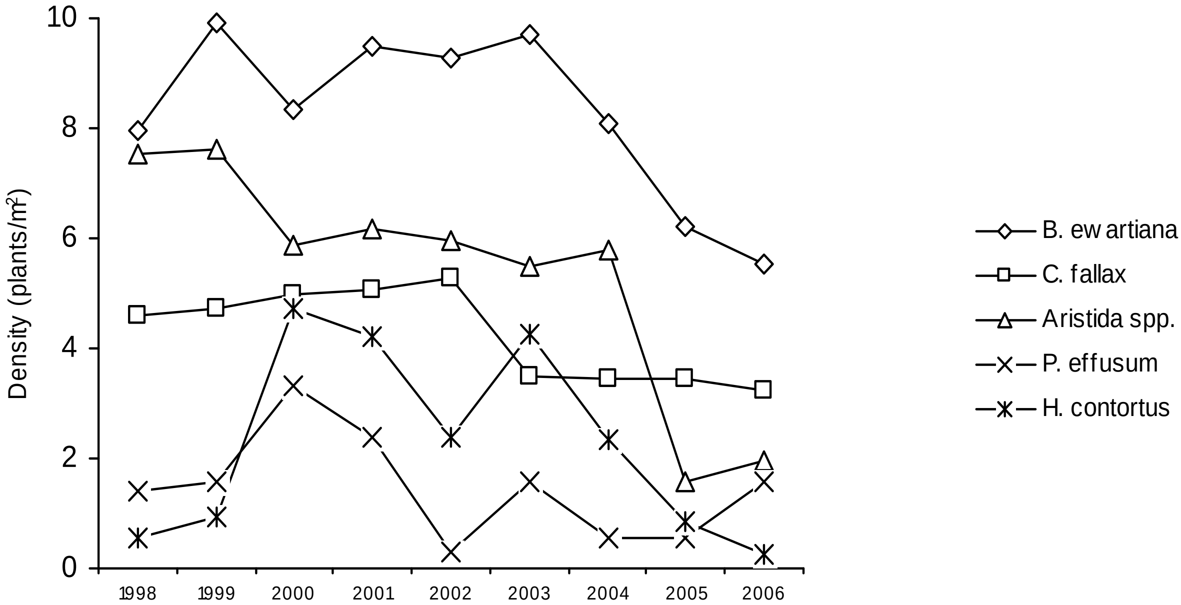


Figure 11.6: Changes in density of 5 perennial grasses (data meaned over 3 stocking rates) between 1998 and 2006 at Wambiana.

Plant survival

Survival of the original plants of all species declined markedly (P<0.05) between 1998 and 2006. Survival of *B. ewartiana* plants was significantly (P<0.05) lower in the heavy stocking than in the light stocking treatment. In contrast, the survival of *C. fallax* was greater (P<0.05) under heavy stocking (Fig. 11.7 a, b). Survival of the original *Aristida*, *P. effusum* and *H. contortus* plants was unaffected (P>0.05) by treatment (Fig. 11.7 c).

It is notable that approximately 55% the original *B. ewartiana* plants and 45% the original *C. fallax* plants survived to 2006. In contrast, all but one original *Aristida* plant and all *P. effusum* and *H. contortus* plants had died by 2003. These results agree with paddock observations and frequency trends (Chapter 9) which indicate large scale death of these three species in 2002/03.

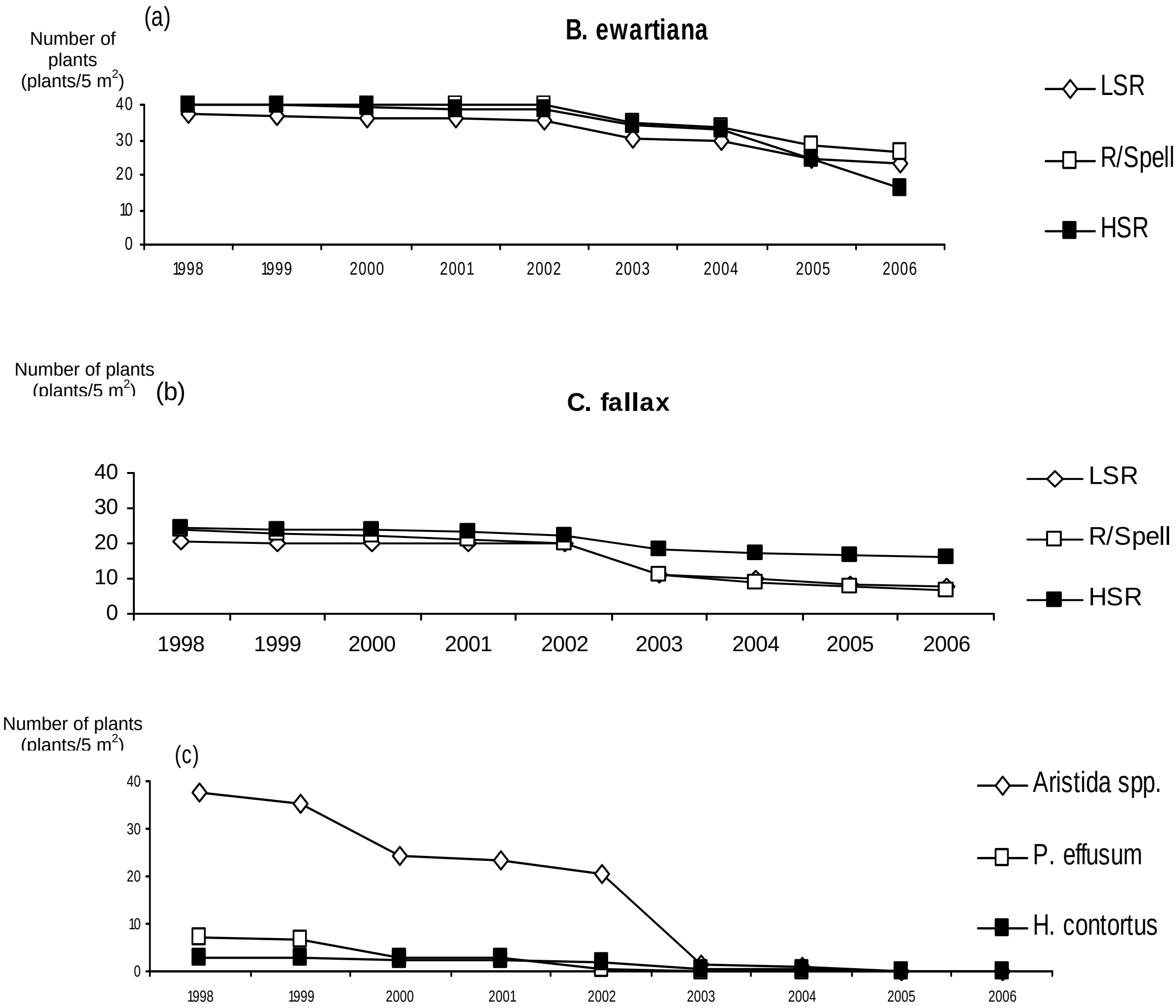


Figure 11.7: Changes in survival of (a) *B. ewartiana*, (b) *C. fallax* and, (c) *Aristida*, *P. effusum* and *H. contortus* (data meaned over 3 stocking rates) plants between 1998 and 2006 at Wambiana.

Basal area

There were no (*P>0.05*) treatment effects on the basal area of any of the 5 species between 1998 and 2006 (Fig. 11.8). *B. ewartiana* has been the major contributor to overall basal area with a large increase in basal area between 1999 and 2001, probably due to above average rainfall, and a large decline post 2002 due to drought.

The absence of a treatment effect on basal area is in direct contrast to the line intercept data recorded in 2004 and reported earlier (11.4.1). This discrepancy in results probably reflects the different sampling scales at which the two techniques were conducted. Based purely on scale, the line intercept data are probably a more accurate reflection of treatment effects than the permanent quadrats.

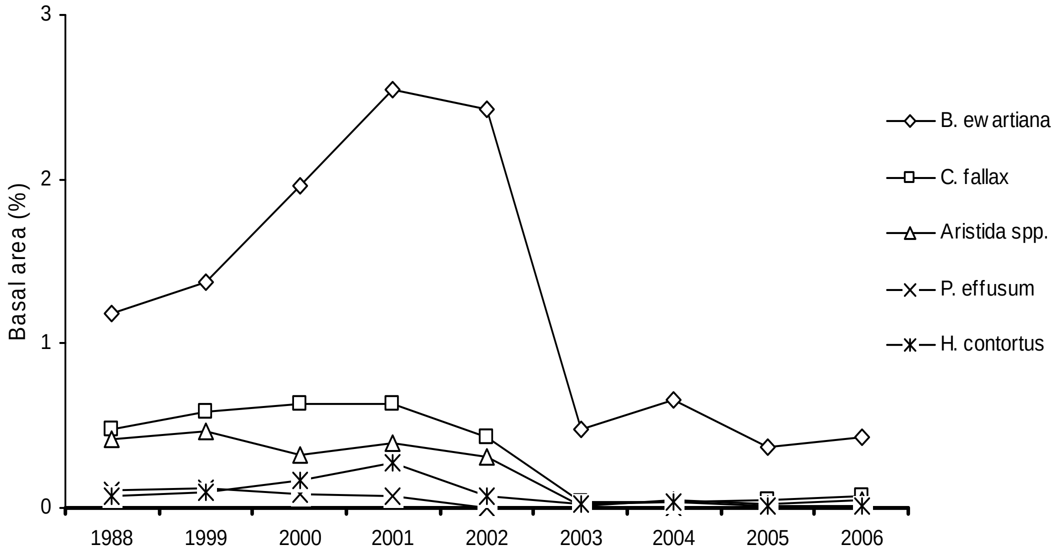


Figure 11.8: Changes in basal area of 5 perennial grasses (data meaned over 3 stocking rates) between 1998 and 2006 at Wambiana.

Recruitment

There were no (*P>0.05*) treatment differences in recruitment of any of the 5 species between 1999 and 2006 (Fig. 11.9). Recruitment of both *B. ewartiana* and *C. fallax* was consistently low (*c.* 0.5 - 2 and 0.5 - 1 seedling/m^2 respectively) across all years while recruitment of *Aristida* spp. and *H. contortus* has displayed large variation between years.

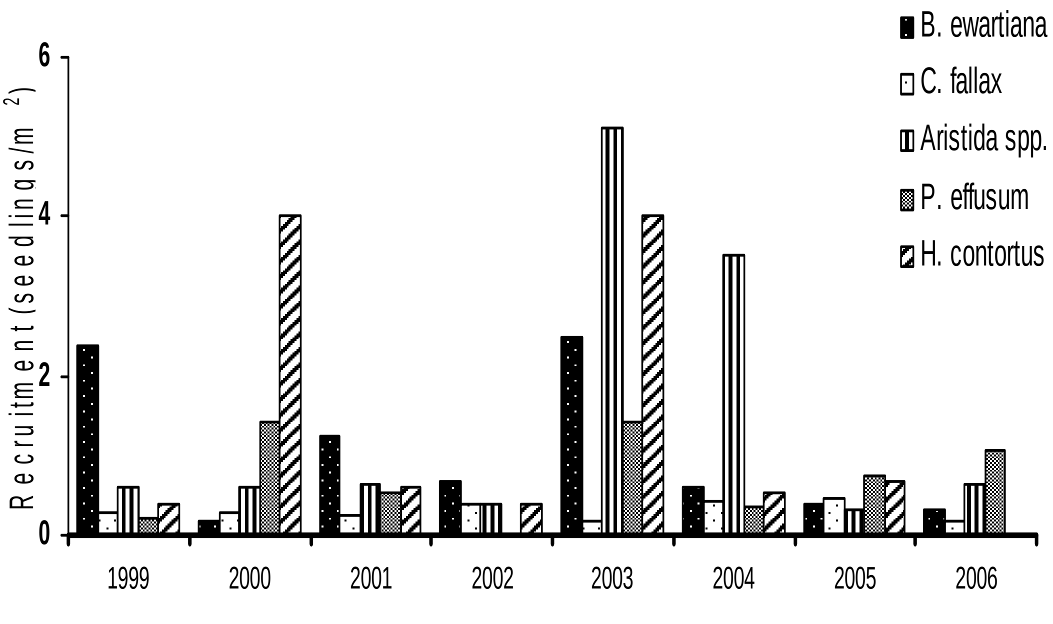


Figure 11.9: Seedling recruitment in 5 perennial grasses (data meaned over 3 stocking rates) between 1998 and 2006 at Wambiana.

11.5. Discussion

Basal cover of grasses in the SOI and VAR treatments was surprisingly low considering the relatively moderate *average* utilisation in these paddocks (Chapter 6) with cover being only marginally better than in the HSR. This suggests that significant damage to basal cover occurred in both former treatments through heavy stocking in the years preceding the 2002/03 drought. Importantly, by 2004 little recovery had occurred despite the subsequent lowering of stocking rates due to the lag-effect of heavy grazing and the reduced rainfall of later years. This suggests that applying very heavy stocking rates even in relatively good seasons can inflict long-term damage to basal cover particularly if these are followed by a prolonged period of below average rainfall.

Basal cover in the R/Spell was surprisingly low considering the well documented positive effects of wet-season spelling on pasture condition (Fig 11.1). The low cover in the R/Spell probably reflects the fact that during the wet season the grazed sections of this treatment were heavily stocked because of the spelling of the third section (Chapter 4). Heavy wet season utilisation, coupled with the lack of spelling of the Box areas that occurred because of the 2001 fire, would inevitably degrade pasture condition relative to the LSR. Nevertheless, the two wet season spells that did occur in the Box areas in 1997/98 and 2000/2001 appear to have partially ameliorated the effects of this heavy grazing, ensuring that basal cover was still markedly higher than in the HSR, VAR or SOI strategies.

The relatively lower cover of the exclosure in comparison to the LSR is also surprising but the data shows that while tuft density was very high, average tuft basal area in the exclosure was relatively low. Protection from grazing can lead to a decline in tuft density as plants become moribund, but total basal cover would presumably still increase or at least remain constant through the greater basal area of individual plants. The exclosure was open to marsupials but their density was unlikely to have caused any basal cover declines. The low exclosure cover might also reflect inherent soil differences and pre-trial grazing patterns but this cannot be tested given the absence of baseline data.

The study of population dynamics with the permanent quadrats revealed an initial overall lack of treatment differences for the species considered between 1998 and 2006. However, clear treatment effects are emerging and have recently become more evident. For example, a significant reduction in the survival of *B. ewartiana* in the HSR compared with the LSR and R/Spell has developed in the last 2 years. Similarly, the significant reduction in the survival of *C. fallax* in the LSR has only developed in the last 4 years. Overall, these results suggest that stronger treatment differences will emerge in the near future.

The permanent quadrat data also indicates major differences in the life cycles of the 5 grasses studied. Both *B. ewartiana* and *C. fallax* are relatively long lived with low annual recruitment rates but the effects of drought on plant survival were relatively minor. In contrast, *Aristida, P. effusum* and *H. contortus* are all relatively short lived and their presence in the pasture depends on seedling recruitment: they are accordingly strongly impacted upon by drought. The relatively large variation in plant densities reported here (Figure 11.1) are thus the result of large, annual variation in recruitment. Large variation in annual seedling recruitment for both *Aristida* and *H. contortus* (Orr 2004) has also been reported elsewhere in Queensland. These studies, as well as the present results, all emphasise the importance of maintaining perennial grasses in the pasture to minimize year to year fluctuations in cover and forage availability.

11.6. Summary

1. Basal cover of 3-P grasses measured in 2004 was 3-4 times greater in the LSR than in the SOI, VAR or HSR treatments. Basal cover in the R/Spell was intermediate between these levels but still only half that in the LSR. Mean tussock basal area and tussock density were also greater in the LSR than in the VAR or HSR treatments.

2. Basal cover was related to annual utilisation rate applied in earlier years but was not related to average long term utilisation rate. Evidence suggests that a major decline in basal cover occurred in the VAR, SOI and HSR strategies when heavy utilisation rates were applied immediately preceding the 2002/03 drought. Despite a subsequent drop in stocking rates, basal cover had still not recovered in the SOI and VAR strategies by late 2004.

3. The data suggests that the utilisation rate applied in particular years is of equal or greater importance than the long term average utilisation rate in determining pasture basal cover.

4. 3-P Tussock density measured in 2006 was strongly affected by treatment: tussock densities in the LSR and R/Spell (> 3.07/ m^2) were double those in the HSR (1.3/ m^2) with densities in the SOI, VAR being intermediate between these levels.

5. 3-P Tussock density declined on all soil types as long term average utilisation rates for paddocks increased. However, a large variation in response to utilisation rate occurred both within and between soil types.

6. Like basal cover, 3-P tussock density in 2006 was also more strongly correlated with utilisation rate in some years e.g. 2001/02 than in others e.g. 2004/05. This suggests that the major decline in density occurred when high utilisation rates were combined with low rainfall, as happened in the former season.

7. The fact that tussock densities in the SOI and VAR were significantly greater than in the HSR indicates that some recovery occurred and/or further damage was averted by the reduction in stocking rates in the former treatments post 2001/02.

8. 3-P tussock density appears to be determined both by the general long term utilisation rate (as happened in the HSR), and by the relative timing of short-term utilisation rates with seasonal conditions (as happened in the VAR and SOI strategies).

9. Plant demographic studies indicate that *B. ewartiana* and *C. fallax* are relatively long lived species with relatively little recruitment occurring between years. These results reinforce the importance of maintaining a healthy population of perennial species to reduce inter-annual variability in forage production

10. In conclusion, continuous set-stocking at a moderate stocking rate has been the most successful strategy in maximising pasture basal cover and 3-P tussock density. In contrast, constant heavy stocking and/or heavy utilisation in conjunction with low rainfall have inflicted significant damage upon these indices of pasture health. Wet season spelling appears to have some potential to ameliorate the effects of heavy utilisation but further investigation is required.

12. Seasonal and treatment effects on diet quality

12.1. Introduction

Diet quality is a major constraint to animal production in north Queensland with animals generally only maintaining or even losing weight in the dry season due to low forage quality. This seasonal variation in diet quality has been previously explored with fistulated cattle and is being documented in current MLA funded NIRS projects in north Queensland. However, the effect of grazing management, and in particular, stocking strategy, on diet quality has yet to be addressed and the interaction of management with seasonal and inter-annual rainfall variability is largely unknown. There are also few if any predictive equations to predict diet quality and hence LWG from environmental variables like soil moisture in the tropical savannas.

In this chapter we report the effects of rainfall and grazing strategy on the quality of diet selected by animals over a range of rainfall years from 1998 to 2006. A number of predictive equations are presented as well as data on dietary crude protein (CP), *in vivo* digestibility (IVD) and the proportion of non-grass forage species in the diet.

12.2. Objectives

1. Quantify diet quality across all grazing strategies to explain any observed treatment differences in animal production.
2. Monitor seasonal changes in diet quality through the season and across a range of rainfall years.
3. Develop predictive equations relating diet quality to management and environmental factors.

12.3. Procedure

12.3.1 Methodology

Faecal samples were collected approximately every three weeks from July 1998 to the present date. In the first year, only the HSR and the LSR paddocks were sampled but thereafter all paddocks on the trial were individually sampled. In all cases five to ten fresh dung pats were sub-sampled and bulked for each paddock. Faecal samples were stored in plastic bags in the shade at ambient temperature in the field. Samples were then thoroughly mixed, sub-sampled and frozen within 6 to 7 hours of collection. Frozen samples were stored and then analysed for dietary crude protein (CP), *in vivo* digestibility (IVD) and the proportion of non-grass using Near Infra Red Reflectometry (NIRS) at the CSIRO's Davies Laboratory in Townsville (Coates 2004) Faecal samples were dried in a forced draft oven at 65 degrees Celsius, ground in a FOSS Tecator Cyclotec laboratory mill fitted with a 1 mm screen and redried at 65 degrees before loading into spinning sample cups for analysis. NIR spectra (Log 1/R, wavelengths 400-2500 nm) were obtained using a FOSS 6500 scanning monochromator. Predictions were made using calibration equations developed by Coates (2004).

12.3.2 Statistical analysis

To explore the relationship between diet quality and soil moisture, dietary CP and IVD estimates were meaned across all paddocks for individual sampling dates over all years of the trial. Data were then regressed against GRASP estimates (Chapter 6) of plant available soil water in the Box and Ironbark soils and a combined Growth Index value (Box and Ironbark) for each date. As described previously, GRASP was parameterised for the relevant soil types and then run using daily rainfall data for the site. Linear regression analysis was conducted on GENSTAT using each sampling date as a data point.

At the seasonal level, mean CP and IVD levels for the wet and dry seasons were calculated for each treatment. The dry season (DS) was defined as the 1 June to 1 December each year with the remaining months termed the wet season (WS). Treatment comparisons were conducted using ANOVA in GENTSTAT as described previously. Regression analyses of DS or WS quality estimates against rainfall, GI Days and various pasture variables were conducted as described above using 'paddock' as the sampling unit.

12.4. Results

12.4.1 Seasonal changes in diet quality

Dietary Crude Protein and In Vivo Digestibility

Dietary quality followed a distinct seasonal trend in all years with quality being lowest in the dry season and highest in the wet season. Dietary IVD varied from a high of around 60 to 65% early in the wet season to a low of only 45 to 50% digestibility in the dry. Similarly, dietary CP peaked at levels of 10 to 12% CP in the early wet but averaged only about 4% in the dry season. Dietary CP in the dry season was often below maintenance levels (*c.* 5 %) for a non-reproducing animal, and without urea supplementation would lead to weight loss (Figs. 12.1 & 12.2: data only shown for 4 representative years).

These seasonal trends were obviously driven by rainfall as is clearly evident from the tight linkage of both CP and IVD with Growth index days (Fig.12.1). Thus, diet quality increased sharply with the first rains in the early wet season with a three to fourfold increase in CP being common. Thereafter CP and IVD declined slightly but generally remained at an elevated level for the duration of the wet season, the length of which varied according to the duration of the rains. With the onset of the dry season, dietary quality dropped sharply as the soil dried out.

Most of the variability (R^2= 51-59%) in dietary CP and IVD was explained by either plant available soil water or the pasture Growth Index, meaned for Box and Ironbark soils (Table 12.1). Dietary CP and IVD were also related to a lesser extent to soil water on the ironbark soils (R^2 = 47%; *P<0.001*).

Table 12.1: Predictive equations for the relationship between NIRS predictions of crude protein (CP) and in vivo digestibility (IVD) over seven years with GRASP based growth index for box and ironbark soils ($GIndex_{BI}$) and soil water(in mm) for the box soil ($SoilWater_{Box}$)

Var.	**Equation**	R^2	**P**
CP	$4.44 + 4.97*GIndex_{BI}$	58	***P<0.001***
CP	$4.46 + 0.0395*SoilWater_{Box}$	59	***P<0.001***
IVD	$49.46 + 10.00*GIndex_{BI}$	51	***P<0.001***
IVD	$49.37 + 0.0832*SoilWater_{Box}$	57	***P<0.001***

Major differences were also evident between years with both the height and duration of the wet season peak in dietary quality varying with the amount and distribution of rainfall. Inclusion of 'year' as a factor in the equations described above for growth index (GI) Days accounted for another 15 to 20% of the variability in the data.

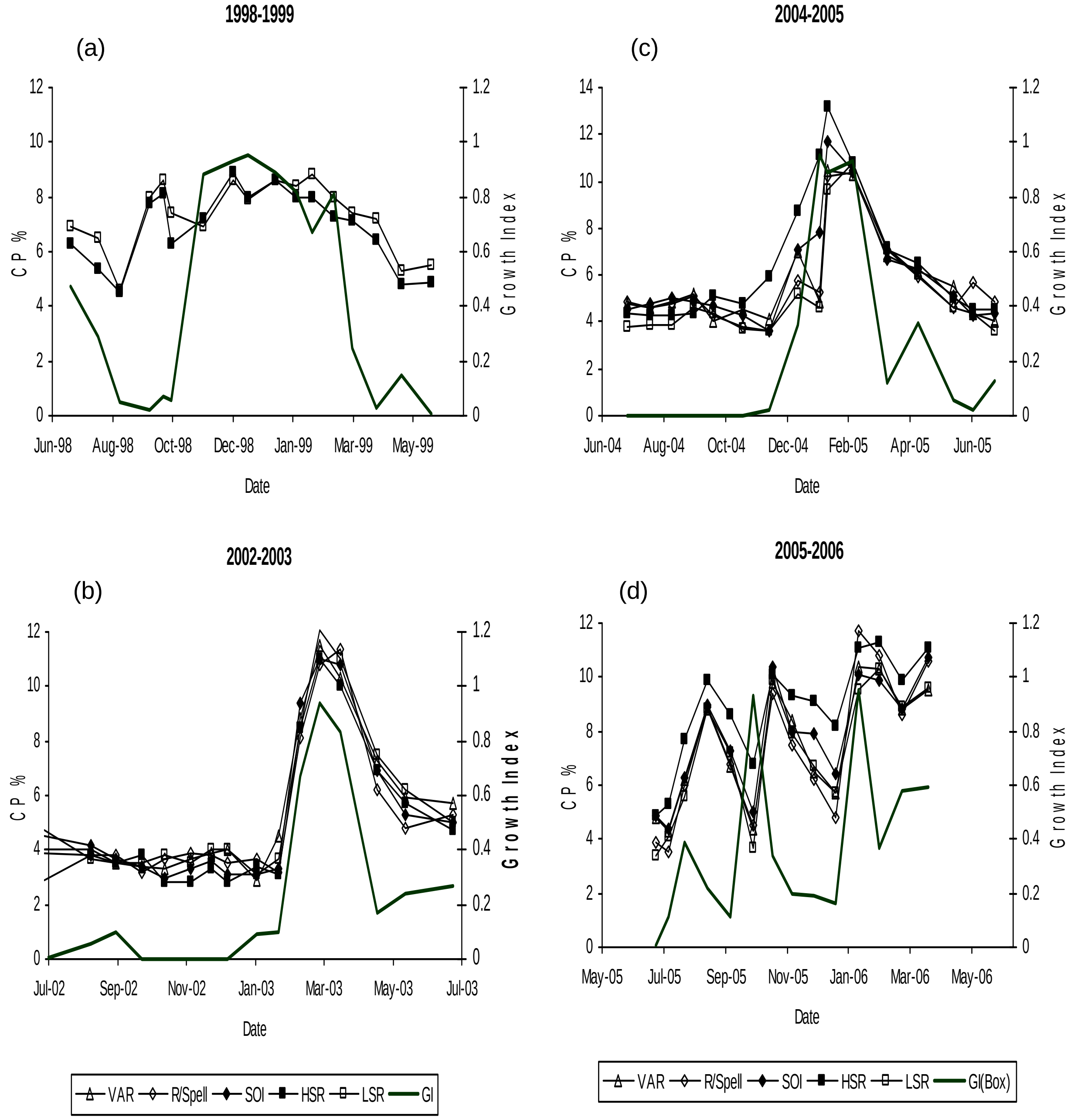


Figure 12.1: Seasonal changes in NIRS predictions of crude protein percentage (CP) and pasture growth index (GI) over four representative seasons at Wambiana. Treatment abbreviations as before**.**

These between year differences are clearly evident from a comparison of the seasonal changes in CP and IVD in different rainfall years (Fig. 12.1). For example, in the 1999-98 season, dietary quality remained consistently high through the year with dietary CP only dropping below maintenance levels for 1 or 2 months of the season. In contrast, in 2002/03 the peak in dietary CP and IVD was restricted to a few weeks in February-March resulting in diets being below maintenance CP levels for most of the remaining months of that year.

The influence of rainfall distribution on diet quality is also particularly evident when comparing the 2004/05 and the 2005/06 seasons. Although both seasons received the same total precipitation (470 mm), the 2004/05 rainfall was poorly distributed with about 60% falling in a single weekend in late January 2005. Overall, dietary quality was generally low with the wet season peak confined to a few weeks between January and February 2005. In contrast, the rains in 2005/06 were well distributed resulting in relatively high dietary quality through the season (Fig.12.1 & 12.2). Differences between years were also apparent in the magnitude of the peak in diet quality achieved in the wet season. For example, dietary CP reached a peak of over 12% in the 2004/05 season, compared to only about 9% in 1998/99.

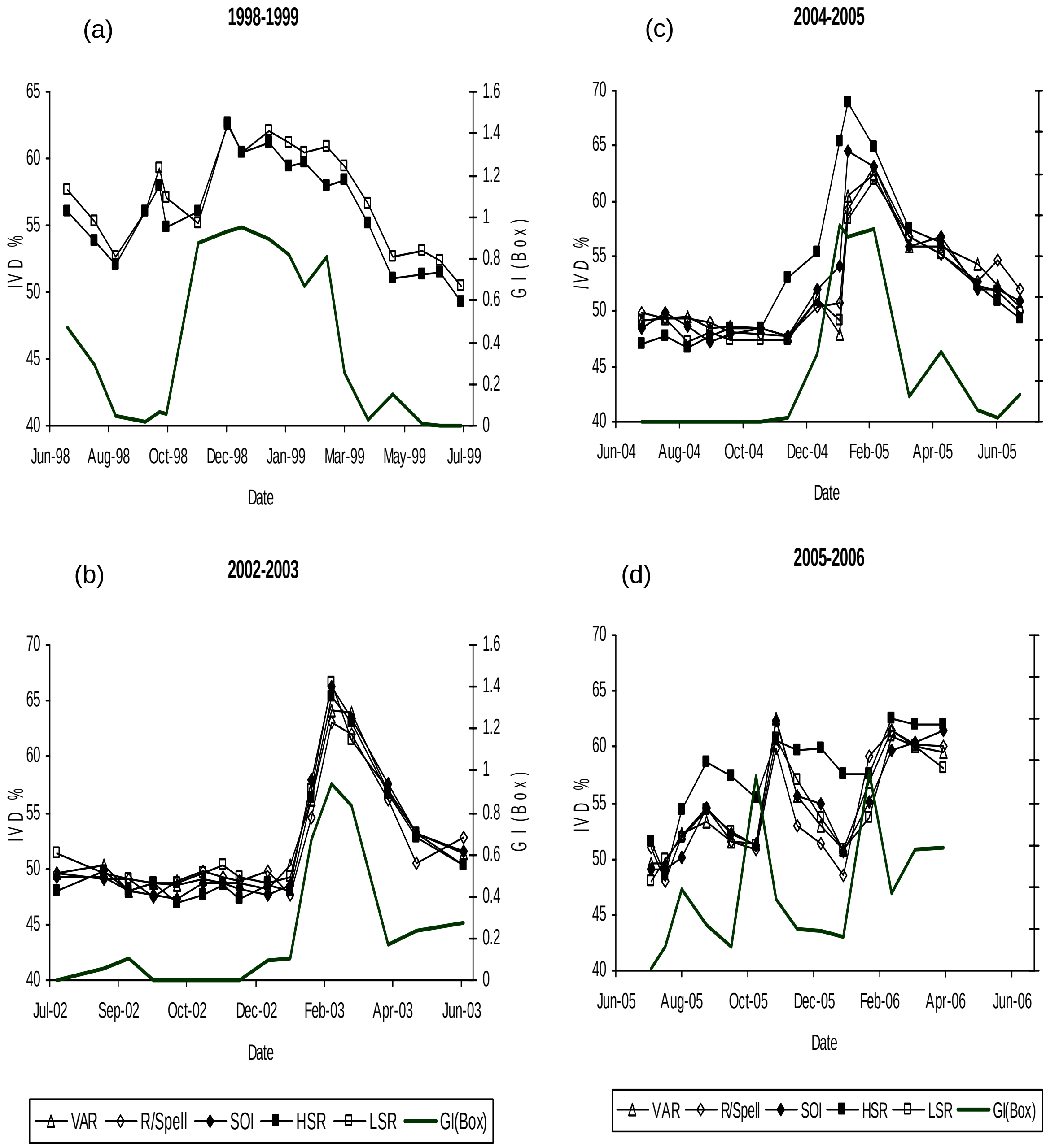


Figure 12.2: Seasonal changes in NIRS predictions of *in vivo* digestibility (IVD) and pasture growth index (GI) over four representative seasons at Wambiana

12.4.2 Proportion of non-grass in diets

The amount of non-grass (NG) present in diets also showed a general seasonal trend, although this was only loosely coupled to soil moisture and growing conditions (Fig.12.3). In general, as the dry season progressed, the % of NG in the diet slowly increased but dropped sharply with the first rains as new pasture growth emerged. In the mid to late wet season however, the % of NG rose again in a distinct fashion, presumably through increased consumption of legumes etc, before dropping again to early dry season levels.

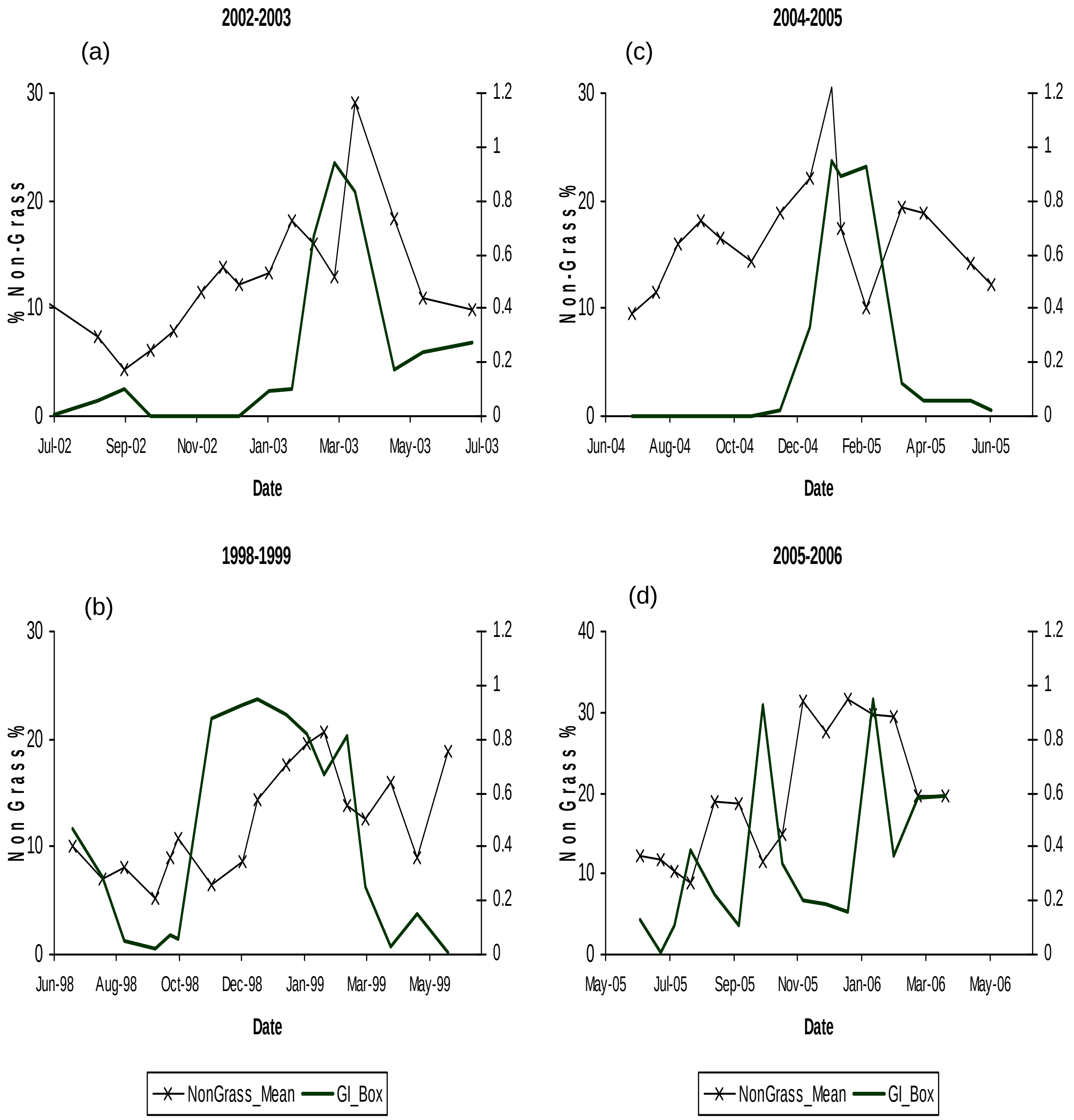


Figure 12.3: Seasonal changes in NIRS predictions of the percentage non grass in diets and the pasture growth index (GI) over four representative seasons at Wambiana.

12.4.3 Determinants of wet and dry season dietary quality

Growth index days and rainfall

As might be expected, dry season (DS) dietary CP (r=0.675) and IVD (r=0.408) were both positively correlated (*P<0.001)* with dry season rainfall. However, the number of DS Growth Index days ($GIDays_{DS}$) was the best single predictor of dry season CP and IVD *(*R^2*=60%; P<0.001).* Predictability of DS diet quality was further improved by inclusion of TSDM at the start of the dry season in the equation with CP and IVD appearing to decline with increasing TSDM (Table 12.2).

Wet season diet CP was correlated with WS rainfall but the best relationship was again with total GIDays which explained 36% of the variation (*P<0.001)* in the data (Table 12.2)*.* Dietary IVD in the wet season was also positively related (R^2=*17 %*) to the yield of annuals at the end of the wet, but was unrelated to any other variables.

Table 12.2: Predictive equations for the relationship between dry season (DS) and wet season (WS) NIRS predictions of crude protein (CP) and in vivo digestibility (IVD), with growth index days (GI Days) and total standing dry matter (TSDM): (SOD=start of dry, EOD=end of dry).

Var.	Equation	R^2	P
CP_{DS}	$3.74 + 0.0489*GIDays_{DS}$	60	***P<0.001***
CP_{DS}	$4.48+0.0489*GIDays_{DS} - 0.000279*TSDM_{SOD}$	81	***P<0.001***
CP_{DS}	$4.30+0.0518*GIDays_{DS} - 0.000357*TSDM_{EOD}$	80	***P<0.001***
IVD_{DS}	$47.44 + 0.1048* GIDays_{DS}$	60	***P<0.001***
IVD_{DS}	$48.36+0.1049*GIDays_{DS} - 0.000348*TSDM_{SOD}$	67	***P<0.001***
CP_{WS}	$5.385+0.0411 *GIDays_{TOTAL}$	36	***P<0.001***

Impact of utilisation rate on diet quality
Utilisation rate had a negative impact (*P<0.001)* on overall DS diet quality with CP (R^2=*17 %;*) and IVD (R^2=*30 %*) declining as utilisation rates increased. Wet season CP (R^2=*17 %*) was also negatively related to utilisation rate. When analysed on the basis of individual years*,* dry and wet season dietary IVD were both negatively related to utilisation rate at the paddock level for the first four years of the trial. All equations developed incorporating utilisation rate with the pasture Growth Index, or with different pasture variables were non significant.

Relationship between diet quality and percentage non-grass
There was a strong relationship between the % of NG in the diet and WS dietary CP (R^2=56; *P<0.001*) and, to a lesser extent, wet season IVD (R^2=29; *P<0.001).* In the dry season, the % NG in diets was also a relatively important determinant of CP (R^2=26; P<0.001), but not dietary IVD.

12.4.4 Treatment effects on dietary quality

Statistical comparisons were made between all grazing treatments, but for clarity results are only presented for the HSR and LSR strategies as these covered the extremes of utilisation and pasture availabilities experienced through the trial.

Compared to soil moisture and pasture growth index, the effects of treatment on diet quality were relatively minor. Distinct treatment differences were nevertheless evident in most years, but these effects changed markedly with time as the grazing trial progressed. From 1998/99 to 2003/04 both dry and wet season mean CP and IVD were consistently higher in the LSR than the HSR strategy with these differences being significant *(P<0.05)* in two of the five years (Fig. 12.4). Differences between the HSR and the LSR for individual season means ranged from 0.21 to 1.16% points for CP and 0.67 to 1.94% points for IVD.

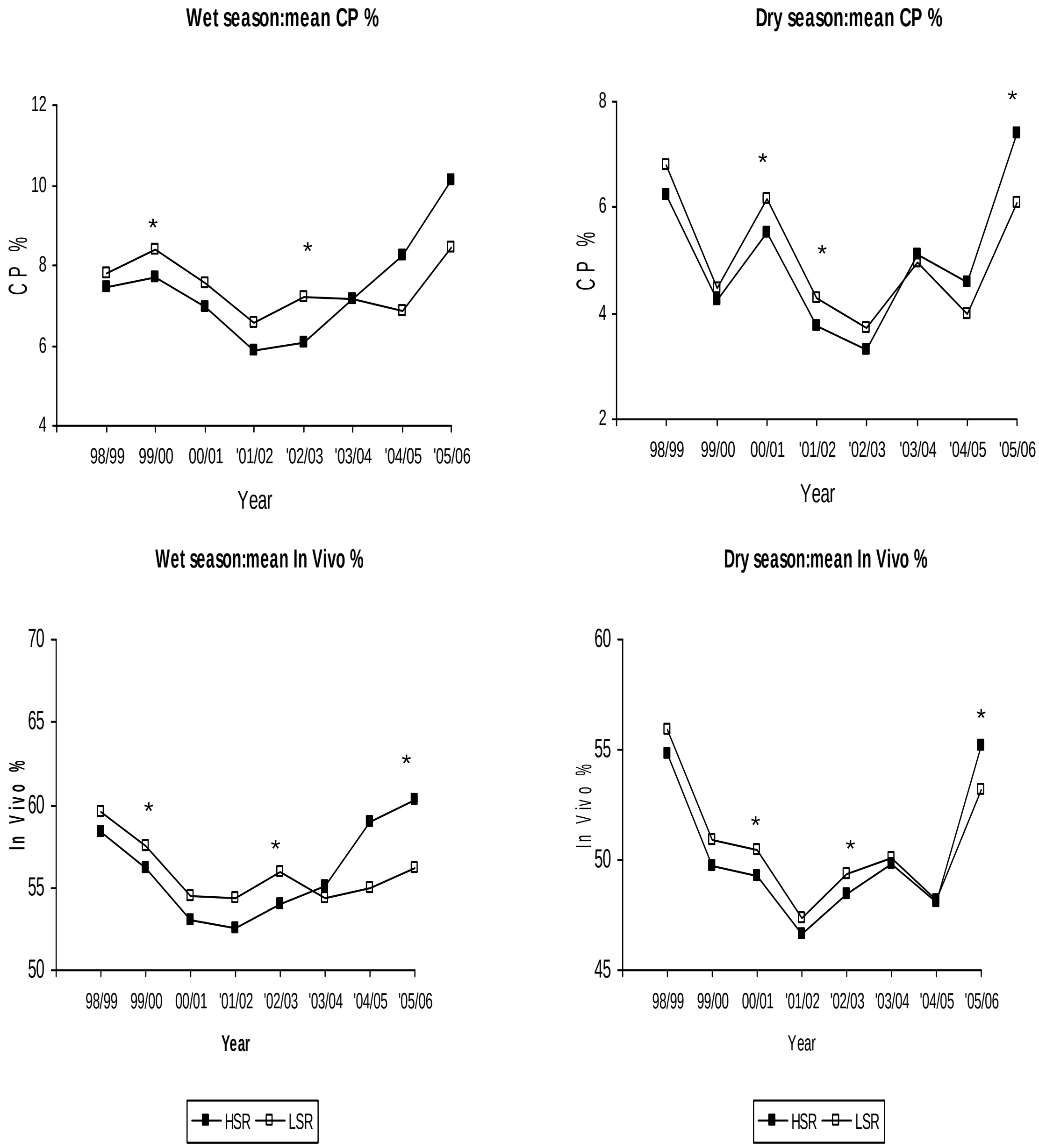


Fig. 12.4 Comparison of NIRS predictions of mean crude protein (CP) and *in vivo* digestibility (IVD) of diets selected in the wet and dry seasons under heavy (HSR) and light stocking rates (LSR) over different years at Wambiana. (*denotes significant differences between treatments within the same year: *P<0.05*).

In 2003/04 however, no treatment differences in diet quality were evident (Fig. 12.4). Thereafter, an apparent switch occurred with wet and dry season CP and IVD generally being higher in the HSR than in the LSR in both 2004/05 and 2005/06 *(P<0.05*).

12.4.5 Relationship between LWG and diet quality

Dry season live weight gain (LWG_{DS}) was significantly related to diet quality:

$$LWG_{DS} = -533.6 + 10.96*IVD_{DS} \quad (R^2=41\ \%;\ P<0.001)$$
$$LWG_{DS} = -95.1 + 22.18*\ CP_{DS} \quad (R^2=37\ \%;\ P<0.001).$$

Total LWG over the whole season (LWG) was also strongly related to dry season diet quality:

$$LWG = -313.5 + 8.62*IVD_{DS} \quad (R^2=32\ \%;\ P<0.001)$$
$$LWG = 32.5 + 17.21*\ CP_{DS} \quad (R^2=23\ \%;\ P<0.001).$$

Total LWG was only weakly related to wet season IVD (R^2=9 %; *P<0.004*) but showed a stronger relationship with wet season CP:

$$LWG= -33.8 + 20.70*\ CP_{WS}\ (R^2=28\ \%;\ P<0.001).$$

Surprisingly wet season live weight gain was not related to diet quality.

12.5. Discussion

The seasonal patterns in diet quality observed in the northern tropics are obviously a direct result of rainfall and its effects upon plant growth and forage quality. Typically, with wetting up of the soil after the dry season a large nitrogen (N) pulse is released; this N comes from accumulated atmospheric dust over the dry season, death of microbes in the drought, photo-oxidation of organic material and the opening of clay minerals through drying, improving access by microbes to organic matter between the clay sheets. Plants rapidly access this N, and produce high quality green growth for grazing. Aside from its concentrated N content, this fresh growth is undiluted young leaf, giving a high diet quality.

As the season advances however, soil N availability is reduced through immobilisation in micro-organisms and plant tissue. Plant N also becomes diluted through general pasture growth, while sward structure also changes with increasing stemminess and leaf maturation. Accordingly, diet quality often declines slowly as the wet season progresses, despite continued rain.

Near the end of the wet season, forage quality drops rapidly as perennial grasses translocate N and carbohydrate reserves to underground storage organs. At the same time, drying of the soil also initiates leaf senescence and the annual grasses and forbs, die and dry out. Diet quality is lowest in the dry season as animals are forced to consume low quality items like dead leaf and stem. Quality often declines further as the dry progresses through depletion of the better quality items and weathering and loss of nutrients from standing feed.

In comparison to dietary CP and IVD, the seasonal patterns in NG consumption are relatively difficult to interpret, in part because the index does not differentiate between different C_3 plant groups i.e. forbs, legumes or woody browse. However, given the general absence of legumes and forbs in the late dry season the increased % of NG commonly observed at this stage most probably reflects browsing of woody shrubs, saplings and/or consumption of fallen leaves to supplement diet quality. Browse typically has a high N content with for example, fresh *E. brownii* and *A. harpophylla* leaves having N contents of 1.16% and 1.53% respectively (O'Reagain *unpublished data*). Conversely, browse species have relatively high levels of fibre and are frequently protected by tannins and other secondary chemicals, which may depress digestibility and adversely affect animal production.

With the break of the wet however, fresh green forage would be readily available and the % NG in diets dropped sharply, as would be expected if the animals were seeking out fresh grass leaf.

Work on *Stylosanthes* pastures also indicates that cattle select strongly for grass during the early wet (Coates 1996). The rise in the proportion of NG in the mid to late wet season presumably occurred through the increased consumption of legumes and forbs, as observed by Coates (1996) and (Ash and McIvor 1998) in oversown pastures. Animals presumably select for legumes in the late wet in an attempt to compensate for declining grass N levels. Thereafter, the % NG in the diet generally declined into the dry, presumably because of the senescence of annual legumes and forbs and/or leaf drop in perennial species.

Given the close coupling between diet quality and rainfall, it is it is logical that forage quality is directly related to the GI index. However, the GI is unlikely to explain all the variation in diet quality for a number of reasons: First, lag effects are likely to occur at the scale of days to a few weeks in the response of the pasture to changes in soil moisture. For example, while the GI may suddenly increase due to a fall of rain, pasture green-up typically takes up to a week or more to occur, or may not even occur. Pastures can also remain green for some time into dry spells giving unusually high estimates of diet quality on relatively dry soils. At the other extreme, quality can be depressed when soils are saturated for long periods due to swards becoming rank and stemmy and N dilution in large pasture yields.

Second, GRASP uses spatially averaged rainfall across the site and hence only gives an ‘average’ Growth Index for a single soil type. Accordingly, it cannot capture the spatial rainfall variability that inevitably occurs or its interaction with the different soil types across the site. Faecal samples in comparison are an integrated sample of forage across the whole site, from all soil types grazed over the previous 48 to 72 hours.

Third, soil N availability varies markedly between years due to differences in N mineralisation and cycling, and these yearly variations have a major impact upon diet quality. Typically, soil N availability peaks in droughts, resulting in a major pulse in available N in the seasons(s) that immediately follow. In contrast, N availability usually declines with a run of good seasons as N is immobilised in microbes and plant material. An important factor responsible for the year to year variation in diet quality could thus be the recent rainfall history of a site and in particular, the length and severity of intervening dry seasons.

Print 12: Rainfall was the major determinant of diet quality: cattle in the VAR treatment grazing ‘green pick’ on a heavy clay soil following unseasonable showers in August 2005.

The interaction of management with rainfall is also likely to have a substantial effect on forage quality. In the short term, this will be due to changes in sward structure with short leafy swards, giving higher dietary quality than taller, stemmy swards. Carry-over of old herbage from previous seasons could also depress diet quality through its effects upon bite quality. In the longer term, management induced changes in species composition can have profound effects on forage quality, depending upon the species involved. These changes will ultimately also impact upon soil N cycling, through a change in the quality and quantity of plant litter.

The present results confirm that management, in terms of the stocking strategy applied, is also an important determinant of diet quality. In the short term at least, this largely was a function of stocking rate with diet quality being higher under light than under heavy stocking, at least for the first five years of the trial. In these seasons pasture TSDM was generally abundant in all treatments (Chapter 10) and physical i.e. sward structure, limitations to intake were unlikely to have occurred. Accordingly, the higher diet quality in the LSR may be attributed to the reduced competition between animals for the higher quality items within the sward such as young leaf, legumes, forbs etc. The negative relationship observed between diet quality and mean utilisation rate supports the contention that animals under heavy stocking are forced to utilise more of the pasture and cannot be as selective as those in lightly stocked paddocks.

In the later years when diet quality was apparently higher under heavy stocking, pastures yields were extremely low in HSR paddocks. Any new pasture growth that did occur in response to rain would have been easily accessible, and undiluted by poorer quality components like stem or dead material. On some occasions e.g. February 2005, large flushes of annual grasses and forbs further improved diet quality. These conditions would have occurred in the HSR paddocks in the 2004/05 wet season as well as through the entire 2005/06 season, possibly facilitating higher diet quality. It is important to note nevertheless, that actual DM intakes would have been extremely low and these animals only survived through the dry season with M8U supplementation.

The higher levels of CP in the HSR in the 2004/05 dry season is difficult to explain as little rain fell during this period and grass forage was almost non-existent. These high CP levels could result from browsing, or alternatively, may simply be distortion of readings resulting from the feeding of M8U late in the dry season. Interestingly, there was no treatment difference in IVD at this stage, which may reflect the increased fibre levels associated with browse.

Compared to the overwhelming effect of rainfall on diet quality, the treatment differences recorded here of *c.* 1% for CP and IVD appear relatively minor. Nevertheless these small differences in quality would have major impacts upon LWG in these low quality forage environments, through their effects on passage rate and hence the intake of digestible energy. The present data confirms this with diet quality explaining a substantial amount of the variation in annual LWG.

12.6. Conclusions

1. Diet quality followed a distinct seasonal trend and was lowest in the dry season and highest in the wet. Dietary CP and IVD varied from a peak of *c.*12% and *c.*60- 65% respectively in the wet, to lows of *c.*4% and 45-50% respectively, in the dry season.

2. Seasonal trends were closely coupled with soil moisture and varied markedly between years depending on rainfall distribution. For example, CP levels in the 1998/99 season were below maintenance requirements (5%) for only two months compared to nine months in 2002/03. Marked differences also occurred between years in terms of the magnitude of the peak in wet season and the rate of fall? in dry season diet quality.

3. Seasonal trends in the percentage of non-grass (NG) in the diet were less obvious but still broadly linked to rainfall. Overall, the % of NG increased in the late dry season due to browsing of woody species and in the mid-late wet season due to the consumption of legumes and forbs. Dietary CP in the wet and dry, and IVD in the wet season were positively related to the % NG in the diet.

4. Treatment effects on diet quality were also observed with diet quality declining as pasture utilisation rates increased. For the first five years of the trial dietary CP and IVD were lower in the HSR than in the LSR, due to greater competition for higher quality forage items. In the last two years however, diet quality tended to be higher in the HSR due to the shortness of these pastures. Nevertheless, HSR animals required extensive dry season supplementation with M8U to remain alive.

5. Dietary quality was strongly correlated with soil moisture with a pasture Growth Index explaining about 60% of the variability in diet quality data. 'Year' explained a further 15 – 20% of data variability, indicating that other management and environmental factors e.g. plant available N, were also important in determining diet quality.

6. Overall, diet quality was not related in any meaningful way to any of the measured variables of pasture yield or composition. However, dry season diet quality appeared to decline with increasing pasture TSDM while wet season CP appeared to be positively related to the yield of annual grasses in the pasture. Both factors however, require further investigation.

13. Economic performance of different grazing strategies

13.1. Introduction

Determining the effect of different grazing strategies on animal production and resource condition is a vital step in developing sustainable grazing strategies for the northern savannas. However, a crucial element for the managers who have to implement these strategies is their relative economic performance. In this chapter an economic analysis of the different grazing strategies based on their performance over nine different grazing seasons at Wambiana is presented. The relatively short term nature of this data and the fact that the data was derived from non-reproductive animals is emphasised. In particular, the readers' attention is drawn to the importance of the underlying assumptions in any economic analysis and the major effect that these have on outcomes.

13.2. Objectives

The objectives of this section were to determine the:

- Marginal value of increased stocking rates under different interest rate, season and price premium scenarios
- Gross margins and accumulated cash surpluses of the different grazing strategies over the period of the grazing trial.

13.3. Procedure

13.3.1 Gross margin analysis

Beef produced per strategy/annum was calculated from the difference in total fasted mass of all animals in a paddock at the start and end of the grazing season. Where animals (fillers) had been added or removed during the season e.g. in the SOI strategy, their total weight gain or loss was computed separately and added to the total mass of beef produced in the paddock (Table 13.1). Animals were valued at $1.80/kg at the start of the season on the assumption that younger steers attract a price premium relative to older animals. At the end of the season (May), animals were valued at either $1.80/kg or $1.60/kg depending upon condition score (Table 13.1). This assumption was based on sale returns for the trial which indicated an approximate price premium of about $0.20/kg for better condition animals. Cattle removed in mid-season to reduce stocking rates, as happened in the SOI in November 2001 or the R/Spell in late 2003, were valued at the lower price due to their relatively plain (unfinished) condition.

Variable costs were derived from supplement consumption per strategy (meaned over both paddocks) but vaccination or HGP costs were not considered. Dry season urea was priced at $0.55/kg (2005/06) or $0.45/ kg (other years), wet season P at $0.78/kg and M8U (delivered) at $0.52/kg. The cost of feeding 'Weaner Plus P' to a small group of animals in the late dry of 2001 was $37 per head and was proportionally allocated to the relevant paddocks. An estimated agistment cost of $2.20 per beast per week was substituted for the costs of hay feeding in Paddock 4 in late 2004 as hay feeding was not considered a realistic option for graziers.

Interest costs on livestock capital were calculated according to the total value of livestock entering a paddock at the start of the season i.e. total mass * $1.80/kg. A range of interest rates were tested but the default was 10%. This imputed interest cost may be viewed as the potential value of that capital if it were to be withdrawn from livestock and used for other purposes such as reducing overdraft (B. Holmes, *pers.comm.*,DPI&F, Townsville)

13.3.2 Marginal analysis of increasing stocking rates

Marginal analysis of the return per extra large stock unit (LSU) per 100 ha of the increased stocking rates in the heavy stocking rate (HSR) relative to the light stocking rate (LSR) strategy were conducted across all years of the trial in the following manner. First, the increase in the value of beef produced was calculated from the annual difference in the value of beef produced in these two treatments. Second, the increase in variable and interest costs through applying heavy stocking was calculated. The marginal return per LSU was then calculated from the total change in gross margin divided by the difference in LSUs in the two treatments.

Sensitivity analysis on the effects of different interest rates on livestock capital and condition-based price premiums for marketed cattle on the marginal returns of running extra LSU were also conducted. Simulations were run for a range of scenarios involving all combinations of interest rate (0, 5, 10, 15 and 20%) and price premium (0, 5, 10, 15 and 20 c/kg). Results for different scenarios are presented as the margin per LSU meaned over all years, as well as separately for wet (1997/8 to 2001/02) and dry years (2002/03 to 2005/06).

13.4. Results

13.4.1 Marginal analysis of high vs. low stocking rates

In the first four years of the trial, there was a clear economic advantage to heavy stocking, with estimated margins of around $183 per extra LSU above that in the LSR (Fig. 13.1). This resulted from the relatively low variable costs, the lack of any price penalty for heavier stocking and the relatively high levels of animal production per unit area in the heavier stocked strategies in these wetter years. Moreover, treatment effects on pasture composition had yet to emerge.

This situation changed drastically in 2001/02 when the advent of the drier years saw a sharp drop in marginal returns with estimated losses of about negative $200 per extra LSU. This occurred because of the high variable costs caused by drought feeding, the price penalties incurred for poorer condition animals and the relatively large drop in production per unit area that occurred in the HSR in drier years. These negative margins continued to slowly decline and averaged about negative $ 280/annum over the next three seasons.

In 2005/06, margins dropped even further to reach a low of negative $640 per LSU. This is somewhat surprising considering that the season not only had the same rainfall (470 mm) as the previous year but that this rainfall was also far better distributed. The reduction in stocking rate in the HSR in May 2005 should also have improved margins through reduced variable costs and improved individual animal production.

In reality the HSR was still penalized in 2005/06 by the costs of drought feeding, price penalties and reduced production per unit area, despite having a stocking rate only about a third heavier than that in the LSR. These factors strongly suggest that treatment effects on pasture production documented in earlier chapters were finally impacting upon secondary production. Conventional wisdom amongst certain graziers suggests that this trend might be reversed with the return of better rainfall years but this remains to be tested.

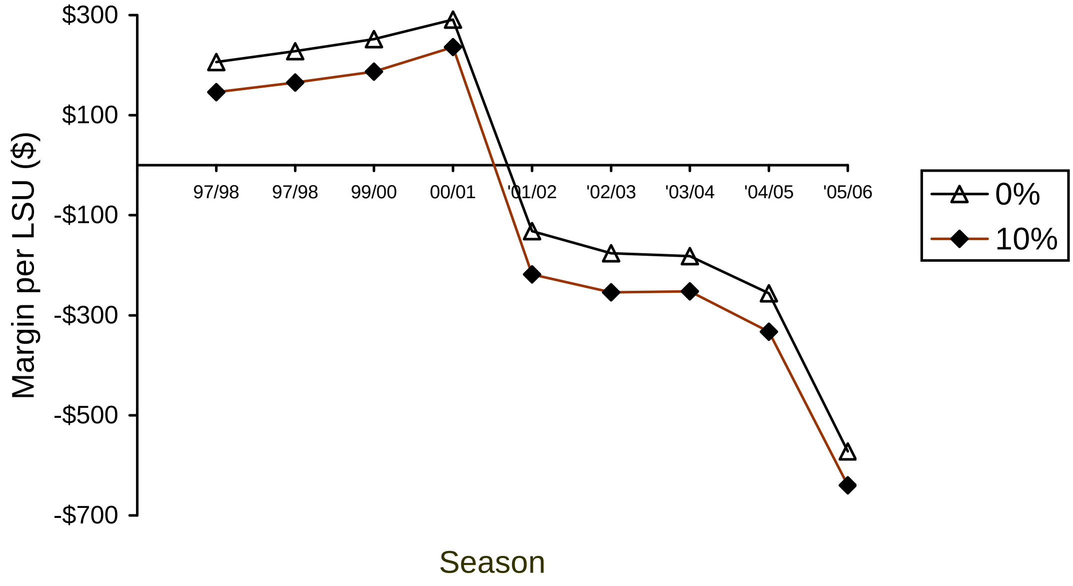


Figure 13.1: Marginal return per LSU per 100 ha for heavy versus light stocking at 0% and 10% interest on livestock capital at Wambiana for all years. See text for details.

13.4.2 Sensitivity to different interest rates and price differentials

When meaned over all years of the trial, heavy stocking nearly always resulted in a negative margin per extra LSU over that applied in the HSR. i.e. with the possible exception of the zero interest, no-price differential scenario, there was no financial advantage to running extra animals (Fig. 13.2). For example, even at a 0% interest on livestock capital and a price differential of $0.10c/kg, each extra LSU in the HSR diminished the potential total gross margin/100 ha by at least $100. The negative margins became larger as interest rates rose and the price differential for better condition animals increased. Thus at a 10% interest rate and a $0.20/kg price differential, each extra LSU above that in the LSR decreased the total gross margin by more than $200 per 100 ha.

In dry years, a similar pattern was observed, except that margins per extra LSU were always negative, irrespective of how favourable interest rates were or whether prices were linked to animal condition. In dry years, the drought feeding costs associated with heavy stocking are a major determinant of profitability and, given that animal condition is likely to be poor and impose price penalties, losses of nearly $300 per extra LSU could easily be expected.

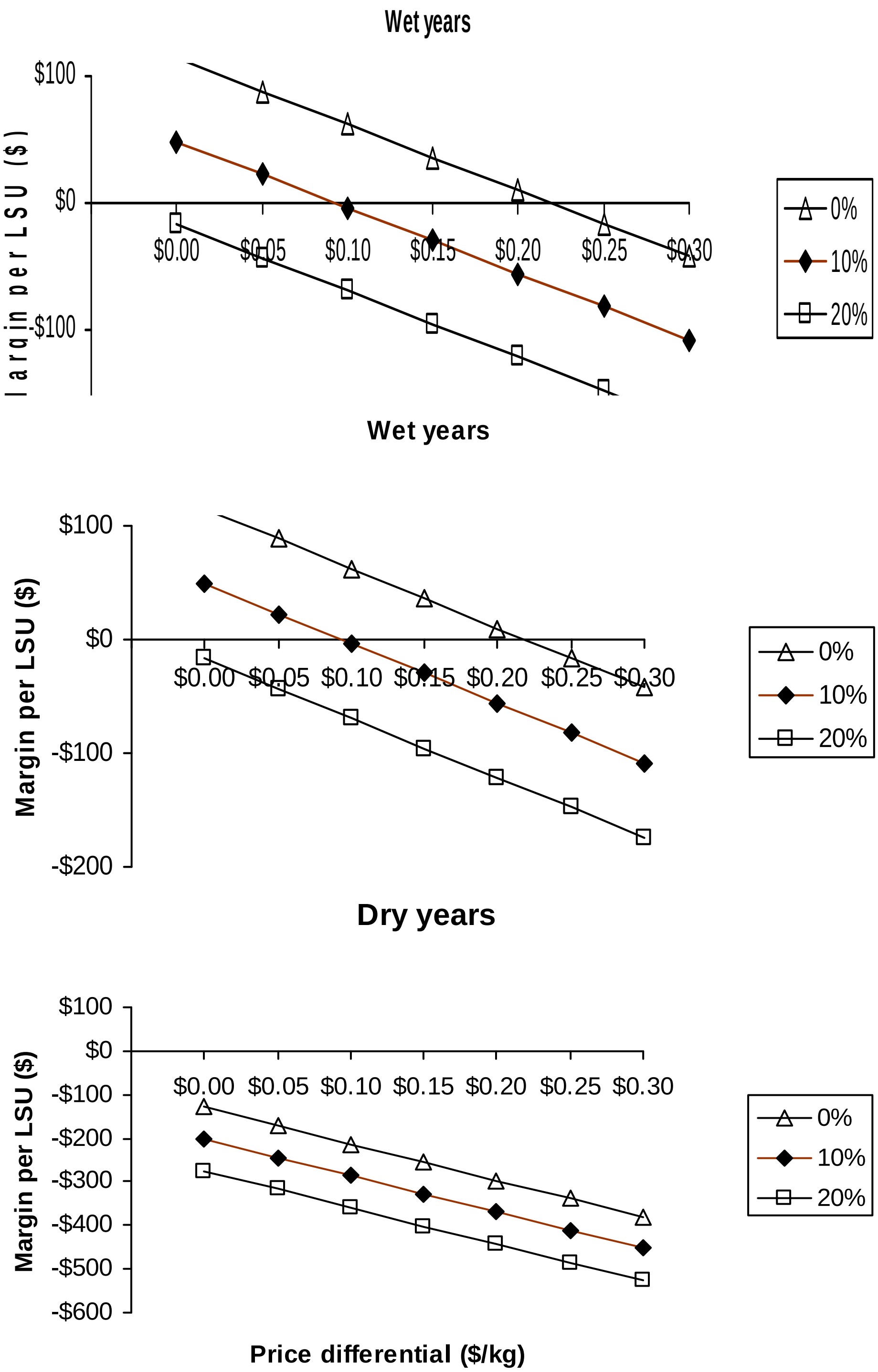


Figure 13.2: Marginal return per LSU per 100 ha for heavy versus light stocking over different interest rate and price differential scenarios at Wambiana for all years (top), wet years (middle) and dry years (bottom). See text for details.

The only conditions where running stocking rates above those in the LSR was shown to pay was in wet years, when (1) interest rates were <10% and the price differential for better condition cattle was <$0.10/kg or (2) when interest rates were zero and the price differential was <$0.20 or less per kg.

It is important to note that firstly, these wet years were exceptional both in the sequence in which they occurred and in their distribution of rainfall. Secondly and more importantly, these years occurred at the start of the trial prior to any treatment effects emerging. It is possible that in other wet years, the slope of these lines could be substantially steeper due to pasture degradation and an overall decline in productive capacity.

13.4.3 Gross margins of different grazing strategies

Gross margins (GM) varied markedly between years from *c.* $5000 per 100 ha in the best years (2000/01) with predicted losses of more than -$2000 per 100 ha occurring in the worst years (Fig. 13.3). These differences obviously reflect the large variation in rainfall and hence LWG and carrying capacity between years.

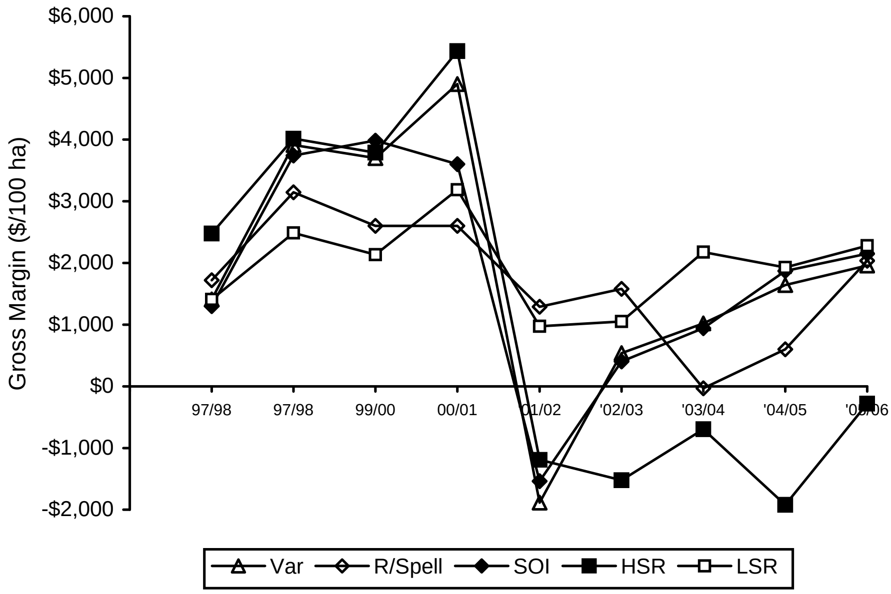


Figure 13.3: Gross margin ($) per 100 ha for five different grazing strategies at Wambiana from 1997/98 to 2005/06. Interest at 10% and price differential based on condition score

There were also major differences in GM between grazing strategies both within and between years. In the earlier, wetter years (1997 – 2001) the heavier stocked strategies (HSR, VAR, SOI) had far higher gross margins than the R/Spell or LSR strategy. These differences were relatively substantial with, for example, the HSR earning about $1627 more per annum than the LSR over this period. The superior performance of the heavily stocked strategies in these years occurred because firstly, these years were exceptionally good and stocking rate effects on animal condition were relatively muted with all treatments receiving the same price/kg despite obvious differences in live weight. Secondly the variable costs of running these larger animal numbers were very small due to the abundance of forage and the fact that no drought feeding was required. Thirdly, the trial had only just started and treatment effects on yield and pasture composition had not emerged

With the onset of dry years in 2001/02 however, gross margins dropped in all treatments and major changes occurred in the relative profitability of the different strategies. While the decline in

GM in 2001/02 was minor in the R/Spell and LSR, margins plummeted to a net loss of about \$1500 in the SOI, VAR and HSR treatments from a profit of *c.* \$3500 per 100 ha the previous season. Thus from 2001/02 onwards the LSR consistently delivered profit margins as good as or even far better (2003/04) than the other strategies. Margins remained relatively high in the LSR through these dry years partly because of the superior prices obtained for heavier, better condition animals but more importantly, because of the low variable and interest costs of this strategy.

Initially, GMs in the R/Spell were slightly better in these dry years than those in the LSR due to a combination of good individual animal performance and the marginally greater stocking rate (Fig.13.3). Unfortunately, the carryover effects of the 2001 fire resulted in the consistent heavy grazing of the two grazed sections of this strategy. This heavy grazing, coupled with the poor seasons, resulted in a shortage of forage which compromised LWG and also precipitated the forced sale of relatively poor condition animals in November 2003. Accordingly, GMs in the R/Spell were relatively low in both 2003/04 and 2004/05 but had recovered to be second highest (\$2035) in 2005/06.

The sharp decline in GM in the heavier stocked strategies in 2001/02 occurred for a number of reasons: first, stocking rate had a distinct impact on condition score triggering price penalties for the lighter animals in heavier stocked treatments. Second, LWG/ha declined with poorer rainfall, sharply reducing the margin above interest costs on livestock capital. In the SOI strategy, the negative GM also reflected the decision to reduce stocking rates in November 2001 when poor condition filler animals were sold at a net loss.

Nevertheless, in 2002/03 margins recovered strongly in both the SOI and VAR as a direct result of the decision to cut stocking rates in both strategies. At these stocking rates individual animal performance improved, allowing both strategies to achieve the same price premiums as those in the LSR. Critically, lower stocking rates meant that expensive drought feeding was not required and interest costs on livestock capital were reduced.

In stark contrast, maintaining heavy stocking rates in the HSR resulted in a consistently negative GM between 2001/02 and 2005/06 because of high interest costs on larger animal numbers and the high variable costs resulting from drought feeding. Gross margins have also remained low in the HSR due to the price penalties imposed upon poorer condition animals. These high costs and price penalties will probably continue at least for the next year given the current lack of pasture (August 2006) and the possibility of further declines carrying capacity in this treatment.

13.4.4 Accumulated cash surplus under different grazing strategies

As might be expected from the GM analysis, the heavier stocked strategies made rapid initial gains in accumulated cash surplus (ACS) in the earlier wetter seasons, so that by 2000/01 the HSR has an ACS \$6000 greater than in the LSR (Fig. 13.4). Thereafter however, ACS steadily declined in the HSR as the strategy ran at a consistent loss through the dry years. In contrast, ACS grew steadily with time in the LSR and R/Spell and in 2003/04 both strategies equalled, and thereafter exceeded, accumulated cash surplus in the HSR.

In the VAR and SOI strategies there was a clear financial benefit of running extra stock in the earlier wetter years. However, this benefit was neutralised by the losses incurred through forced sales and/or reduced poor animal performance at the beginning of the dry years. Accordingly, ACS in the SOI and VAR strategies declined to similar levels to that in the LSR in 2001/02. Nevertheless, the rapid reduction in stocking rates in the VAR and SOI treatments allowed GMs to recover and, in contrast to the HSR, allowed ACS to continue to grow in the years thereafter (Fig. 13.4).

After nine years, accumulated cash surplus per 100 ha was highest in the LSR and VAR strategies (mean: $17 410) but lowest in the HSR ($10 112). Cash surpluses in the SOI and R/Spell were somewhat (*c*. $1500) lower than those in the LSR and VAR but still well ahead of those in the HSR (Fig 13.4.). Based on current data and assumptions, these differences equate to a difference in gross income over 9 years of $140 000 between LSR and HSR for a property size of 20 000 ha.

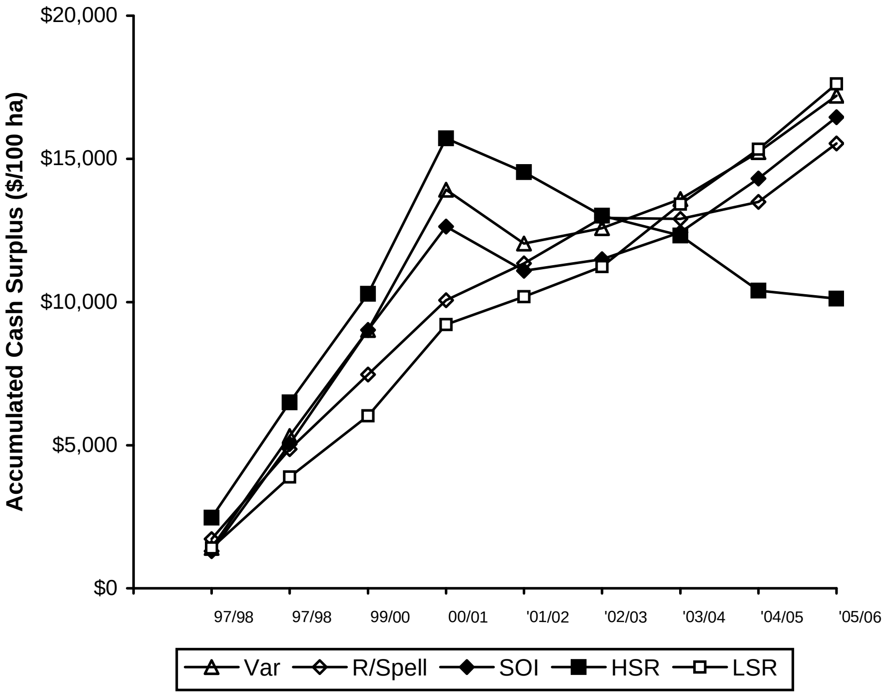


Figure 13.4: Accumulated cash surplus ($) per 100 ha for five different grazing strategies at Wambiana from 1997/98 to 2005/06. Interest on livestock capital at 10% and price differential based on condition score – see text for details.

Rainfall and grazing strategy were undoubtedly the major determinants of ACS, but the above results are obviously sensitive to assumptions about interest rates on livestock capital: in general, increasing interest rates depressed the relative performance of the heavier stocked strategies, particularly in the dry years. Thus increasing interest rates from 10% to 15% resulted in the cross over point in ACS between HSR and LSR occurring a year sooner in 2002/03 rather than in 2003/04. Conversely, dropping interest rates to 0% reduced treatment differences, with all strategies having relatively similar accumulated cash surpluses after nine years. Nevertheless, even at 0% interest the final ACS after nine years was still lower in the HSR ($22 069) then in the LSR ($ 23 856), equating to a predicted difference of $36 000 at a property size of 20 000 ha.

13.5. Discussion

Present results suggest that the VAR and SOI did not perform as well as the LSR, and did not seem to bestow any long term financial advantage given the risk involved in running extra stock. However, these strategies were probably unfairly penalised in the present trial by a number of factors: First, the poor cattle performance observed in the SOI and VAR strategies in 2001/02 resulted partly from poor dry season diet quality, a problem that could possibly have easily been ameliorated by the provision of a urea. Second, the stocking rates applied in the good years like 2000/01 exceeded those applied in the HSR. In retrospect, these were excessive and undoubtedly had a negative effect on pasture and animal production. It is possible that more conservative increases in stocking rate in wet years might avoid this problem.

Thirdly, the SOI strategy was additionally penalised in 2001/02 by the forced sale of animals in November. Due to dry season weight loss and poor condition these were sold at a loss after being nominally ‘purchased’ in June at a higher price. Again, these animals may have maintained weight better with a urea lick in the dry season and so reduced the financial losses to this treatment. Nevertheless the issue of late dry season adjustments to stock numbers highlights the fact that the current three month lead time for SOI forecasts is a major limitation to its practical application in managing for climate variability.

13.6. Summary

1. Marginal economic analysis indicated that heavy stocking paid in the early wetter years (1998-2000) with margins of about $200 per extra LSU (per 100 ha). However, this changed abruptly in the drier years from 2001 onwards with negative margins of about negative $200 per LSU occurring due to the interest and drought feeding costs, price penalties for poorer animal condition and reduced production per unit area.

2. Marginal returns from heavy stocking dropped to nearly negative $600 per LSU in 2005/06 despite better rainfall distribution and reduced stocking rates, suggesting that declining pasture condition in the HSR was affecting secondary production.

3. Sensitivity analyses indicated that the marginal returns per LSU under heavy stocking were sensitive to season, interest rates on livestock capital and a condition-based price differential for sale cattle. Increasing interest rates and a greater price differential caused margins per LSU to decline under heavy stocking.

4. Sensitivity analyses indicated that heavy stocking only gives a positive marginal return in wet years when interest rates are zero and the price differential is <$0.20 per kg or when interest rates are <10% and a price differential of less than $0.10/kg occurs. In dry years, margins were negative for high stocking rates and declined sharply to *c.* - $ 600 per LSU as interest rates rose and the price differential based on condition score increased.

5. Gross margins in the early wet years were markedly higher in the heavily stocked SOI, VAR and HSR strategies (mean: $3522/100 ha) than in the LSR and R/Spell (mean: $2 409/100 ha). However, GMs in the former treatments dropped sharply with the advent of dry years in 2001/02 to negative levels (mean: - $1537/100 ha) due to reduced animal production and high interest costs on livestock capital.

6. Reducing stock numbers in line with declining seasonal conditions allowed GMs in the SOI and VAR to recover post 2002, but the losses incurred in 2001/02 largely neutralised the advantages of running extra stock in the previous wetter years. In contrast, maintaining stocking rates in the HSR through the dry years resulted in a consistently negative GM because of high costs incurred through drought feeding and condition-based price penalties on sale animals.

7. Light stocking was the least sensitive to seasonal climate variation and gave strong, positive gross margins throughout the dry years and conserved land condition. But missed the opportunity to increase stock numbers in the wetter years.

8. Gross margins in the R/Spell were also reasonably good but the strategy was severely penalised by the fire of 2001 and its resultant effects upon carrying capacity and animal production.

9. Accumulated cash surplus initially increased fastest in the heavier stocked treatments because of the good seasons. However, by 2006 the LSR had the highest cash surplus ($17 621/100 ha) because of consistently good animal production and low costs. In contrast, accumulated cash surplus in the HSR was the lowest ($10 112/100 ha) of all strategies. For a 20 000 ha property this equates to a difference in cash surplus of approximately $140 000 after nine years.

Table 13.1: Total gain, value of gain, variable costs, interest costs and gross margin for different grazing strategies from 1997/98 to 2005/06. Filler animals (SOI) or forced sales (R/Spell) sold at $1.60/kg.**Due to weight loss of fillers sold in November 2001.

	1997/98	1998/99	1999/00	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06
					Light stocking				
Total gain(kg/100ha)	1049	1745	1479	2041	970	1216	1850	1710	1819
Sale price ($/kg)	$1.80	$1.80	$1.80	$1.80	$1.80	$1.80	$1.80	$1.80	$1.80
Value of weight gain ($/100ha)	$1,888	$3,141	$2,663	$3,674	$1,745	$2,190	$3,329	$3,077	$3,274
Variable costs ($/100ha)	$0	$0	$0	$0	$0	$424	$341	$261	$99
Interest on livestock capital (@10%)	$480	$655	$527	$490	$772	$713	$812	$890	$896
Gross margin ($/100 ha)	$1,408	$2,485	$2,136	$3,184	$973	$1,052	$2,177	$1,927	$2,278
					Heavy stocking				
Total gain(kg/100ha)	1887	2918	2720	3586	1405	1463	2442	2492	2040
Sale price ($/kg)	$1.80	$1.80	$1.80	$1.80	$1.60	$1.60	$1.60	$1.60	$1.60
Value of weight gain ($/100ha)	$3,397	$5,252	$4,897	$6,454	$448	$672	$2,118	$2,013	$1,965
Variable costs ($/100ha)	$0	$0	$0	$0	$18	$691	$1,199	$2,160	$1,079
Interest on livestock capital (@10%)	$921	$1,234	$1,106	$1,018	$1,621	$1,502	$1,610	$1,777	$1,169
Gross margin ($/100 ha)	$2,476	$4,018	$3,790	$5,437	-$1,191	-$1,521	-$692	-$1,924	-$282
					Variable stocking				
Total gain(kg/100ha)	1046	2849	2676	4834	1432	1055	1110	1364	1523
Sale price ($/kg)	$1.80	$1.80	$1.80	$1.60	$1.60	$1.80	$1.80	$1.80	$1.80
Value of weight gain ($/100ha)	$1,884	$5,128	$4,816	$6,222	$155	$1,898	$1,999	$2,455	$2,741
Variable costs ($/100ha)	$0	$0	$0	$0	$116	$542	$243	$201	$78
Interest on livestock capital (@10%)	$476	$1,216	$1,118	$1,319	$1,923	$815	$736	$609	$704
Gross margin ($/100 ha)	$1,407	$3,911	$3,698	$4,903	-$1,884	$541	$1,020	$1,645	$1,958
					SOI-Variable				
Total gain(kg/100ha)	993	2619	2812	3953	317**	1054	1153	1562	1687
Sale price ($/kg)	$1.80	$1.80	$1.80	$1.60	$1.80*	$1.80	$1.80	$1.80	$1.80
Value of gain ($/100ha)	$1,788	$4,658	$5,062	$4,779	$117	$1,778	$1,929	$2,812	$3,037
Variable costs ($/100ha)	$0	$0	$0	$0	$380	$530	$240	$218	$90
Interest on livestock capital (@10%)	$487	$915	$1,080	$1,178	$1,274	$846	$746	$722	$798
Gross margin ($/100 ha)	$1,301	$3,743	$3,983	$3,601	-$1,538	$402	$943	$1,871	$2,149
					R/Spell				
Total gain(kg/100ha)	1323	2235	1883	2570	1300	1779	931	1406	1614
Sale price ($/kg)	$1.80	$1.80	$1.80	$1.60	$1.80	$1.80	$1.80*	$1.60	$1.80
Value of gain ($/100ha)	$2,380	$4,023	$3,388	$3,316	$2,339	$3,203	$1,180	$1,476	$2,904
Variable costs ($/100ha)	$0	$0	$0	$0	$0	$647	$330	$177	$69
Interest on livestock capital (@10%)	$663	$879	$788	$716	$1,052	$977	$882.56	$696	$800
Gross margin ($/100 ha)	$1,717	$3,144	$2,600	$2,600	$1,287	$1,578	-$32	$602	$2,035

14. Effects of fire on woodland composition and structure

14.1. Introduction

There are approximately 60M ha of Eucalypt and Acacia savannas in Queensland with the vast majority of these woodlands being utilised by the beef industry (Burrows, Henry *et al.* 2002). Historical accounts indicate that much of these woodlands were formerly fairly open but convincing anecdotal and empirical evidence exists to suggest that significant thickening of the woody component has occurred in recent years. For example, a recent assessment of long term monitoring sites in Queensland indicates that over the last fourteen years total tree basal area has increased by an average of 1.06m^2 ha^{-1} (Burrows *et al*. 2002). Whilst this increase has potential benefits in terms of CO_2 sequestration, it is of concern to the grazing industry due to its likely impacts upon pasture production, carrying capacity and hence long-term economic and ecological sustainability.

The most likely explanation for woodland thickening is that it results from increased grazing pressure and, in particular, from a reduction in fire frequency and intensity (Scholes and Archer 1997). Accordingly, regular burning is widely recommended to manage the northern Australian savannas (O'Reagain and Ash 2002). However, most of the information on fire management relevant to the northern savannas is derived from work conducted at a few sites in the Northern Territory (Williams, Cook *et al.* 1999);(Dyer, Russel-Smith *et al.* 2002). Consequently, major gaps exist in our understanding of the response of the structurally and compositionally distinct north Queensland savannas to fire.

14.2. Objective

To examine the effects of fire on mortality and regrowth in different woody species in three, different woodland types.

14.3. Procedure

14.3.1 Site description and measurements

In early 1999, sites were established to monitor woody vegetation demographics in the LSR, HSR and R/Spell treatments. A subset of sites from already established pasture monitoring sites (Chapter 9) were chosen to represent each of the three main soil-vegetation associations i.e. Ironbark, Box and Brigalow. At each site three (R/Spell) or five (HSR and LSR), 4 by 100m permanent belt transects were established and all woody species within these transects recorded using the TRAPS sampling methodology (Back, Burrows *et al.* 1999).

Due to plant density and time constraints, *Carissa ovata* cover along transects was measured using the line-intercept method: a 100m tape was stretched out along transects and the point at which the tape crosses and leaves each Carissa canopy recorded. In this procedure it is assumed that any break between successive contacts along the tape of > 30 cm constitutes a new canopy. Further, only branch or canopy areas > 5 cm in width were recorded. The summation of all distances along the tape with Carissa cover thus gave an estimate of total cover at that particular site.

14.3.2 Burning procedure

All paddocks on the experiment were burnt on 11 and 12 October 1999 using head fires. High grass fuel loads (*c*. 4000 kg/ha), abundant litter, a strong breeze and high air temperatures (30-35 C) resulted in extremely hot fires with flame heights of between 3 to 5m and an estimated intensity of 10-20 000 kW/m (Williams, Gill *et al.* 1998). Transects were re-surveyed in

September 2000 to determine mortality and regrowth. Mortality was defined as the complete absence of any form of re-sprouting on the plant.

To monitor the survival and subsequent effects of fire on *E. melanophloia* seedlings, 100 seedlings that had emerged following the 1999 fire were randomly located and their position mapped in each paddock of the R/Spell and HSR (n=400). As described below, the relevant sections of the R/Spell paddocks were burnt again in November 2001 while the HSR remained as the unburnt control. All seedlings were resurveyed in 2002 and their status recorded as either live or dead.

Two subsequent fires were applied as part of the burning/spelling treatment to selected sections of the R/Spell paddocks in October 2000 (Section 3) and November 2001 (Section 1). The monitoring sites in these sections were also re-surveyed again post-fire but the resultant data is not presented.

14.3.3 Statistical analysis

Data was log transformed and analysed using an analysis of variance on an individual species basis in GENSTAT. The response variate was the number of plants per hectare in each size class. 'Site' was used as a replicate and 'year' as treatment. Results are presented only for the dominant species *E. melanophloia*, *E. brownii* and *A. harpophylla* and for the sub-dominant *Eremophila mitchelli.*

14.4. Results

14.4.1 Woodland structure

Fire had a marked effect on woodland structure and induced a significant (P<0.001) shift from the larger to the smaller size classes in *E. brownii*, *Eremophila mitchelli* and *A. harpophylla* (Fig. 14.1). The shift to smaller size classes was particularly significant amongst individuals in the 1 – 5m size range and resulted in a major increase in the number of individuals smaller than 1m. This change resulted from the complete or partial top-kill of stems and subsequent re-sprouting via epicormic buds lower down the main trunk or via basal buds situated at the plant base (Gill 1997). Interestingly, in the cooler, subsequent fire applied in 2000 to the Box sections of the R/Spell paddock, a number of top-killed Box trees that resprouted from basal buds post-1999 were killed. This aspect requires further investigation as it suggests that tree mortality might be significantly increased by the applications of an initial hot fire to cause top-kill, followed by a relatively cool fire to kill the re-sprouting basal buds and hence the whole tree.

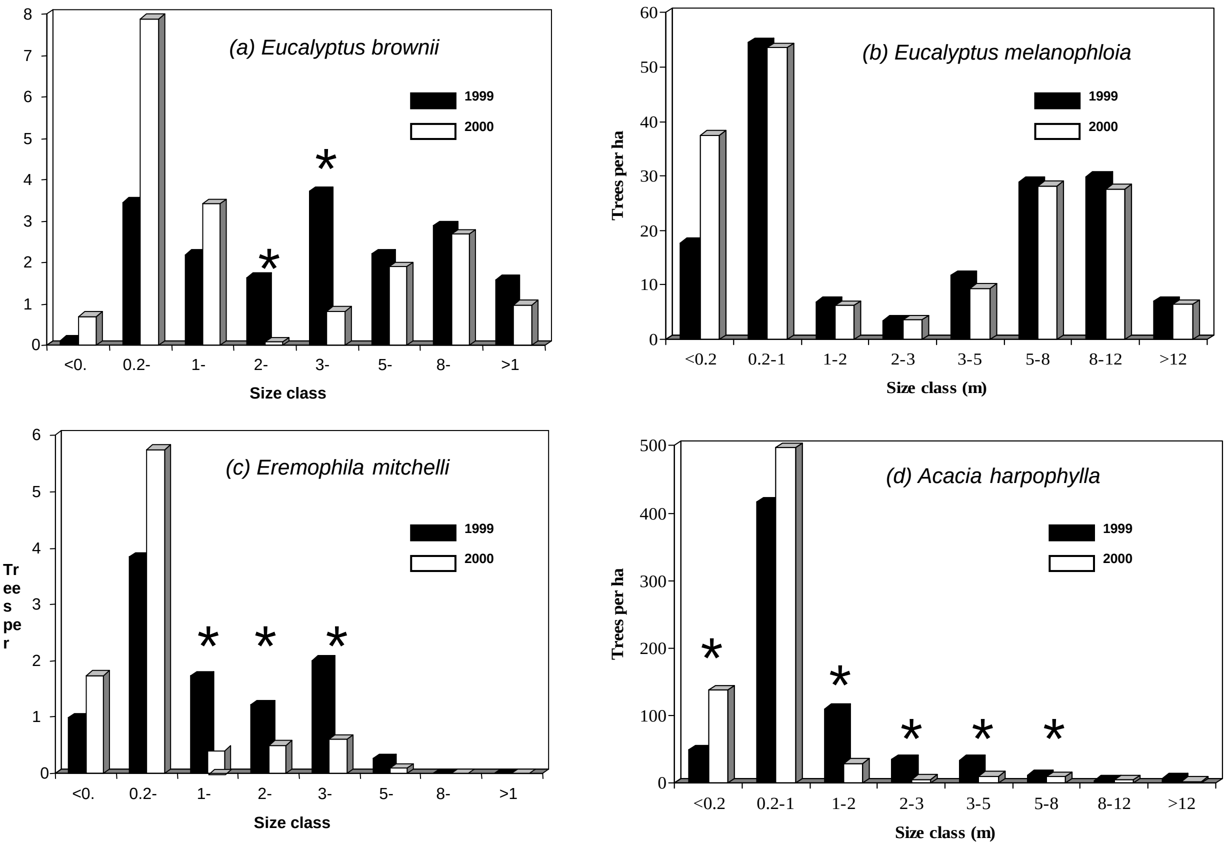


Figure 14.1: Numbers of trees per hectare in different size classes for four species in 1999 (pre-fire) and 2000 (post-fire) at the Wambiana site. Asterisks indicate a significant difference within size classes at the ($P<0.05$) level.

14.4.2 Woodland composition

Despite the intensity of the applied fire, overall tree mortality rates were low, varying from only 3.5% for *Eucalyptus brownii* to 16.5% for *Eremophila mitchelli* (Table 14.1). These rates are comparable to an average mortality rate of 14.3% recorded for a range of woody species following intense fire in a monsoon savanna in the Northern Territory (Lonsdale & Braithwaite 1991). As expected, there was a marked differential in mortality across different size classes in all species: in general, mortality was greatest in the smaller size classes (<1m) and tended to decline with increasing tree size. Surprisingly, mortality rates in both *Eucalyptus brownii* and *A. harpophylla* tended to subsequently increase for large trees greater than 12m (Table 14.1). Williams *et al.* (1999) noted a similar increase in mortality in the largest size classes and attributed this reduced survival to approaching senescence. However, in the present study, at least some of these larger trees succumbed to the intense heat generated by burning logs lying adjacent to the trunk, rather than the primary effects of the fire front *per se.* The fire also felled a number of larger (> 8 m) *E. melanophloia* and *E. brownii* trees, which had previously been hollowed out by termites. Nevertheless, these individuals all subsequently re-sprouted.

Table 14.1: Percentage mortality of plants in different height size classes following the 1999 fire at Wambiana. Numbers given in brackets refer to the total number of live plants in all size classes recorded for a species prior to burning.

Species	**Size class – height (m)**						**All classes**
	< 0.2	**0.2 - 1**	**1 - 3**	**3-- 8**	**8 - 12**	**> 12**	
A. harpophylla (n=833)	14.5	13.5	8.1	3.3	0	37.5	11.9
E. brownii (n=372)	0	10.8	1.2	0	3.5	5.3	3.5
E. melanophloia (n=370)	31.9	10.5	0	3.3	0	0	8.4
E. mitchelli (n=231)	21.7	7.1	3.0	11.1	-	-	16.5

14.4.3 Seedlings

The 1991 fire also stimulated recruitment of new individuals in at least three tree species. In *A. harpophylla*, a total population increase of 30% was recorded through the fire-induced stimulation of root suckers. Recruitment from seed also occurred in *E. melanophloia, E. brownii* and *E. cambageana,* but was patchy and localised. In the latter two species, recruitment appeared to be confined to ash beds while seedlings of *E. melanophloia* emerged in both ash beds and non-ashy areas. This seedling recruitment probably resulted from the post-fire release of seed from capsules held in the canopy combined with the creation of a range of micro-sites such as ash beds, favourable for seed germination (Gill 1981). Establishment and growth of seedlings would also have been favoured by the above average rainfall received in the wet season immediately following the fire.

Despite these initial favourable condition, the subsequent survival of the seedlings was very low: of the 400 *E. melanophloia* seedlings monitored, survival rates three years later were 5-10% in paddocks not receiving a subsequent burn and 0% in paddocks receiving a second burn in November 2001. Conditions post 2001 were relatively dry, so in years with good rainfall, the survival of seedlings in unburnt paddocks may possibly be greater than that recorded here.

14.4.4 Effects of fire on *Carissa ovata*

Although the effects of fire on *Carissa* mortality were not specifically measured, field observations indicated that extensive top-kill of the shrub occurred. However, few if any plants were actually killed by the fire, and re-sprouting from basal buds was obvious within a few months of the fire. These new shoots grew very rapidly with some growing to a length of 50 or 60cm within the first wet season. Nevertheless, the fire of 1999 did result in a dramatic decline in *Carissa* canopy cover on all soils types with cover on the Box soils for example, dropping from around 14% to about 5% post fire (Fig. 14.2). This effect was relatively short lived however and within two to three years, canopy cover appeared to have reverted to its former levels. Although some of the years post-fire were very wet, the present results support the contention of (Back 2005)Back (2005) that fire is required every 5 or 6 years to keep *Carissa* under control.

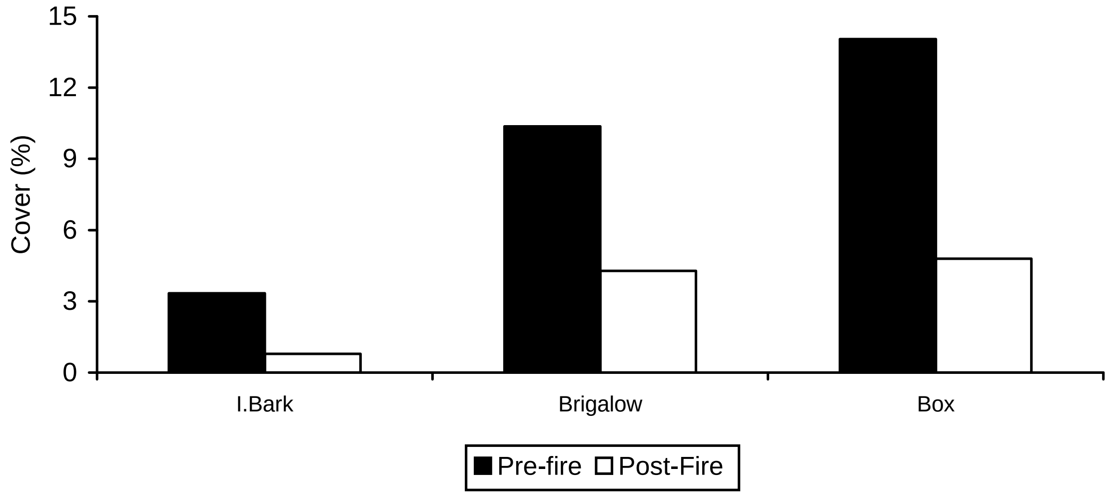


Figure 14.2: *Carissa ovata* cover pre-fire and one year post-fire on three soil-vegetation associations at the Wambiana trial.

14.5. Discussion

The present results indicate that an intense, hot fire is successful in opening up woodland structure by shifting plants to smaller size classes. Although overall plant mortality was low, significant mortality in the smaller size classes was recorded. This suggests that in the savannas in question, regular fire could be successful in controlling both woodland structure and density by firstly, suppressing small to moderate size trees and preventing their recruitment to adulthood. And secondly, by causing the slow attrition of plants in the larger size class through fire induced mortality. Further research is nevertheless needed to investigate the effects of the timing and intensity of different types of fire on mortality and structure in these woodland communities.

14.6. Summary

1. Fire killed relatively few trees with mortality rates ranging from only 3.5% for Box (*E. brownii*) up to 16% for false sandalwood (*E. mitchelli*). The highest kill rates were in the smallest size classes (<1m) with fire effects declining with tree size. Surprisingly, mortality rates for Box and Brigalow were also relatively high in the largest size class (> 12 m) but this largely occurred when fallen timber incinerated nearby trees.

2. Virtually all trees re-sprouted post-fire from either basal or epicormic buds. In *A. harpophylla*, fire led to a 30% increase in root-suckers. However, a number of top-killed *E. brownii* trees that resprouted from basal buds were subsequently killed by a cool fire applied the following year to two sections of the R/Spell treatment.

3. Fire also stimulated seedling recruitment in *E. brownii, E. melanophloia* and *E. cambageana* but most of the *E. melanophloia* seedlings monitored (> 90%) subsequently died.

4. Fire had a significant effect on woodland structure and caused a marked shift from the bigger to smaller size classes across all tree species. The greatest shift to smaller size classes occurred in the 1-5m size class.

5. Fire caused complete top-kill in *Carissa ovata* resulting in a sharp, but relatively short lived, decline in cover. However, extensive and rapid re-sprouting from root buds in the subsequent favourable wet seasons ensured that *Carissa* cover recovered to pre-fire levels within two to three years.

Print 13: Sequence showing the effect of the 1999 fire on a large *E. melanophloia* tree and an adjacent *Carissa ovata shrub: Top* – before the fire in April 1999. *Middle* – immediately after the fire in October 1999. *Bottom* – five months after the fire in April 2000. Despite the apparent damage both individuals recovered rapidly and were still alive in late 2006.

15. Net primary production on different soil types at Wambiana

15.1. Introduction

Landtypes vary widely in soil structure and fertility and obviously differ in their potential pasture production and hence carrying capacity. Estimation of the long term carrying capacity of different landtypes is critical for sustainable grazing management but traditionally has been subjective. Simulation models like GRASP have the potential to objectively quantify the long-term carrying capacity of different land types from rainfall and soil characteristics. Detailed model calibration for the land types involved is however critical in calculating realistic carrying capacities.

In this section, long term pasture production, composition and nitrogen (N) uptake data collected for calibration of GRASP for a range of soil types at the Wambiana trial is presented. The data provide important insights into the productive potential of these land types and, more importantly, also allow derivation of simple equations to predict pasture production from rainfall.

15.2. Objectives

1. Quantify the pasture production potential, species composition and N uptake of a range of land types on the Wambiana grazing trial.
2. Develop basic predictive relations to allow prediction of above ground net primary productivity (NPP) for these land types from rainfall, grass basal area and N uptake.
3. Calibrate the GRASP model to predict pasture production from rainfall and other climate data for these land types

15.3. Procedure

15.3.1 Procedure and data collection

Seven SWYFTSYND exclosures (Day and Philp 1993) were established in September 1998 across different land types on the trial (Table 15.1). Exclosures are approximately 25 by 25m and contain nine, 3 by 3m plots. Sites were chosen to represent a ‘typical’ area of a particular land type. Two exclosures were erected on the Ironbark (yellow kandosols) and Box soils (brown sodosols) respectively and one each on the vertosols (Brigalow), grey earths (Coolibah) and grey sodosols (Black Butt).

Exclosures were only used for 2 to 3 years to avoid any effects of clipping and mowing on pasture production. New exclosures were usually located close to or adjacent to the old exclosures and, where possible, reflected the species composition of the original sites. In later years however, pasture condition changed appreciably both inside and outside exclosures through the effects of drought and grazing/mowing. In these situations, the yields reported here reflect not only the rainfall recorded in a particular year but also the accumulated effects of previous seasons and management.

All exclosures were defoliated, usually by mowing, late in the dry season to prevent the carryover of residual material into the subsequent season. Sampling occurred thereafter at *c*. 3 monthly intervals depending upon rainfall. In each exclosure a $1m^2$ quadrat was clipped using sheep shears from a previously unharvested area of each plot. Data collected included dry matter yield, contribution of major pasture species to yield and ground cover (Day and Philp 1993). During the mid and/or late wet season harvests, a sub-sample of clipped material from each plot was collected, dried, ground and analysed for N content using the Kjeldahl technique. Total N uptake was calculated as the product of N concentration and peak yield (usually March or April).

Table 15.1: A brief description of SWYFTSYND sites at the Wambiana grazing trial. Soil classifications by Mike Cannon and Gary Rodgers. TBA=tree basal area (see text for details).

Name	Vegetation	Tree spp.	Soil classification	Dalrymple soil type	TBA (m^2/ha)	Pasture species
P1 Box	*Reid River Box*	*E. brownii*	Brown kandosol/chromosol	Boston over clay subsoil	8	*Bothriochloa ewartiana, Chrysopogon fallax, Aristida spp. Panicum spp.*
P1 Ironbark	*Silver Leaf Ironbark*	*E. melanophloia*	Haplic dystrophic brown kandosol	Boston	8	*Chrysopogon fallax, Aristida spp., Enneapogon virens, Stylosanthes hamata*
P3 Ironbark	*Silver Leaf Ironbark*	*E. melanophloia*	Ferric petroferric brown kandosol	Wattle vale	6	*Eriachne mucronata, Aristida spp., annual grasses, Heteropogon contortus*
P6 Blackbutt	*Blackbutt*	*E. cambageana*	Brown sodosol	Liontown	6	*B. ewartiana, Enteropogon acicularis, Fimbristylis spp., Chrysopogon fallax, Aristida spp, Chloris spp.*
P7 Box	*Reid River Box*	*E. brownii*	Brown sodosol	Liontown	6	*B. ewartiana, Chrysopogon fallax, Aristida spp., Fimbristylis, H. contortus, Panicum spp.*
P9 Brigalow	*Brigalow on Melonholes*	*A. harpophylla*	Epipedal grey vertosol	Powlathanga	4	*B. ewartiana, Dicanthium sericeum, Brachyachne convergens, Forbs, Sporobolus spp., native legumes*
P10 Coolibah	*Open Coolibah*	*E. coolibah*	Epipedal grey vertosol	Powlathanga	4	*D. sericeum, B. ewartiana, Eulalia aurea, Sedges, Sesbania cannabina*

On some occasions soil samples were also taken at 10 cm depth intervals to assess gravimetric soil moisture (data not shown). Exclosures were assessed every second or third year for both grass (900 points) and tree basal area. Rainfall was measured using the network of rain gauges described in Chapter 5. Distances from rain gauges to individual SWYFTSYND sites varied from less than 100m to 800m. Total accumulated rainfall for each site was computed as the sum of all rainfall events at the nearest gauges between the 1 July and the date of a particular harvest.

15.3.2 Data analysis

Predictive equations were developed individually for each site using regression analysis in GENSAT. Regression analyses were also run using all data from all sites using 'soil' as a grouping factor. Where slopes and intercepts were not significantly different, sites on similar soils were lumped together into generic land types e.g. P1 and P7 Box, P10 Coolibah and P9 Brigalow.

15.3.3 Parameterisation of GRASP

Parameterisation of GRASP for the different soil types was conducted as discussed in Chapter 6.

15.4. Results

15.4.1 Yield and species composition

At all sites Net Primary Production (NPP), estimated from peak yield, changed sharply over time with NPP being highest from 1999 to 2001 but dropping sharply to very low levels (<1 200 kg/ha) in 2003 due to low rainfall and its associated effects on plant populations. NPP has partially recovered in recent seasons on the Brigalow, Coolibah and P3 Ironbark sites but other site yields remain low (Fig. 15.1).

NPP was highest on clay soils due to fertility, the deep infiltration of water via deep soil cracks, run-on of water (Coolibah) and the large water storage capacity of the soil profile, while NPP on Ironbark was probably largely limited by fertility. In drought years or years with poorly distributed rainfall, NPP on Box soils was limited by the relatively shallow top soil, the impermeable subsoil and the relatively low water holding capacity of the profile.

Pasture composition and hence the proportion and production of useable forage also varied markedly between sites. NPP was not only highest on the Box and Brigalow, but these sites also had the greatest proportion of relatively productive, palatable species of value to cattle. On the Ironbark, NPP was largely comprised of relatively unpalatable, low quality grasses like *Eriachne mucronata* and *Aristida.* The Blackbutt site also had a relatively low NPP, but in contrast to the Ironbark sites, a good proportion of this production consisted of 3-P species and/or favoured grasses like *Enteropogon acicularis* (Fig. 15.1).

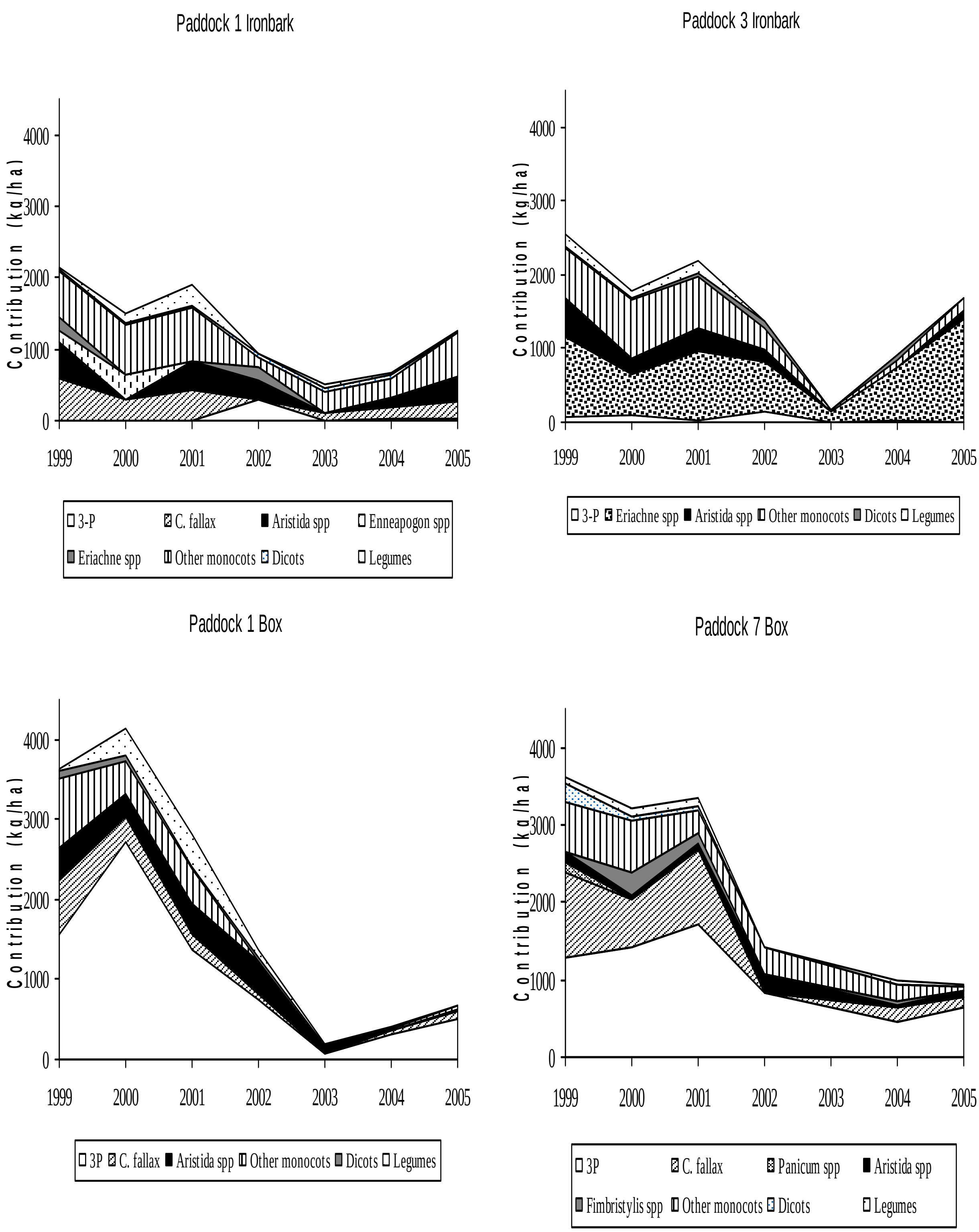


Figure 15.1: Change in net primary production (peak pasture yield) and species contribution to yield at different SWYFTSYND sites between 1998 and 2005 at the Wambiana grazing trial.

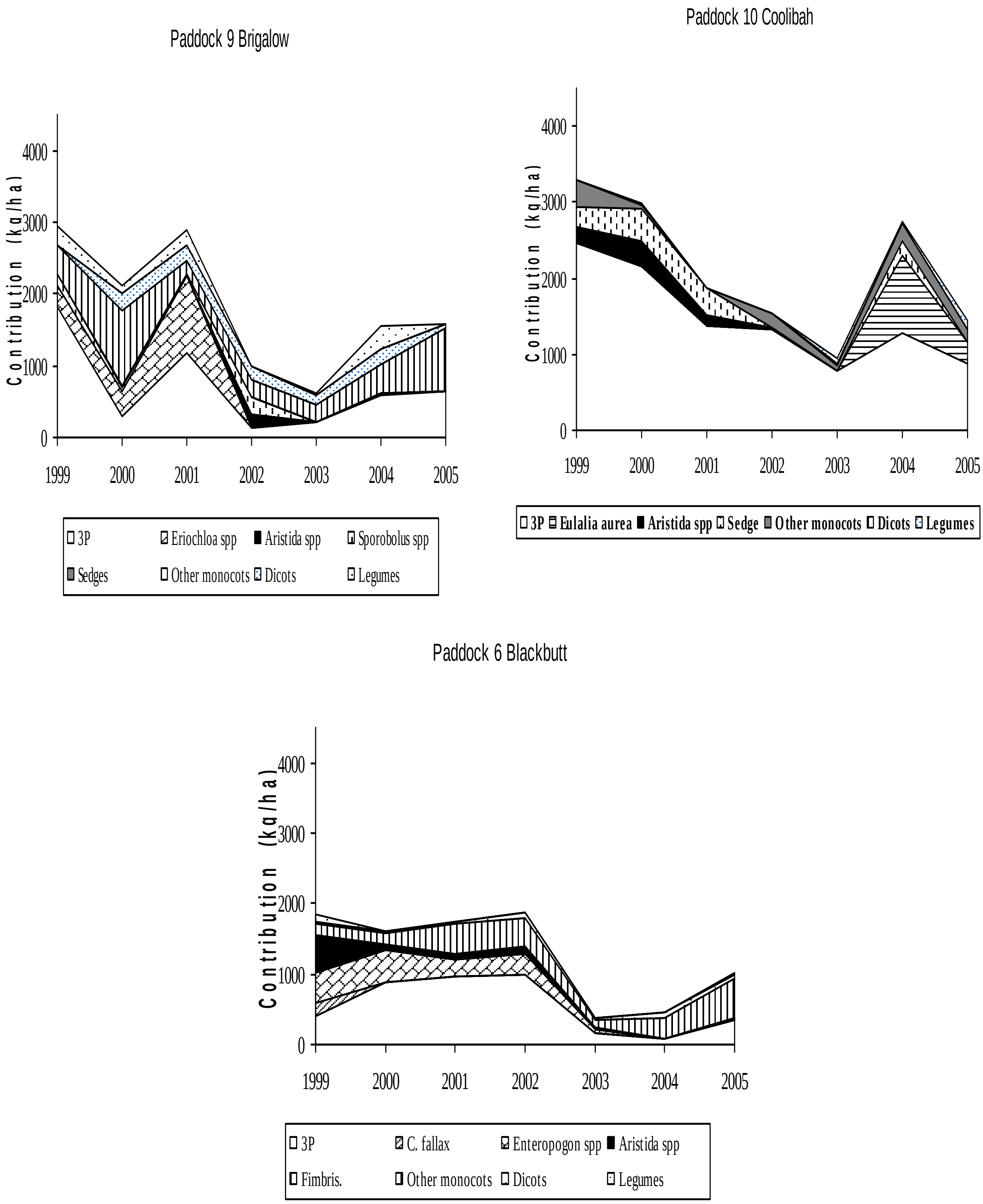


Figure 15.1: (Contd.) Change in net primary production (peak yield) and species contribution to yield at different SWYFTSYND sites between 1998 and 2005 at the Wambiana grazing trial.

Pasture composition was not static but changed markedly over time within individual sites, largely due to the effects of rainfall. In particular, *C. fallax* yields declined on the Box sites in later years, while *Eriochloa* virtually disappeared completely on the Brigalow (Fig. 15.1). The contribution of the various *Aristida* spp. to yield also declined in the later drier years on many sites.

In contrast, while the actual yields of 3-P species also declined with reduced rainfall, these provided a large proportion of the useful forage at most sites through both wet and dry years. This provides further evidence for the importance of 3-P grasses to maintaining long term animal production irrespective of changing seasonal conditions.

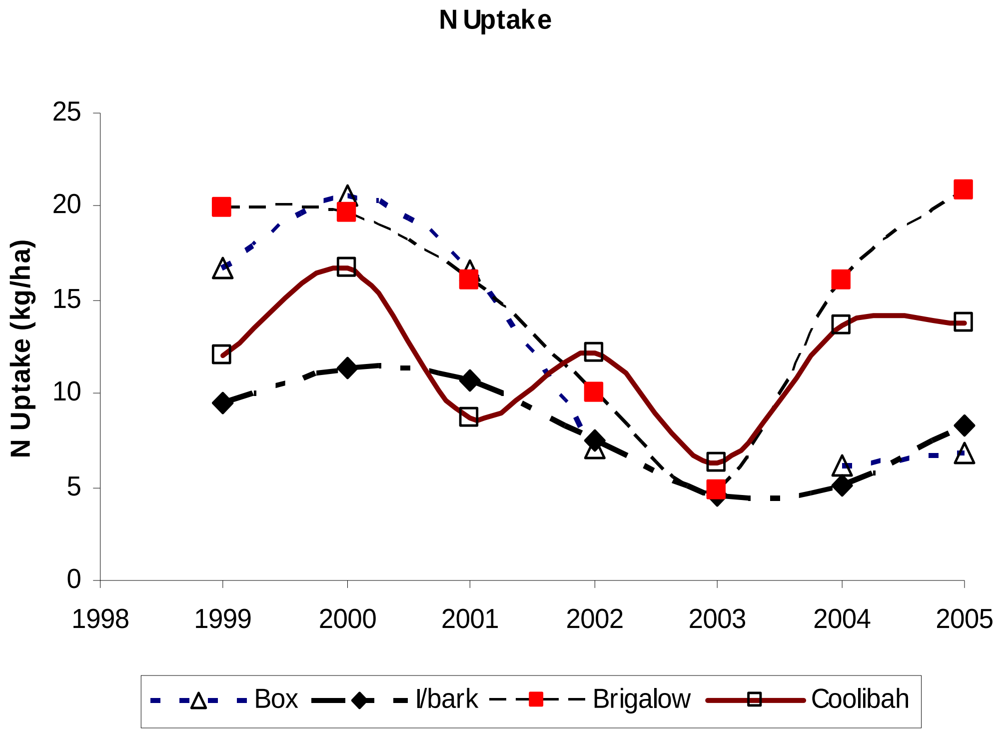


Figure 15.2: N uptake at SWYFTSYND sites (1998-2005) at the Wambiana trial. Box and Ironbark values are the mean of two sites. For clarity lines were smoothed and Blackbutt values were excluded

15.4.2 Nitrogen uptake

N uptake varied markedly between land types (Table 15.2) with average N uptake ranging from a maximum of 15.32 kg/ha on the Brigalow to a minimum of 8.15 kg/ha on the relatively infertile Ironbark. However, N uptake on individual land types also varied sharply between years with changing seasonal conditions: total N uptake was highest in the early wet years of 1999 and 2000 but lowest in the relatively dry years of 2003. For example N uptake in the Brigalow varied from a high of 19.87 kg/ha in 1999 to less than 4.89 kg/ha in 2003. N uptake in the last two years has been inconsistent with the Coolibah and Brigalow returning to pre-drought levels but N uptake remaining depressed in the Box and Ironbark sites (Fig. 15.2). Overall, the present levels of N uptake are relatively low compared to those reported by Dyer *et al.* (2003) for a number of sites in the Victoria River District of the Northern Territory (mean: 21 kg/ha).

Table 15.2: Mean, maximum and minimum N uptake between 1999 and 2005 for SWYFTSYND exclosure sites on five land types at the Wambiana trial NB: Values for the Box and I/bark are the means of two individual sites (see Table 15.1).

	N Uptake (kg/ha/yr)		
Landtype	**Mean**	**Minimum**	**Maximum**
Box	12.31	6.09	20.52
I/bark	8.15	4.56	11.37
Bbutt	11.78	5.44	16.99
Brigalow	15.32	4.79	20.89
Coolibah	11.91	6.25	16.71

Taken over all sites, total N uptake was positively correlated (R^2= *20 %; P<0.001)* with rainfall from the start of the season. Including a factor for 'soil type' improved this relationship further (*R^2= 47 %; P<0.001).* In contrast, pasture N concentration (%) was negatively related (*R^2= 30 %; P<0.001)* to total rainfall. Again, including soil types as a factor improved this relationship (*R^2= 42 %; P<0.001).)*

15.4.3 Relationship between NPP, rainfall and other parameters

Taken over all soil types NPP increased linearly with total rainfall since the start of the season (*R^2= 61%; P<0.001*). Adding pasture basal cover and/or N uptake to the equation did not improve this regression. However, including the factor 'soil type' improved the strength of the NPP by rainfall relationship (*R^2= 67%; P<0.001).* When NPP was regressed against rainfall for four broad groups of soil i.e. heavy clays, Box, Blackbutt and Ironbark, all relationships were significant with R^2 values ranging from 61% for Blackbutt to 81% for the Box type soils (Fig. 15.3).

Comparison of the slopes of these equations indicated that the response to total rainfall since the start of the season varied from just over 2 kg/ha/mm for the Blackbutt and Ironbark, up to 3.62 kg/ha/mm for the heavy clays and 5.6 kg/ha/mm for the Box (Fig. 15.3). These slopes indicate the potential growth response to rainfall of a particular soil and theoretically should reflect soil fertility. To some extent this concurs with the data with nutrients probably being more limiting to NPP on the less fertile soils like the Ironbark. Based on fertility alone however, the heavy clays would be expected to have superior growth potentials to the Box soil, while the Blackbutt should have a potential similar or equal to the Box.

The x-intercepts should also reflect the amount of rainfall required for soil moisture to increase above wilting point and growth to occur. Theoretically, clay soils should require the most water to allow growth to proceed and the Ironbark soils (sandy-loams) the least. The present results suggest however that Box soils require a far larger amount of rainfall (*c.* 200m) than the clay soils to allow pasture growth to proceed. This is illogical and it can only be concluded that some other factor(s) is responsible for the very high x-intercept observed for the Box soils.

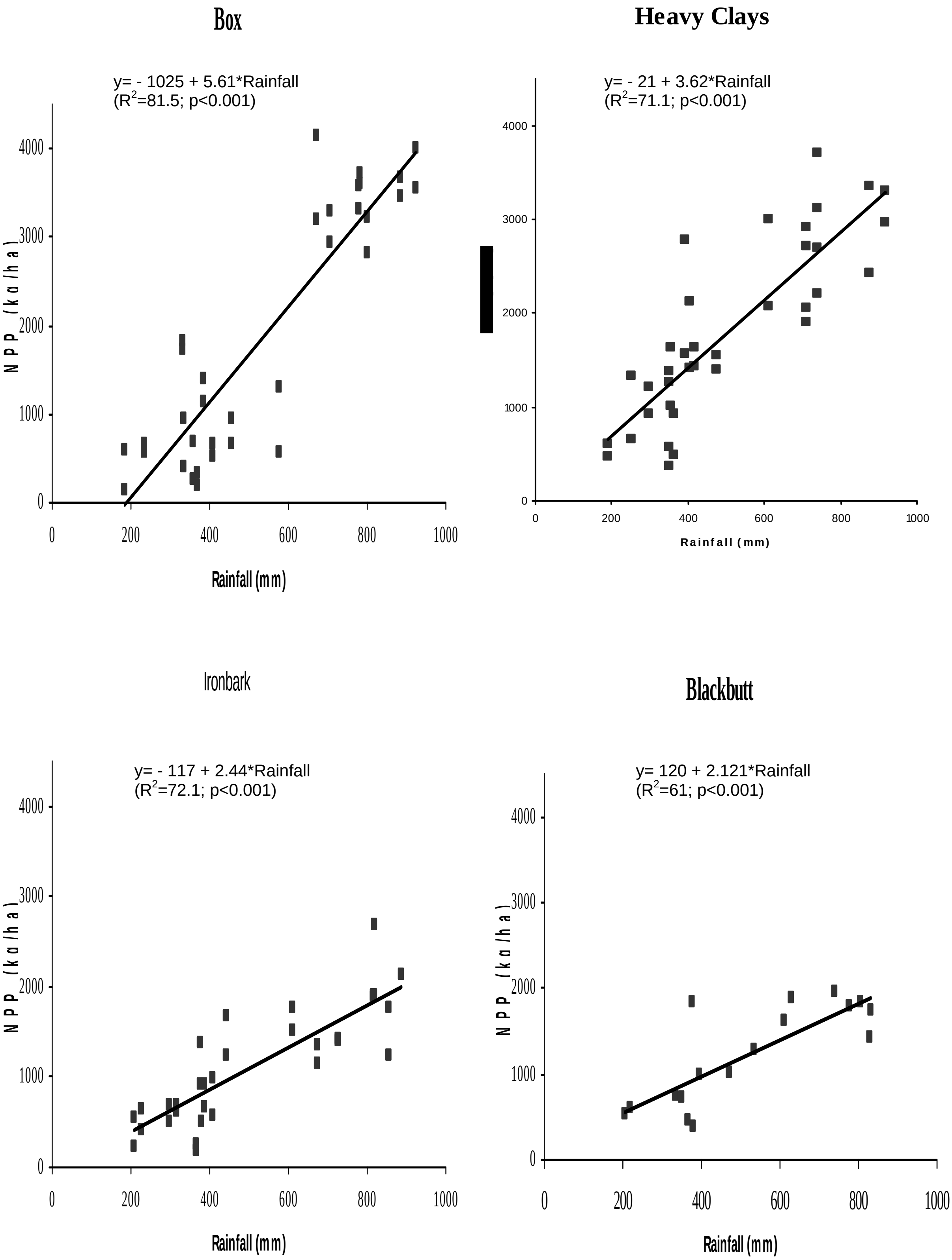


Figure 15.3: Relationship between net primary production (NPP) and rainfall since the start of the season on four land types at the Wambiana grazing trial.

15.4.4 Calibration of the GRASP model

GRASP was successfully parameterised and calibrated to each major land type on the site (See Chapter 6 for more detail). Simulations were run over all years in which data were collected and these generally show good agreement between model predictions and actual yields (Fig. 15.4). These simulations are the foundation for a large number of pasture yield tables currently used to estimate long term carrying capacities in the MLA funded Grazing Land Management Education package (Chilcott *et al.,* 2003).

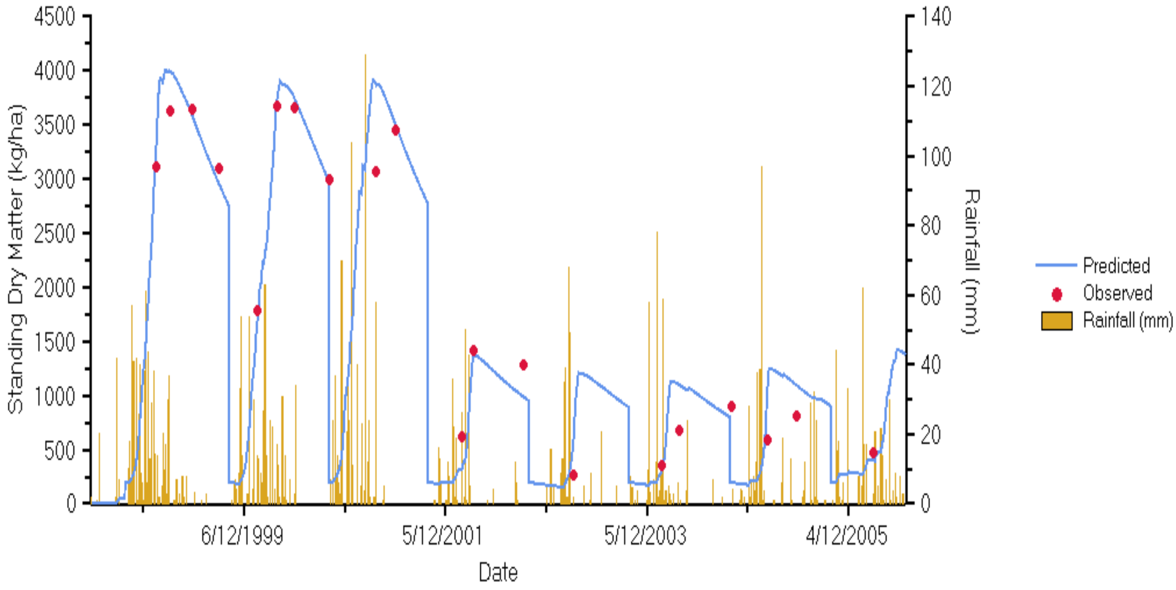


Figure 15.4: Example of GRASP predicted Total Standing Dry Matter and observed values against rainfall for a Box soil from 1999 to 2005. [Graph courtesy of P. Timmers, CNRS, NR&M, Brisbane]

15.5. Summary

1. Above Ground Net Primary Production (NPP) varied sharply between soil types: overall NPP was highest on the Brigalow, Coolibah and Box soils and lowest on the Ironbark and Blackbutt soils. These differences were particularly noticeable in the early wet years when NPP in the Box was 83% greater than on the Ironbark soils.

2. Pasture composition and hence the proportion of usable forage also varied between soil types: NPP on Ironbark soils was largely comprised of unpalatable, poor quality species like *Eriachne* but on the Box and Brigalow NPP was dominated by better quality, more productive 3-P species like *Bothriochloa ewartiana.* Differences in pasture composition together with yield will accentuate differences in NPP and hence carrying capacity between land types.

3. Total N uptake was highest on the Brigalow (mean: 15.32 kg/ha) and Box (mean: 12.31 kg/ha) and lowest on the relatively infertile Ironbark sites (mean: 8.15 kg/ha). N uptake also varied markedly between years in response to seasonal conditions: overall, plant % N was negatively related to rainfall while total N uptake increased with rainfall.

4. NPP changed markedly between years in response to changing seasonal conditions: taken over all years NPP increased with rainfall since the start of the season on all soil types (range: R^2= 61 % to 81%). In terms of pasture production, the response to rainfall varied from about 2 to about 5 kg of pasture growth per mm of rainfall for Ironbark and Box respectively.

5. Parameterisation of the model GRASP for the soil types in question was successful with good agreement between predicted and observed pasture production. GRASP has accordingly been used to generate pasture growth tables for calculation of sustainable carrying capacities for a wide range of similar land types in Queensland.

Print 14: The Brigalow SWYFTSYND exclosure in late 1998 after mowing (left) and two months later after substantial rains (right). Note: the tree stumps are from trees that died some years previously.

16. Runoff and soil loss under different grazing strategies

16.1. Introduction

Aside from the obvious issues of animal production, pasture condition and economic performance, a key issue in savanna management is that of soil loss and runoff. Increased sediment and nutrient inputs from grazing lands have been identified as major threats to the Great Barrier Reef (GBR) lagoon and water quality is obviously of major relevance to the grazing industry. However, an aspect usually given lesser prominence is that excessive loss of runoff and nutrients will inevitably compromise long term pasture and animal production.

Previous studies conducted on grano-diorite and sedimentary landscapes showed that runoff and sediment loss increased sharply as cover declined ((McIvor, Williams *et al.* 1995); (Scanlan, Pressland *et al.* 1996). However, neither study addressed the issue of nutrient loss from these systems. Furthermore, both studies were conducted on relatively small plots: under these conditions much of the sediment moved is likely to be re-deposited before entering water ways, making it difficult to extrapolate sediment losses to larger catchment scales.

Major knowledge gaps thus exist concerning the relationship between management and runoff in extensive grazing lands. These are firstly, how runoff and water quality are affected by grazing management on the relatively flat, infertile, tertiary sediments, which make up *c.* 20% of the Burdekin catchment. Secondly, how grazing management affects water quality, particularly N and P. And thirdly, the extent (if any) of the trade-off between reduced soil loss and economic productivity in grazing management.

In this section data is presented on the long-term effects of different grazing strategies on water quality and soil loss at the Wambiana trial. To add context, water quality data is also presented from a number of creeks and rivers in the Burdekin catchment.

16.2. Objectives

The objectives of the present study were to:
- Quantify the effects of different grazing strategies on soil and nutrient loss.
- Develop empirical relationships relating soil loss to cover and utilisation rate.

16.3. Procedure

16.3.1 Measurement of runoff

Bounded runoff catchments (*c.* 1 ha) were established in a single paddock of all treatments in October 1998 (HSR, SOI, and R/Spell) and November 1999 (LSR and VAR). Catchments are located in the Box soil-vegetation association on gently sloping (0.5-1.5%) brown-grey sodosols (Isbell, 1996). Runoff was collected at the bottom of catchments by wing-walls which funnel runoff towards a sediment trap (1 x 1 x 0.2m) and San-Dimas flume (2.5 x 0.5 x 0.5m). Flow height and duration through the flume were recorded at one-minute intervals using Macquarie borehole loggers (Windstream technologies, Mona Vale, NSW, Australia), allowing quantification of runoff rates and volumes. Rainfall quantities and intensities were recorded at one minute intervals using tipping-bucket pluviometers.

Basal cover and the percentage of bare ground, litter and attached litter etc were measured twice a year using the Levy Bridge (Bonham 1989). Points were initially spaced 10cm apart but this was increased to 20cm in 2000 because the spacing was observed to be too narrow. Initially 1000 points were done per site but this was increased to 2000 points from 2001 onwards.

Projected ground cover (%) was also subjectively estimated 2 to 3 times a year using a 0.25m^2 quadrat (200 placements per site). All cover measurements were conducted along five permanent transects running parallel to the slope.

16.3.2 Water quality

Water samples were automatically collected from flumes using Macquarie (1999-2001) or refrigerated ISCO 3700 (2002 onwards) auto-samplers (ISCO, Lincoln, Nebraska, U.S.A.). Samplers were initially only fitted to the HSR and VAR sites but in November 2002 ISCO samplers were installed at all sites. Samplers extracted 500ml samples with the first flush of water through the flume and thereafter at every 10mm change in flow height. Depending upon accessibility water samples were generally collected within 24 hours of a runoff event. Samples were returned to Charters Towers on ice where they were sub-sampled for nutrients analyses, which included filtration using pre-rinsed Sartorius Minisart filter modules (0.45µm pore size). All samples were stored on ice prior to their transfer to the Australian Centre for Tropical Freshwater Research (ACTFR), James Cook University, Townsville.

Bedload was collected annually in those years in which it had accumulated in sediment traps. All bedload was dried in a forced air oven after which woody debris and leaves were removed by hand sieving. Where large amounts of organic material were present this was removed with hydrogen peroxide.

During flood events, reference samples were opportunistically collected from nearby waterways, i.e. Policeman, Oaky and Yarraman Creeks and the Campaspe River. The Burdekin, Broughton and Fanning Rivers were also sampled during large flood events.

16.3.3 Statistical analysis

Due to the lack of replication of flumes, data was analysed using regression analysis in GENSTAT or by comparing the distribution of data points. For water quality samples collected in a particular event, nitrogen (N), phosphorus (P) and totally suspended sediment (TSS) were meaned across all sample bottles for that date. Utilisation rates were derived as explained in Chapter 6. Bedload data are presented and analysed on a per year basis.

16.4. Results

16.4.1 Rainfall

Annual rainfall (July-June) exceeded the long term average for the area over the first three years of the study but was markedly below average in subsequent seasons (Chapter 5). There were a total of 383 rainfall events over the period from 1999 to 2006, but most of these were relatively small with only 27 events exceeding 40mm in 24 hours. Apart from a few extreme events, rainfall intensities were also relatively low. Many of the larger events like that over the 2005 Australia Day weekend (203mm), were of only moderate intensity.

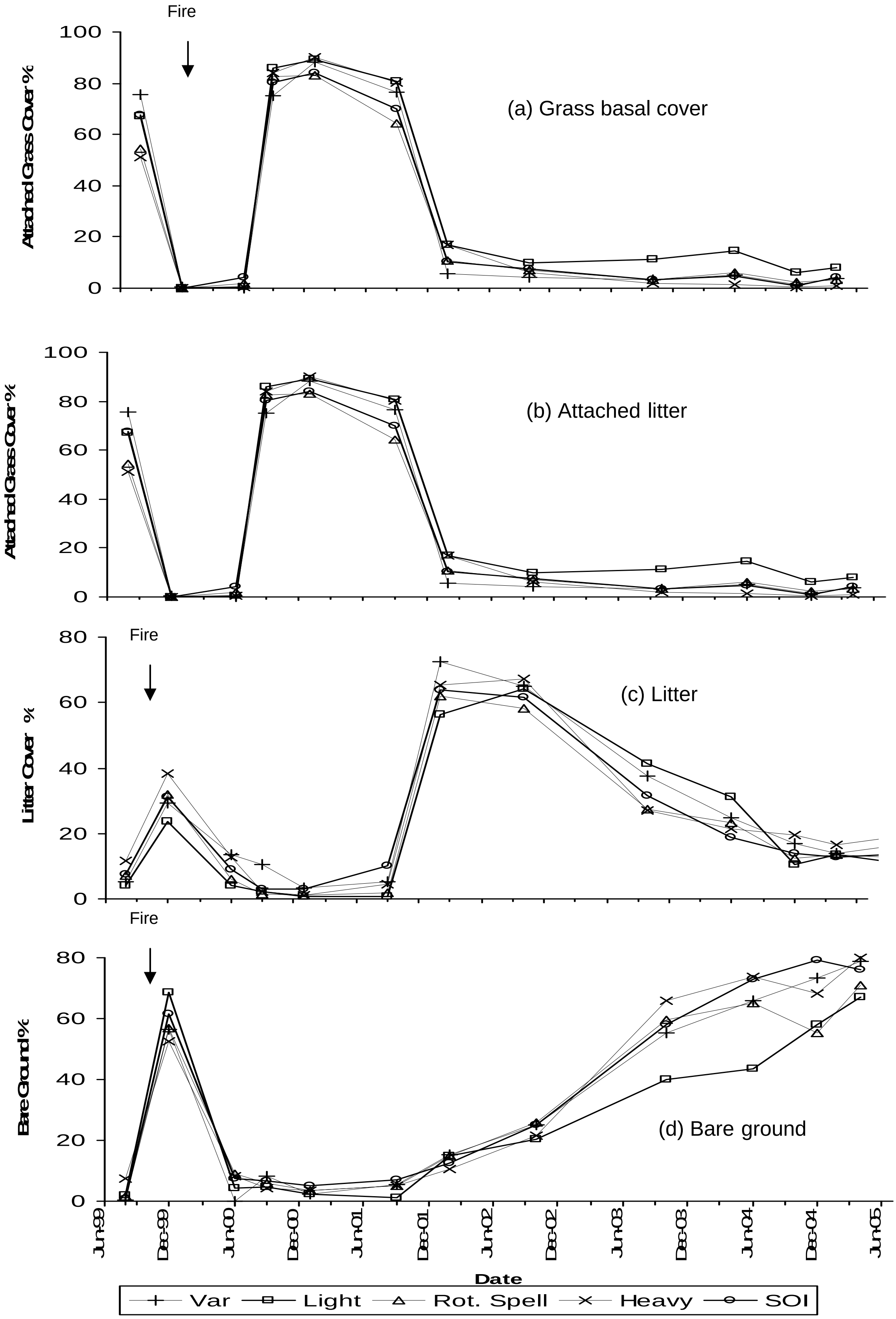


Figure 17.1: Change in (a) percentage grass basal cover, (b) percentage attached litter, (c) percentage litter and (d) percentage bare ground at five runoff catchments from July 1999 to April 2005 on different stocking strategies at the Wambiana trial

16.4.2 Cover

Ground cover and its various components changed dramatically between August 1999 and May 2005 (Fig. 17.1). Ground cover was high during the good seasons of 2000/01 with most cover being provided by attached plant material. However, as rainfall declined into 2001/02, attached cover decreased due to detachment, grazing and trampling. This increased litter fall obviously led to the greater litter cover recorded in 2002. Although this litter initially maintained total cover at acceptable levels (<20% bare ground), the low rainfall and relatively greater grazing pressure reduced litter inputs, leading to a rapid decline in litter cover through weathering, decomposition and grazing. Basal cover of grass tussocks also declined through this period from *c.* 4% to under 1% on some sites. The percentage of bare ground present accordingly increased rapidly in all treatments from < 20% in December 2001 to > 70% bare ground in May 2005.

Despite the overriding influence of rainfall on cover, strong treatment differences were apparent with litter and basal cover declining fastest under heavy stocking. For example, in the 2003/04 wet season, there was twice as much bare ground (70% vs. 40%) in the HSR as there was in the LSR (Fig. 17.1). However, current cover levels are fairly similar in both treatments (80% vs. 70% bare ground respectively).

16.4.3 Runoff events

Between ten and twenty runoff events occurred per catchment between 1999 and 2006. The number of events varied markedly between sites due to spatial variability in rainfall and treatment differences in cover, soil health and pasture condition. Mean percentage runoff per event over all treatments was 26% but varied between 1% and 71% depending upon rainfall intensity, antecedent soil moisture and cover (Table 17.1).

Table 17.1: Mean, maximum and minimum values for percentage runoff and the total loss of sediment, N and P from runoff catchments per event over all grazing strategies at the Wambiana grazing trial. Bedload is per annum.

	% Runoff	**Sediment loss (kg ha^{-1})**	**Bedload (kg ha^{-1})**	**N loss (g ha^{-1})**	**P loss (g ha^{-1})**
Mean	26	7	0.718*	442	19
Maximum	71	20	2.837	1900	71
Minimum	1	3	0.019	10	1

The relatively low number of runoff events recorded may be partly attributed to the nature of the rainfall received: although rain fell on 383 occasions, only 27 events exceeded 40mm and only about half of these were of sufficient size and/or intensity to generate runoff. Overall, only six runoff flows exceeding 50mm were recorded. The low number of flows also reflects the low slope of these sedimentary landscapes and the very high cover levels encountered in the early years of the trial. On a small number of occasions runoff events that did occur were not recorded due to equipment failure, lightening strike or flooding from nearby watercourses.

Runoff generally occurred under two different situations: On some occasions runoff was generated by high volume, high intensity rainfall events falling on relatively dry soil at the start of the wet season such as the event on 1 February 2004 (Fig. 17.2). This event had the highest 15-minute maximum rainfall intensity and the lowest cover relative to previous events and recorded a high peak runoff rate. Here, runoff obviously occurred when the rainfall intensity exceeded the infiltration rate of the unsaturated soil, resulting in a sharp runoff peak of relatively short duration (Fig. 17.2).

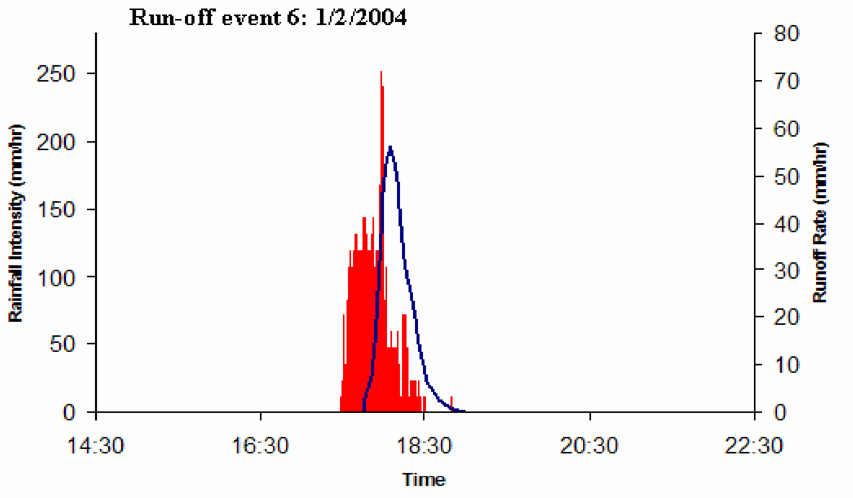


Figure 7.2: Rainfall intensity and runoff rate for a high intensity rainfall event in the VAR treatment at Wambiana.

The majority of runoff events however, occurred later in the wet season when rain fell on soils with high antecedent soil moisture. For example, the event on the 22 February 2000 occurred despite the relatively low rainfall intensity due to the inability of water to enter the saturated profile. This led to a prolonged runoff event with a relatively low peak (Fig. 17.3). Interestingly, although this event required only small amount of rainfall to generate surface runoff it had a very high surface runoff (71%) compared to the high intensity event (27% runoff) which occurred on the relatively dry soil.

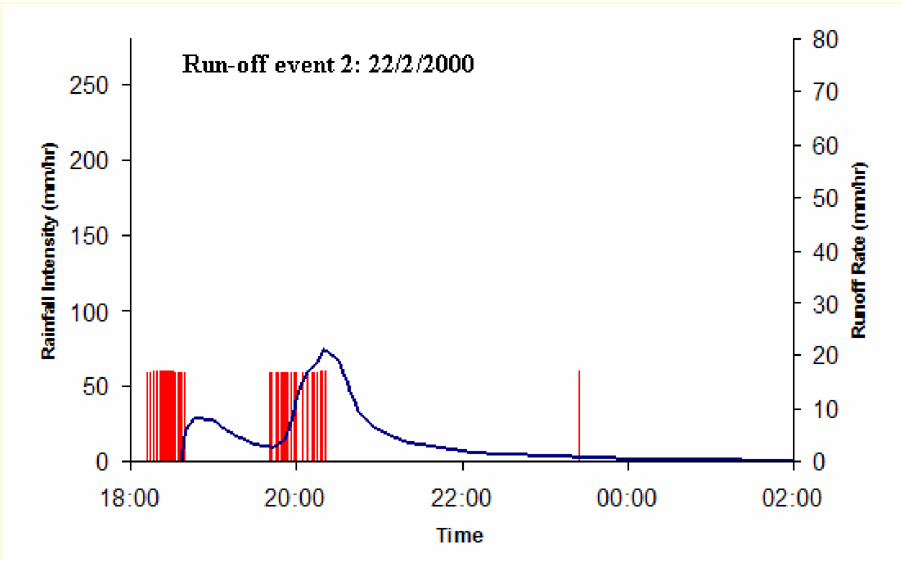
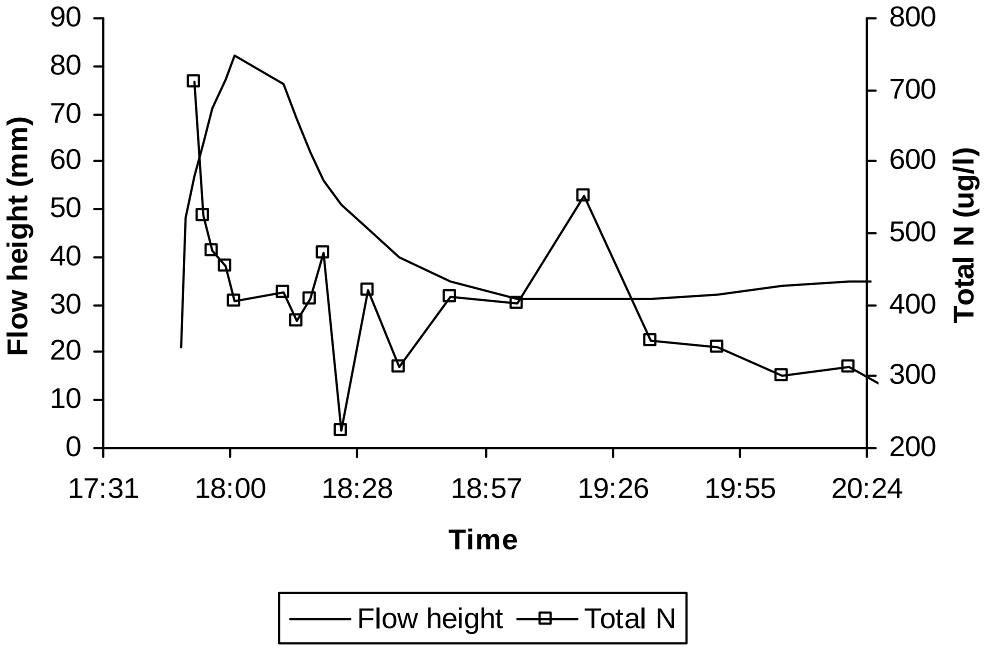


Figure 17.3: Rainfall intensity and runoff rate for a low intensity event in the VAR treatment at Wambiana.

In all events recorded, water flow and the movement of sediment and nutrients followed a typical pattern (Fig. 17.4): once sufficient rainfall occurred to generate runoff, flow height through the flume rose rapidly to peak flood volume. Flow height then declined as overland flow decreased through the event, giving a skewed, sharply bell-shaped curve.



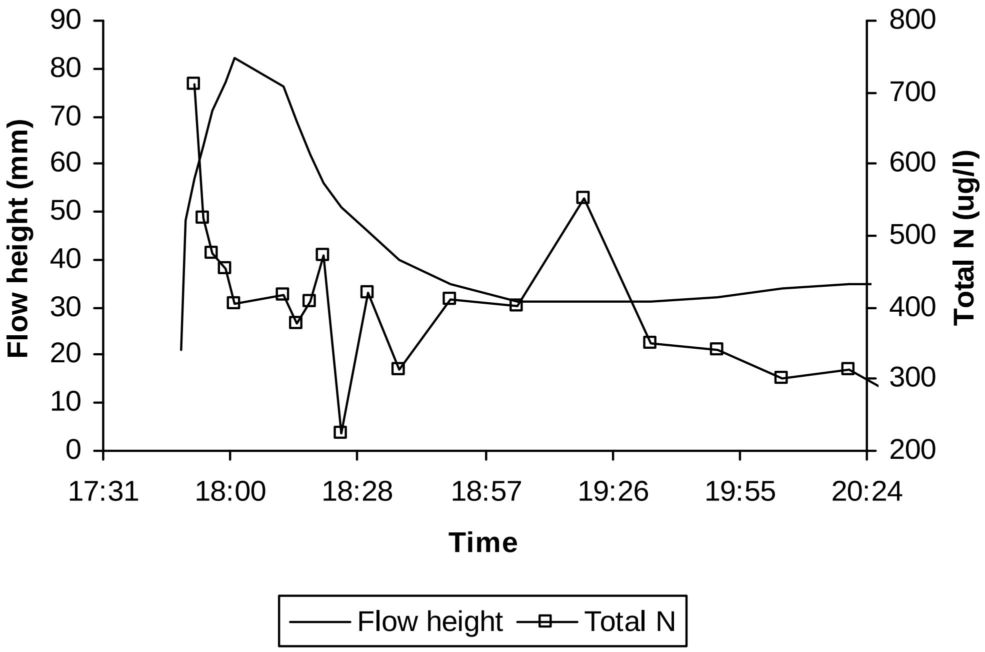


Figure 17.4: Change in Total Suspended Sediment (TSS), Total P and Total N with time through a runoff event at the Wambiana trial.

16.4.4 Treatment differences in runoff events

There were no clear differences between treatments in percentage runoff, particularly through the initial good seasons (data not shown). The lack of a treatment effect is not surprising considering the high cover levels in all treatments through the first five years of the trial. These cover levels in turn reflect the good seasons and the relatively short period over which the grazing treatments had to express themselves.

However, major differences in the frequency and nature of runoff events are beginning to emerge, at least in the HSR and LSR: while flumes in both treatments had similar amounts and intensities of rainfall between 29 November 2004 and 19 January 2005, five runoff events occurred in the HSR compared to only two in the LSR (Fig. 17.5). Runoff events were also larger and of shorter and sharper intensity in HSR treatment. For example, on the 8 January 2005, more than twice as much runoff occurred under heavy compared to light stocking (9cm vs. 4cm): the duration of this runoff event was also shorter and sharper than in the latter treatment.

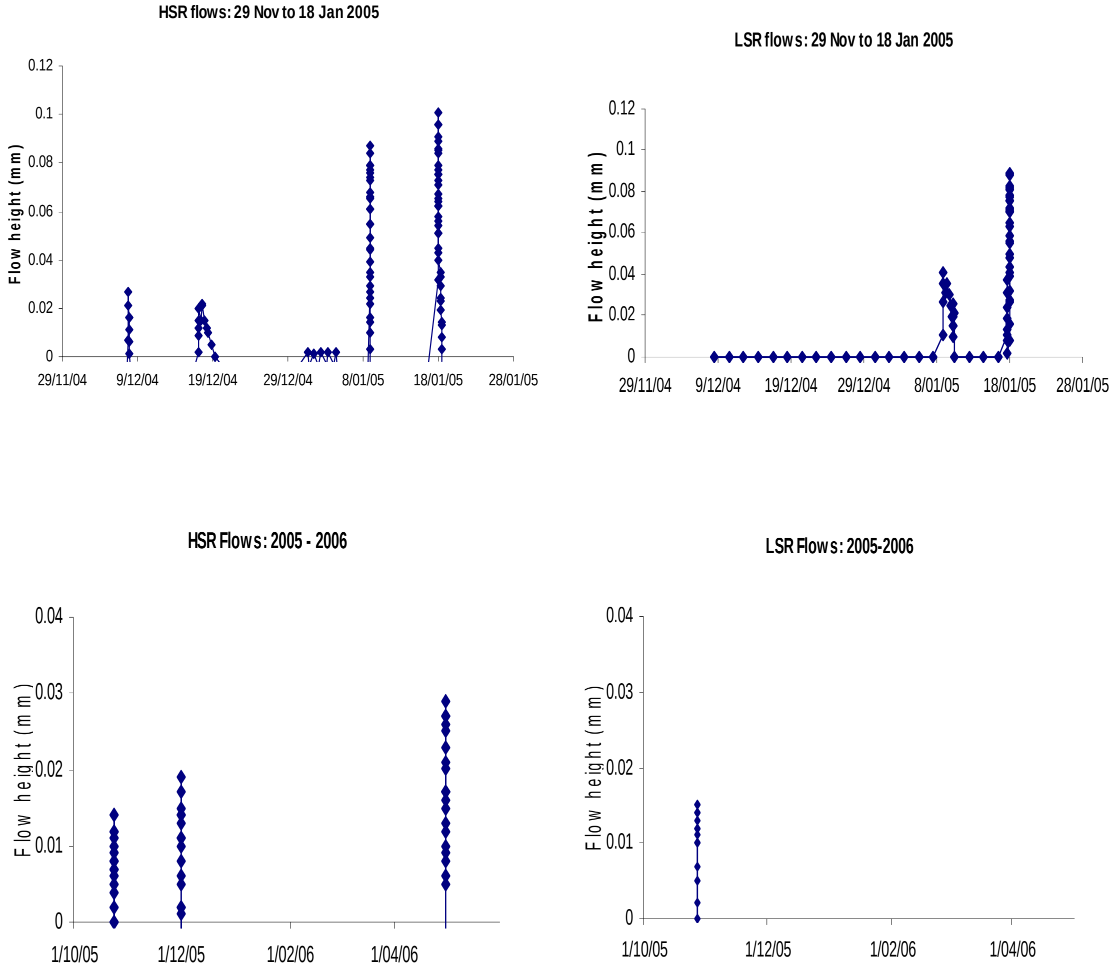


Figure 17.5: Runoff events and flow heights for the flumes located in the heavy and light stocking rates (top) between 29 November 2004 and 18 January 2005 and (bottom) over the 2005 – 2006 season

In a similar fashion, three flows occurred in the 2005-2006 season in the HSR compared to only a single flow in the LSR (Fig. 17.5). What is of interest in both treatments is that relatively small amounts of rain are now triggering runoff events. This contrasts sharply with the earlier years when runoff generally only occurred in conjunction with very large rainfall events. The increased frequency and magnitude of runoff events occurring in the HSR (and to a limited extent, the LSR) obviously reflects the declining cover, soil surface condition and landscape functionality emerging in all treatments. All these factors are likely to reduce rainfall infiltration and increase the amount and speed of water moving off the landscape. This thesis is supported by soil moisture measurements taken over the same period on grassed and bare patches at these flumes: at all sites, soil moisture increased more and too a greater depth following a rainfall event on grassed compared to bare patches. These differences obviously have major implications for rainfall use efficiency, and hence potential pasture growth and green-up, particularly in the late dry season when forage quality and quantity are often limiting.

16.4.5 Water quality and nutrient movement

When runoff did occur, nutrient and sediment levels in runoff water were highest early in the event but declined sharply as the event proceeded (Fig. 17.4). This pattern arises from the flushing of accumulated soluble nutrients and sediment from disaggregated soil in the first flood flow and is in agreement with published trends for both large and plot-scale catchments. For ease of comparison box-and-whisker plots of water quality samples are presented for all treatments in Fig. 17.6. Note that plots were derived from *all* samples collected through the runoff flow in all runoff events for each treatment. Overall, runoff water quality was moderate across all treatments with relatively low concentrations of total N (range: 166 – 6110 µg l^{-1}), total P (range: 12 – 738 µg l^{-1}) and total suspended sediment (range: 3 – 1409 mg l^{-1}) recorded. As the concentrations of sediments and nutrients were generally low, only small quantities of total sediment and nutrient were moved off site with a maximum of only 1.9 kg/ha of N being moved off site (Table 17.1).

Although some treatment differences in water quality appear to be present, these should be viewed with caution given the relatively small number of actual runoff events (n=4) *sampled* in the LSR and R/Spell compared to the HSR (n=12), the VAR (n=8) and the SOI treatments (n=10). Despite these differences in sample size, there is the suggestion that a much greater range of TSS, TN and TP in runoff water occurred in the latter treatments.

However, it is also of interest to compare runoff water quality sampled in the LSR and HSR within individual events in later years. For example, in late 2004 treatment differences were obvious with both TSS and TN being markedly higher under heavy than under light stocking (Fig. 17.7). These trends obviously reflect the changed soil surfaces and runoff characteristics that are occurring within the different treatments.

Comparison of trial water with rivers and creeks

Trial results contrast markedly with those collected from rivers and creeks in the general region (Figs 17.6). Trial water quality was similar to that in the Campaspe River which drains the surrounding flatter, tertiary landscapes on which the trial is situated. This suggests that the present runoff sites provide a reasonably accurate estimate of the sediment and nutrients entering waterways in this area. Trial water quality was however significantly better than samples collected from Oaky Creek and the more distant water Broughton and Burdekin rivers. These differences can be largely attributed to differences in land types, topography and management: for example, in contrast to the trial area, Oaky Creek drains undulating, grano-diorite landscapes with low cover and active hill slope and gully erosion (O'Reagain *pers. obs*.).

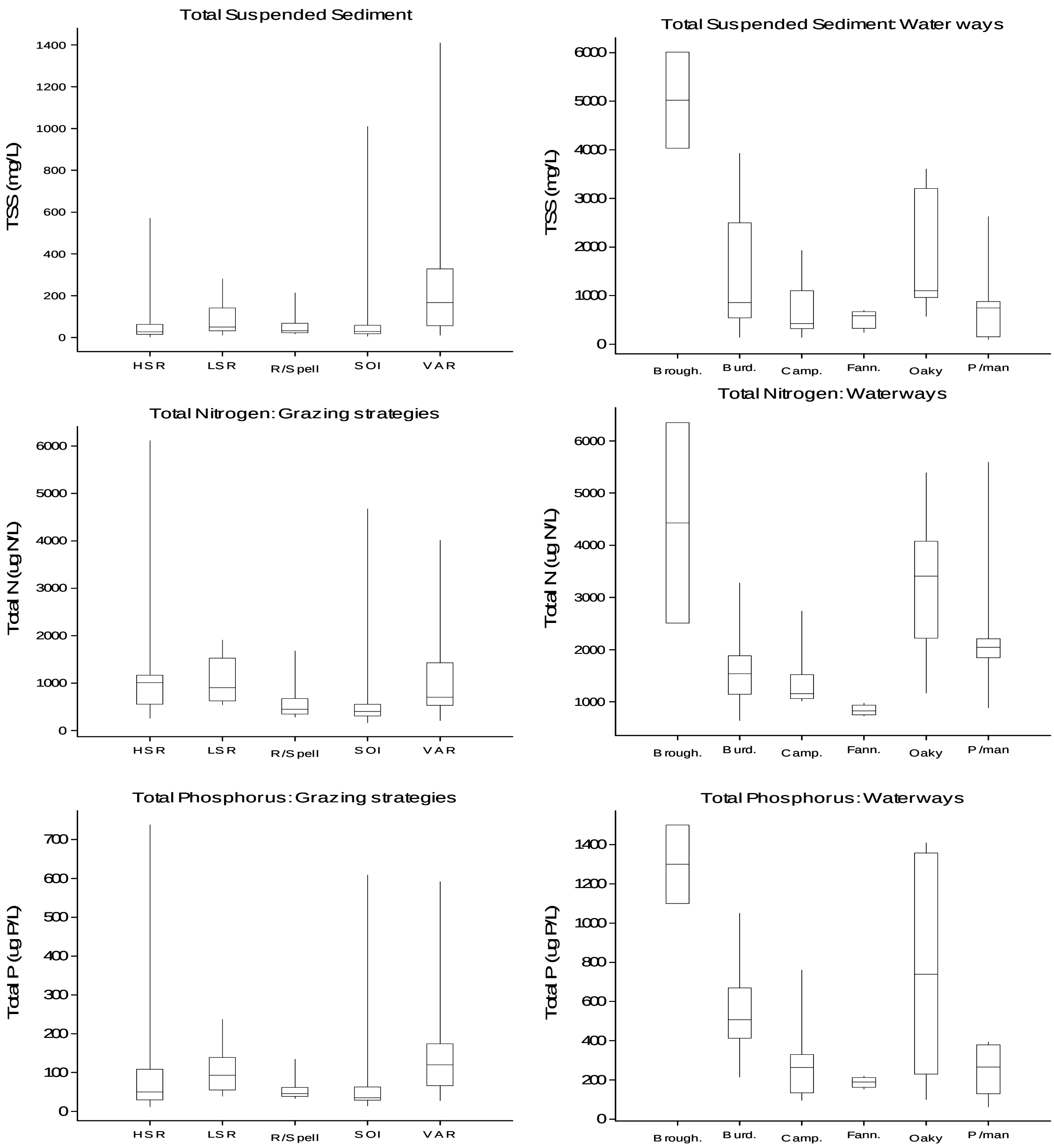


Figure 17.6: Concentrations of total suspended sediment (TSS), total nitrogen (N) and total phosphorus (P), in (left) runoff water collected under different grazing strategies at the Wambiana trial and (right) water samples collected from different rivers and creeks between 2000 and 2006. Note differences in axis scale between figures.

Effect of cover and utilisation rate on water quality

Both TSS *(R^2=21.7; P<0.006)* and Total P *(R^2=9.4; P<0.049)* were negatively related to projected ground cover i.e. water quality declined as cover levels decreased through the trial. Although the predictive power of cover is relatively low, runoff and water quality are also determined by an array of other factors such as rainfall intensity, antecedent soil moisture, herbage mass and soil surface condition. The relationship between water quality and these factors will be explored in greater depth in a later publication.

Annual pasture utilisation rate had no apparent effect on the quality of runoff water sampled in the same year (<1 year). However, TSS, TN and TP in runoff water all generally increased with increasing mean long term utilisation rate (ULTRM) for a particular paddock i.e.:

$$TSS = -41.2 + 9.25*ULTRM\ (R^2=12.1;\ P<0.029)$$

$$TN = 84 + 57.8*ULTRM\ (R^2=10.3;\ P<0.046)$$

$$TP = -55.9 + 9.70*ULTRM\ (R^2=23.0;\ P<0.004)$$

This suggests that while heavy utilisation rates may have little effect on water quality in the short term, in the longer term water quality will decline as the effects of heavy pasture utilisation on factors such as cover and soil surface condition accumulates and runoff is increased.

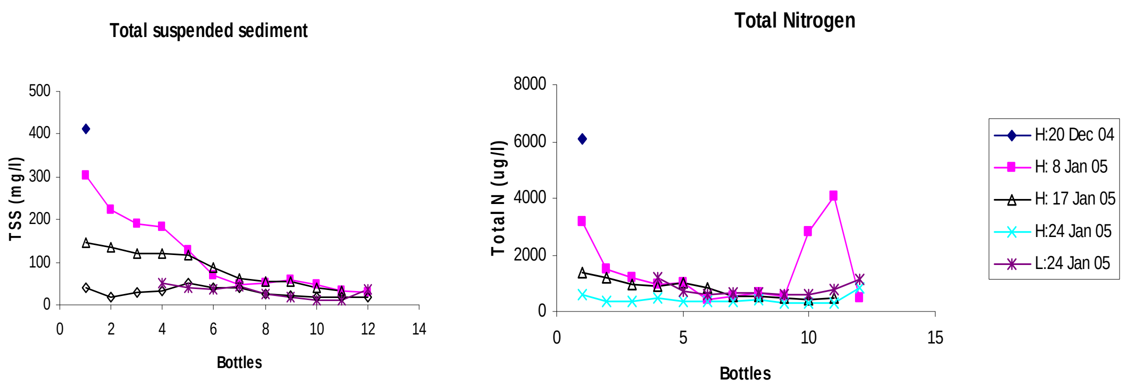


Figure. 17.7: Total suspended sediment (Top) and Total N (bottom) through an event for different runoff events in the heavy (H) and light (L) stocking rates between 20 December 2004 and 24 January 2005*.*

Effect of cover and utilisation rate on bedload

Total bedload movement was low in comparison to other studies with a maximum of 2.83 kg/ha being moved in any year (Table 17.1). Combined with TSS, the maximum total sediment loss recorded per unit area was thus only about 22 kg/ha.

Total bedload collected per annum was negatively related to grass basal cover and projected ground cover, but, as expected, was positively related to the percentage of bare ground (Fig. 17.8). Although the data set is relatively modest (n=15), the relationships suggest that bed load movement increases sharply once grass basal cover or ground cover decline below about 1.5 % and 50 % respectively (Fig. 17.8). There was however, considerable variation in bedload movement below these cover levels due to the factors discussed above such as rainfall intensity, antecedent soil moisture etc. Overall bedload movement was positively correlated with the long term mean utilisation rate (ULTRM) of a paddock:

$$Bedload\ (g/ha) = -271 + 691 * ULTRM\ (R^2=0.22;\ P<0.042)$$

As discussed in previous chapters, these utilisation rates are paddock means and do not necessarily reflect the actual utilisation imposed on the runoff site. Nevertheless, these rates are likely to be a good index of the accumulated long term utilisation experienced by the different paddocks up to the particular year in which the bedload was collected.

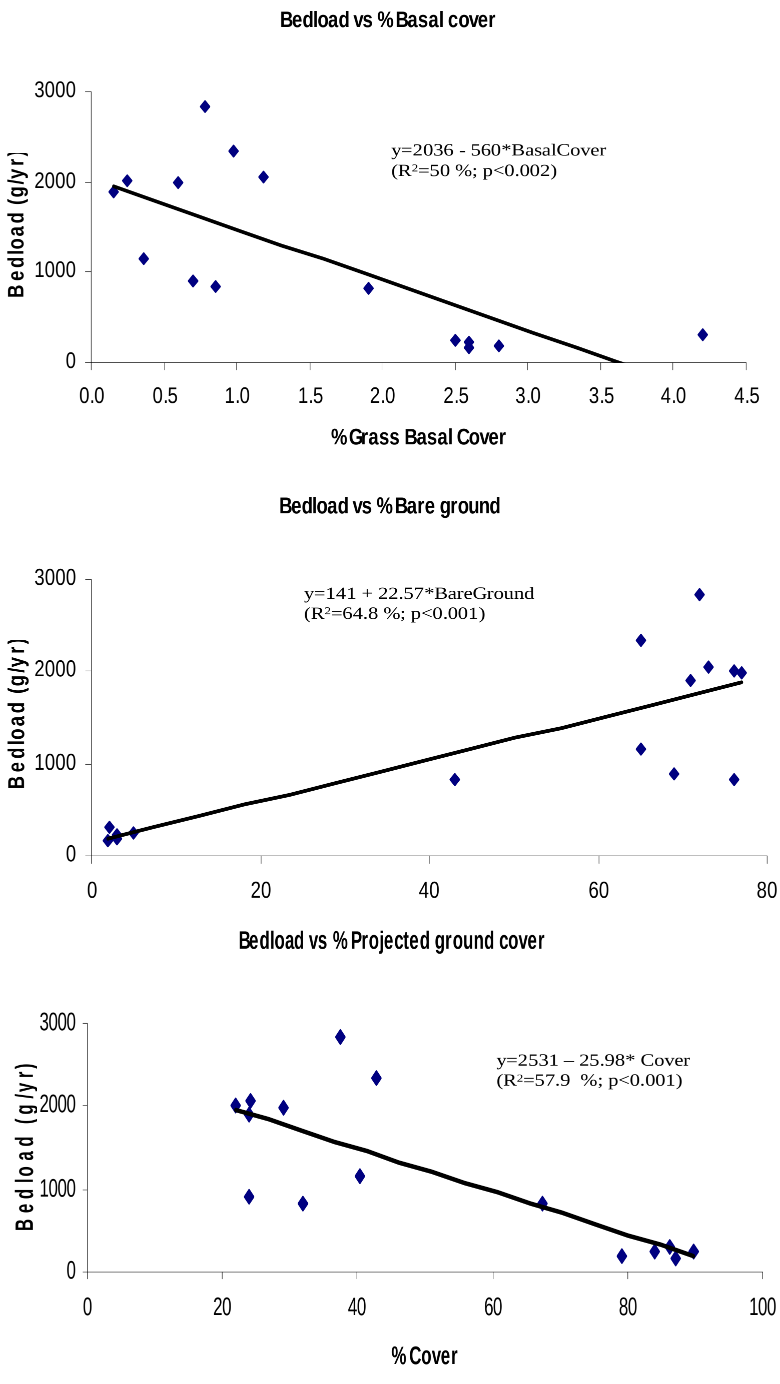


Figure 17.8: Relationship between bedload and percentage grass basal area, percentage bare ground and percentage projected ground cover at the Wambiana grazing trial

16.5. Discussion

Initially, there were few if any treatment differences in runoff and water quality due largely to the very high cover levels encountered and the generally low intensity of rainfall experienced. However, with time and the continuing run of dry seasons, differences are starting to emerge with an apparent increase in the frequency and intensity of runoff events under heavy stocking. Given that measurements collected in associated Tropical Savanna-CRC projects indicate significant differences between treatments in landscape functionality (Dawes-Gromadzki, *pers. comm.,* *CSIRO SE, Darwin)* these differences in runoff and nutrient loss are likely to become more pronounced in the next few seasons.

Relative to other studies, total sediment loss per unit area was surprisingly low with total soil loss (suspended sediment and bed load) varying from 3 to a maximum of 20 kg ha^{-1} per event. Although comparable data are not available, losses of N and P from the runoff catchments also appear low. In comparison, sediment movements of 40 to 590 kg ha^{-1} per annum have been recorded from small (13 km^2) catchments dominated by *Bothriochloa pertusa* on grano-diorite landscapes east of Charters Towers (Roth, Prosser *et al.* 2003). Similarly, Scanlan *et al.,* (1996) reported sediment movements of 10 to 1000 kg ha^{-1} per annum from small runoff plots (250 – 1200 m^2) on grano-diorite landscapes near Charters Towers and undulating, sedimentary landscapes near Greenvale.

Comparisons between different data sets should, of course, be conducted with caution, given differences in methodology, scale, land type, rainfall and cover between different studies. Nevertheless, the measured rates of soil loss at the Wambiana site suggest that these relatively flat tertiary sediments contribute substantially less per unit area to overall sediment loads than steeper, more erodible, grano-diorite and sedimentary landscapes in other parts of the Burdekin.

The present data suggest, that at least on the relatively flat, sedimentary landscapes of the Burdekin catchment, extensive cattle grazing is compatible with achieving an acceptable standard of water quality, provided adequate levels of ground cover are maintained. In contrast, data from creeks and rivers in the catchment suggest nutrient and sediment loss is a serious issue on certain land types, particularly those of grano-diorite origins. Aside from their obvious consequences for water quality, these losses will ultimately have serious implications for the long-term productivity and sustainability of grazing operations in these areas.

16.6. Summary

1. Ground cover was initially high during the earlier good seasons but dropped sharply in later years due to below average rainfall and grazing pressure. Grass basal cover declined from *c.* 4% in 1999 to about 1% in 2006, while the percentage of bare ground increased from <20% to more than 70% over the same period.
2. Ten to twenty runoff events occurred per runoff catchment between 1999 and 2006. The number of events per site varied markedly due to spatial variability in rainfall and treatment differences in cover and pasture condition. Mean percentage runoff per event over all treatments was 26% but varied between 1% and 71% depending upon rainfall intensity, antecedent soil moisture and cover etc.
3. Overall, treatment differences in the amount and percentage of runoff were small, particularly in the initial, high-cover years. However, large differences in the frequency and nature of runoff events have started to emerge with the HSR having five vs. two flows in 2004/05 and three versus one flow in 2005/06 relative to the LSR treatment. The duration of the HSR runoff events also appear to be shorter and sharper than in the LSR.
4. Nutrient and sediment levels in runoff water followed a typical pattern through events with nutrients and sediments being highest in the first flush of water but declining rapidly as the event proceeded.
5. In general, water quality was moderate across all treatments with relatively low concentrations of total N (TN), total P (TP) and total suspended sediment (TSS) in runoff. Accordingly, only small quantities of sediment and nutrient were moved off site relative to that measured in other studies on steeper, more erosive land types.

6. In later years treatment differences started to emerge between the HSR and LSR with TSS and TN appearing markedly higher under heavy than under light stocking. These trends obviously reflect the changed soil surfaces and runoff characteristics emerging between the different treatments.
7. Trial water quality was similar to that from nearby water courses like the Campaspe River but was markedly better than samples collected from Oaky Creek and the Broughton and Burdekin rivers, which carried relatively high sediment and nutrient loads. These differences can be largely attributed to differences in land types, topography and management.
8. Both TSS and TP were negatively related to projected ground cover i.e. water quality declined as cover levels decreased through the trial. Annual pasture utilisation rate had no apparent effect on water quality but TSS, TN and TP levels increased with increasing mean long term utilisation rate (ULTRM) for a particular paddock.
9. Total bedload movement was relatively low with a maximum of 2.83 kg/ha being moved in any year. Combined with TSS, the maximum total sediment loss recorded per unit area was thus only about 22 kg/ha. Total bedload movement was negatively related to grass basal cover and projected ground cover but was positively related to the percentage of bare ground.
10. In summary, while there were initially few if any differences between grazing strategies, treatment differences in the frequency, nature and quality of water in runoff events have emerged in later years. In particular, heavy grazing appears to increase both the frequency and intensity of runoff events, leading to a corresponding increase in the loss of sediment and nutrients.

17. Summary of findings

17.1. Introduction

The Wambiana trial tested the ability of a range of grazing strategies to cope with climate variability over eight years (1998 - 2006). The objective was to develop principles and guidelines to assist graziers in managing sustainably and profitably in a variable climate. Grazing strategies tested were constant heavy stocking rate (HSR), constant light stocking (LSR), variable stocking (VAR), a Southern Oscillation Index (SOI) – variable strategy and a rotational wet season spell (R/Spell) strategy. Apart from the SOI, all strategies are currently used in one form or other by graziers.

17.2. Seasonal conditions and grazing pressure

Seasonal conditions changed sharply over the course of the trial (Chapter 5*)*
Rainfall varied markedly with four good years followed by five consecutive below-average seasons. The number of growth index days between seasons also varied substantially. Pasture TSDM varied five-fold from nearly 5000 kg/ha in 1999 to well below 1000 kg/ha in 2006. In the VAR and SOI strategies stocking rates were accordingly very high in the early wetter years (*c*. 4 ha/LSU) but were reduced to *c.* 10 ha/LSU in later drier years as pasture availability dropped sharply. In 2005 stocking rates in the HSR paddocks also had to be reduced by about 30% due to an extreme shortage of feed.

Pasture utilisation rates fluctuated with treatment, season and soil type (Chapter 6)
Annual pasture utilisation rates for all strategies were initially low (<20%) but increased 3 to 6 fold in 2001/02 and 2002/03, depending upon treatment**.** Utilisation rates later declined with reduced stocking rates but remained very high (> 70%) in the HSR, despite the forced reduction in stock numbers in 2005. Cage-based utilisation estimates agreed well with GRASP predictions but highlighted large differences in utilisation between and within soil types. Generally pasture utilisation was the highest on the Brigalow (heavy clays) followed by the Box and then the Ironbark soils.

17.3. Animal production and economics

Individual animal production was greatest at lighter stocking rates (Chapter 7)
Individual live weight gain per head (LWG/hd) varied between 70 to 170 kg/hd/year depending upon rainfall. LWG/hd was consistently higher under light (mean: 126 kg/hd) than under heavy stocking (mean: 96 kg/hd), with the VAR (113 kg/hd), the SOI (111 kg/hd) and the R/Spell (112 kg/hd) intermediate between these levels. These treatment effects largely depended upon the stocking rate applied in a particular year for a specific treatment. Treatment effects were strongest in the dry season when animals in heavily stocked paddocks frequently lost weight: there was no evidence of subsequent compensatory growth by these animals. After two years on the trial, cattle from lighter stocking treatments were accordingly 50 to 100 kg heavier than those from heavily stocked paddocks.

Better LWGs resulted from superior diet quality under light stocking (Chapter 12)
Diet quality was primarily determined by rainfall distribution and green days. However, management was also important, with dietary crude protein and *in vitro* digestibility being consistently higher under lighter stocking. These differences were relatively small but significantly affected LWG in these relatively nutrient poor environments.

GPS collars also indicated that LSR animals walked about 1 kilometre less per day and spent more time resting around waters, than those in the HSR (N. Tomkins, *pers. comm*., CSIRO, Rockhampton). Increased time available for other activities like rumination and/or resting and reduced energy expenditure would also directly impact upon LWG.

Better LWG/hd gives a superior quality product (Chapter 7)
Frame growth and body condition were consistently greater under moderate than under high stocking rates. Better body condition through the season will directly improve marketability and marketing opportunities. Lighter stocked steers returned a better price per kg because of superior carcass condition and weight for age, than those in the HSR. This factor, combined with greater carcass mass, gave a greater return per carcass for animals from lightly stocked treatments.

Rainfall and utilisation rate predict LWG (Chapter 8)
LWG/hd was dependent upon total annual rainfall and, in particular, the number of the growth days per year, although dry season (June-November) rainfall was the best predictor of performance. LWG was negatively related to the annual pasture utilisation rate and in nearly all years declined as stocking rate increased. For the variable strategies (VAR and SOI), the previous seasons utilisation rate was also important as this directly impacted upon the carry-over of feed, and presumably, wet season pasture performance.

Dry season animal performance
Dry season (DS) animal performance was primarily determined by DS rainfall, urea supplementation and pasture TSDM. Urea mediates the response to rainfall by (a) reducing the total weight loss in low rainfall years and (b) increasing the LWG response from about 3.7 to about 4.4 kg LWG per 10mm of DS rainfall. In years with low DS rainfall, target start-of-dry pasture TSDM of 2000 kg/ha and DS utilisation rates of 30-40% should ensure positive LWG for urea supplemented animals.

High stocking rates gave the greatest LWG per unit area but at a cost (Chapter 7 & 8)
LWG/ha varied between years depending upon rainfall and stocking rate. Overall, LWG/ha was greatest in the heavily stocked strategies, with production in the early, wetter years being almost twice that in the LSR. However, this difference narrowed considerably in later years as rainfall declined and treatment effects emerged. In the VAR and SOI strategies, LWG/ha also declined as stock numbers were reduced.

Beyond the first years, the extra LWG/ha in the HSR came at a cost, with drought feeding required over the last three dry seasons, as well as short term agistment in 2004. In May 2005, the stocking rate also had to be reduced by *c.* 30% in the HSR due to feed shortages. This suggests a drop in carrying capacity and productive ability in this treatment which may persist for some time depending on rainfall and subsequent stocking rates.

The economic benefits of heavy stocking are penalised by higher costs and lower product value (Chapter 13)
Gross margins in the early wet years were initially highest in the HSR ($3 522/100 ha) but dropped to negative levels in later dry years, with losses of $ 1527 /100 ha. In comparison, gross margins under LSR were positive in all years, irrespective of rainfall. Gross margins in the HSR were penalised by the high interest costs on livestock capital, the costs of drought feeding and agistment and market penalties due to poorer carcass grades.

When does heavy stocking pay?
A sensitivity analysis using trial data was conducted on the marginal return per extra LSU in the HSR (above those in the LSR) under different rainfall, interest rate and price structure scenarios. The analysis indicates that under heavy stocking a positive return *per extra* LSU (above those in the LSR) only occurs in good rainfall years, when interest costs are < 10% and the price penalty for poorer condition cattle is below $0.20/kg. Note that this analysis was limited to the eight years

of trial data and does not account for any longer term changes in land condition and it's associated effects upon animal production.

Economic performance of variable stocking
For the variable stocking strategies (VAR and SOI) increasing stock numbers in the wetter years was very profitable, at least during the good seasons. However, this benefit was neutralised by the losses associated with selling of poor condition cattle with the onset of the dry years and the reduced pasture production. The SOI strategy was particularly penalised because cattle were 'sold' at a loss in November when stocking rate changes occurred.

The sharp downwards adjustment in stocking rate in the SOI and VAR nevertheless allowed gross margins to recover in subsequent seasons because both strategies avoided the production costs and price penalties incurred by maintaining high stock numbers in the dry years.

VAR and SOI have the potential to combine the higher GMs from higher SRs in a series of wet years with the higher GMs of moderate SRs in a series of dry years. However, not being 6-12 months out of sync wrt stocking rates and pasture growth and avoiding losses in trading of stock present significant challenges. How such a strategy would cope with a sequence of years that alternates between a wet years and a dry year, rather than a series of similar years, is highly problematic. The practical application and benefit of trying to continuously align SRs with forage availability (current and/or prospective) therefore remains highly uncertain.

Over the period of the trail, continuous set-stocking at a moderate stocking rate gave the best economic performance
Accumulated cash surplus was greatest in the heavily stocked strategies (HSR, VAR, SOI) and lowest in the LSR, in the initial wetter years. After nine seasons however, this situation had changed substantially with accumulated cash surplus highest in the LSR and VAR ($17 410/100 ha) and lowest in the HSR ($10 112 /100 ha). For a 20 000 ha property this difference equates to an extra $ 140 000 of income over 9 years.

17.4. Pasture condition and yield

Rainfall is the major driver of pasture species composition (Chapter 9).
Pasture species composition changed markedly over time on all soil types. This was largely driven by rainfall with the frequency of weaker pasture species plummeting in response to an 11 month drought period in 2002/03 and an outbreak of army worm in March 2003. Most perennials (*B. ewartiana, D. sericeum, E. mucronata*) experienced some tussock death but were relatively drought tolerant. However, perennials like *H. contortus* and *A. calycina* and as well as other weaker species like *P. effusum* suffered almost 100% mortality.

The results clearly show that perennial species like *B. ewartiana* and *Dicanthium* form the matrix within which other weaker species fluctuate with rainfall. These perennial species are accordingly the foundation of the forage supply on any property.

Management also affects species composition
The frequency of *B. ewartiana* and *H. contortus* increased, and the frequency of the annual grass *S. fragile* decreased over the course of the trial under light stocking. Spelling also appeared to favour *B. ewartiana* and *H. contortus.* Although long term *average* utilisation rates in the SOI and VAR were relatively low, *B. ewartiana* and *C. fallax* frequency declined in these treatments due to very heavy utilisation in the seasons immediately preceding the 2002/03 drought. The frequency of *Aristida* spp. increased under high strocking rates but eventually declined in the HSR due to its apparent sensitivity to persistently high grazing pressure..

Effects of management and drought on 3-P species are persistent (Chapter 11)
In 2004 after six years of the trial 3-P basal cover was 3 to 4 times greater in the LSR than in the VAR, SOI or HSR. In the R/Spell, basal cover was intermediate between these levels. Importantly, basal cover was not related to *average* pasture utilisation rate (1998 – 2004) but *was* related to the utilisation rate applied in the years preceding the 2002/03 drought.

3-P tussock counts were also conducted in 2006 after nearly nine years of grazing. Across all soil types, 3-P tussock density was highest in the LSR and R/Spell, lowest in the HSR and intermediate in the VAR and SOI. 3-P tussock density was negatively related to both the long term utilisation rate and the utilisation rate applied in specific years in a treatment.

These results suggest that the timing of heavy utilisation in relation to events like drought is of greater importance in determining pasture condition than the average long term utilisation rate. The relatively poor cover and tussock density in the SOI and VAR strategies also indicates that recovery from such an event is very slow, even when stock numbers are cut sharply following such an event.

Rainfall is the major driver of pasture yield (Chapter 10 & 15)
Rainfall was the major determinant of pasture total standing dry matter (TSDM) but this effect was strongly dependent on soil type. Overall, TSDM tended to be highest on the Box (sodosols) and heavy clays but lowest on the Ironbark (kandosol) soils. Pasture grown on the relatively poor condition Ironbark also had a low leaf: stem ratio and was largely comprised of unpalatable wiregrasses like *Eriachne* and *Aristida*.

Net primary production (NPP) increased linearly with rainfall, although the slope and intercepts of these relations varied between soils. This data has allowed the pasture growth model GRASP to be parameterised and calibrated across all soil types at the trial site. GRASP has subsequently generated pasture growth tables for a large range of soil types for use by managers in calculating long-term carrying capacities in the region.

Management is also important in determining pasture yield and composition
Although of lesser significance than rainfall, long term pasture utilisation rate was also an important determinant of pasture TSDM. Although there were initially few treatment differences, from 2001 onwards pasture TSDM was highest in the LSR and lowest in the heavily stocked treatments. By May 2006, TSDM averaged 800 kg/ha over all treatments but had declined to less than 300 kg/ha in the HSR.

Grazing management also affected pasture species composition and the availability of grazeable forage: by May 2006, the percentage contribution to yield of 3-P species in the LSR was double that recorded in the HSR. Conversely, in the HSR the percentage contribution of wiregrasses and annuals to yield was twice that in the LSR strategy.

Pasture composition affects animal production (Chapter 8)
Over all years, total LWG/hd increased with the yield and availability of 3-P grasses, forbs and legumes but showed no relationship with the availability of wiregrass or annual species. For individual years, LWG/hd was generally positively related to the availability of 3-P grasses but negatively related to the availability of wiregrasses in the pasture.

Dry season LWG was also related to species composition and in later years declined as the percentage contribution of wiregrass to start-of-dry yield increased. Dry season LWG was positively related to the percentage contribution of 3-P grasses to start-of-dry yield in some years.

Rainfall and management determine ground cover (Chapter 10)

Groundcover showed a strong but lagged response to rainfall, declining from about 60-70% cover in the early wetter years to only 20-30% cover across all treatments in later years. Management was also important with the best predictor of cover being rainfall and long term pasture utilisation rate.

Treatment strongly affected cover in later drier years (> 2001), with cover being consistently higher in the LSR than in the HSR. However, in 2006 after six below average rainfall seasons, cover was <30% in all treatments and as low as 21% in the HSR. This suggests that for the land types in question, current management recommendations for a target of 40% minimum cover at the end of the dry season will be very difficult to achieve in all years.

Heavy stocking increases runoff and the sediment loss (Chapter 17)
There were few initial treatment differences in runoff due to the high cover levels in early, high rainfall years. Although relatively low compared to other land types, nutrient and sediment loss increased with long term utilisation rate in individual paddocks. Importantly, the number and intensity of runoff events in later years was also greater in the HSR compared to the LSR, particularly with late dry season storms. This increased the loss of sediment and nutrients in the HSR. This increased runoff is likely to directly impact upon animal productivity because of its occurrence in the late dry when forage quality and availability are usually poor.

Print 15: The runoff plot and associated flume in the heavy stocking rate showing the difference in cover and yield between in 1998 (left) and in January 2007 (right).

17.5. Fire

Effect of fire on pasture condition is season dependent
Pasture recovery in the wetter years following the 1999 fire was very rapid on all soil types with groundcover returning to pre-fire levels within 12 months. Fire increased the frequency of *H. contortus* but caused a temporary decline in both *B. ewartiana* and *A. calycina*. Overall, the 1999 fire had little impact upon pasture composition. Similar results were recorded following a second fire on some Box areas in 2000.

However, a fire in 2001 followed by relatively low rainfall caused a long-term drop in cover and the apparent death of many grasses on Ironbark soils. Recovery through the subsequent dry years was slow despite three successive wet season spells. Paradoxically, this fire had relatively little impact upon pasture recovery on the heavy clays, suggesting that the lower fertility and poorer condition of the Ironbark makes these areas relatively fire-sensitive.

Fire has little effect on tree density but changes woodland structure (Chapter 14)
The hot fire applied in October 1999 caused extensive top-kill but killed relatively few trees with mortality rates for different species ranging from 3.5% to 16%. Mortality was greatest for the smallest size classes (<1m) and declined with tree size. Where large (> 12m) trees died this largely occurred where fallen timber incinerated nearby trees.

Virtually all trees resprouted post-fire from basal or epicormic buds causing a major shift in woodland structure from bigger to smaller size classes. The greatest shift occurred in the 1-5m size class. Importantly, some top-killed Box trees that resprouted from basal buds were subsequently killed by a cool fire applied the following year to parts of the R/Spell treatment.

Fire suppresses but does not control *Carissa ovata*

The 1999 fire caused complete top-kill in *Carissa ovata* resulting in a short term decline in *Carissa* cover. However, extensive re-sprouting in the subsequent good seasons ensured that *Carissa* cover recovered to pre-fire levels within two to three years.

Fire can stimulate woody plant recruitment

Burning led to a 30% increase in root-suckers in Brigalow. Fire also stimulated Box, Ironbark and Blackbutt seedling recruitment but most seedlings subsequently died. After three years survival rates of Ironbark seedlings ranged from 0% in paddocks burnt again in November 2001 to 5-10% in unburnt paddocks.

18. Management lessons from the Wambiana trial

18.1. Performance of different grazing strategies

Moderate stocking rate
Continuous set-stocking at a moderate stocking rate gave consistently good LWG, generated good economic returns, maintained pasture condition within acceptable limits and minimised soil loss and runoff despite six consecutive below average rainfall seasons. However, issues of concern are that (1) light stocking without wet season spelling might, in the longer term, lead to some pasture degradation through patch grazing. And (2), in long extended droughts, 'lightly' stocked paddocks could become over-utilised, if stock numbers are not adjusted downwards. This appears to be happening to some extent in the LSR treatment which is currently the second heaviest stocked strategy on the trial after the HSR. Importantly though, the results indicate that a strategy based mainly on continuous grazing is not necessarily inferior to more intensive multi-paddock systems in which the implicit assumption is that continuous stocking is inherently 'bad'.

High stocking rate
Continuous set-stocking at a high stocking rate performed well in the early wetter years giving very good LWG/ha and economic returns without any detectable effect on pasture condition. With the arrival of a series of drier years animal performance dropped and over the last three dry seasons has only been maintained with drought feeding. Accordingly, economic performance has been poor with negative gross margins in the last six seasons.

Pasture condition and cover have also declined drastically, but given that the topsoil and a residual population of 3-P grasses are still intact, cannot be assumed to have collapsed. Runoff and soil loss have also increased but are still far lower than those recorded on other landtypes. The HSR treatment has had a *c.* 30 % drop in carrying capacity and does not appear sustainable, even at this reduced stocking rate, in the medium term.

Therefore, continuous set-stocking at a high stocking rate is unsustainable and unprofitable in any typical sequence of wet and dry years.

Variable stocking using fodder budgeting and/or climate forecasts
Variable stocking (VAR and SOI) shows promise as a means of capitalising on good years but avoiding the economic and environmental risks of heavy stocking rates in low rainfall years. However, the trial also demonstrated the short term economic losses arising when too many cattle are run in good years and a sudden switch to dry seasons occurs. More importantly, the damage inflicted on pasture condition in these transition years is severe. The present data also shows that subsequent recovery can be very slow despite the application of very low stocking rates.

Variable stocking has significant potential but carries a greater degree of environmental and economic risk. Accordingly the strategy requires good management skills as well as firm selling rules and carrying capacity limits to prevent over-stocking in good years. Climate forecasting does add value to the strategy but the present three month lead time, at least for the SOI, reduces its general utility.

Rotational wet season spelling
This strategy originally involved moderate stocking rates combined with rotational wet-season spelling and the appropriate use of fire. Although initially successful, pasture damage and loss of animal production occurred following the 2002 fire and four years of below average rainfall. Stocking rates were cut in 2003 leading to a subsequent improvement in pasture condition.

An objective assessment of the R/Spell treatment *per se* is accordingly difficult but some observations are:

1. Wet season spelling improved pasture condition. This is supported by trial data, other research (Ash *et. al.,* 2001; Healthy Burdekin Catchment Project) and extensive producer experience.
2. Wet season spelling did not appear to buffer the impact of higher utilisation rates on pasture condition, particularly in drier years.
3. Wet season spelling is critical post-fire and may indeed be required for a number of years after burning if recovery is poor.
4. Burning should be applied relatively infrequently and with extreme caution, particularly on less fertile soils.

18.2. Management lessons and observations

The trial has also been valuable in identifying practical problems and issues associated with the implementation of recommended grazing strategies. These are as follows:

18.2.1 Application of an average 'safe' utilisation rate

- The trial has clearly shown the importance of the rate of pasture utilisation applied and, in particular, its timing in relation to specific conditions like drought or good rainfall. This timing may be as, if not more important, than the long term 'average' utilisation rate in terms of its effects on pasture condition and animal production. Such situations can probably only be avoided by being risk averse in stocking rate decisions i.e. erring on the side of caution, and by rapid, flexible management responses to changing conditions.

- Pasture utilisation varies significantly at the patch and land type as shown by the cage-based estimates of utilisation. The *average* utilisation rate in a paddock may be thus be 'correct' but significant over-use and degradation of certain land types can still occur, as happened on the trial. Thus it cannot be assumed that because an acceptable level of utilisation is being applied degradation will not occur. Aside from the basic requirement to fence to landtypes as far as possible, grazing systems must therefore also incorporate spelling and possibly fire to even out utilisation or allow overgrazed patches to recover.

- 'Safe' average utilisation rates based on historical management and/or rainfall records can result in overgrazing during extended periods of low rainfall. This is of particular concern given the expected climate change associated with global warming. Some form of stocking rate adjustment must therefore be used to regulate stock numbers in line with changing seasonal conditions.

18.2.2 Use of seasonal climate forecasts:

Seasonal forecasts like the SOI have enormous potential for managing climate variability, but their use in grazing management remains problematic for the following reasons:

- Integrating forecasts with factors such as feed availability to obtain a composite signal upon which to base management decisions is difficult. Initially, a simple system was used at Wambiana where animal numbers were adjusted to a pre-set stocking rate based on broad categories of herbage availability and SOI values in November (Chapter 5). Subsequently, a more sophisticated system has been devised with stocking rates being calculated partly from a dry season feed and partly, on the predicted wet season growth (See Appendix 8).

- SOI forecasts account for less than 50 % of the variation in annual rainfall, indicating that forecasting skill requires improvement. The SPOTA-1 seasonal forecast currently being evaluated (www.longpaddock.qld.gov.au) has increased skill and a longer lead time but has yet to be released for widespread use. Even with increased skill, climate forecasts should not be used as the sole basis for stocking rate adjustments but should be one of a number of tools used to inform management decisions.

- The current three month lead-time for the SOI restricts stocking rate adjustments too late in the dry season when stock are often not in saleable condition. Stocking rate decisions are very difficult to make in the late dry because early storms can occur and can easily tempt managers to hold on to stock. Other options such as agistment or the purchase of molasses are also often very restricted at this stage of the year.

- The SOI is a regional forecast and skill at the property level is variable and needs verification for individual properties with *Rainman-Streamflow* (Clewett *et. al.,.* 2003). The SOI also does not predict highly stochastic events like early-season storms or cyclones.

- The variation in climate forecasts between agencies is frustrating and undermines confidence in the use of these tools. For the SOI, weekly updates also give changing probabilities that make decision making for next three months very difficult.

18.2.3 Variable stocking with feed budgeting

- Accurately estimating total standing herbage over large, spatially heterogenous areas is difficult, even with detailed pasture surveys. Accordingly, producers can only hope for a rough indication of standing feed in large heterogenous paddocks.

- On a similar note, the actual estimation of 'available' forage is difficult given differences in acceptability between land types and species.

- Paddock yield estimates are generally imprecise whether based upon yield standards or estimated from BOTANAL. Both methods have a large margin of error that increases with pasture TSDM. For example, the standard errors for many BOTANAL yield estimates range from about 200 kg/ha at yields below say 1000 kg/ha, up to 800 or 900 kg/ha for yields of 3000 to 6 000 kg/ha. Given this error it is misleading to assume that stocking rates calculated from feed budgets are precise estimates of short term carrying capacity.

- There is a large degree of uncertainty associated with variables such as losses due to wastage, termites and macropods in fodder budgeting. For example, the pasture wastage factors commonly used are subjective and derived from only one or two studies. In general, wastage is probably directly proportional to TSDM and the leaf: stem ratio of the pasture. When feed is restricted wastage is probably low especially with supplemented animals. It is also suggested that both a wastage factor and a minimum TSDM buffer should be used, as grazing 100 % of pasture would probably inflict serious damage on any 3-P grasses.

- Pasture quality is also important in estimating dry season stocking rates as it will directly impact LWG. For example, in June 2001 a large bulk of standing forage existed in the VAR paddocks indicating that a heavy stocking rate could be safely applied for the following 12 months. However, poor animal performance in the dry season necessitated the subsequent removal and hand feeding of a number of animals from this treatment. This problem might have been avoided by either the provision of urea supplementation and/or the use of lighter stocking rates.

- The potential problem of overgrazing in subsequent seasons is a serious problem in the use of dry season fodder budgeting. When yields are large, estimated stocking rates are often unrealistically high and can well lead to over-utilisation the following wet season especially if poor seasons follow good rainfall years (as happened in 2001/2002). For this reason, stocking rate limits should be set based on long term carrying capacity estimates from GRASP and local knowledge.

- Heavy utilisation during the dry season is assumed to have little impact upon pasture condition, but observations from the trial indicate that this assumption may be invalid. Firstly, while dry season clipping or whipper-snipping of tussocks had no impact on subsequent regrowth in wetter years, in other years, this caused a major set back to pastures. Secondly, perennials like *B. ewartiana* re-sprout both from the tussock base and aerially from old tillers and dry stems. These observations suggest that severe dry season grazing could have a negative impact upon growth in the subsequent wet season.

- The end of dry season minimum pasture residue required to limit runoff and maintain pasture condition for many landtypes is largely unknown. When pasture yields are very low varying this minimum residue in DS feed budgets results in large fluctuations in the estimated stocking rate. For example, with a TSDM of 800 kg/ha, changing the minimum residual yield from 700 to 600 kg/ha results in a doubling of the calculated stocking rate for the dry season. (See Fig. 18.1).

- In poor seasons TSDM can be so low that some allowance must be made for the availability of next seasons growth for grazing, otherwise paddocks would have to be destocked (e.g. very low yields in VAR and SOI paddocks in 2003 and 2004). However, the likely yields for the next season are unknown when the DS feed budget is conducted in May or June.

18.2.4 Wet season spelling

- In dry years the *response of pasture condition* to wet season spelling is often minimal. Areas being spelled for pasture recovery may therefore need repeated spelling, particularly if rainfall is below average.

- *Wet season spelling does not necessarily buffer the impact of heavier utilisation rates* i.e. *c. 35 %* utilisation, on pasture condition, particularly in drier years. As stated before the current results are confounded with the use of fire: nevertheless they suggest extreme caution in assuming that wet season spelling automatically balances the adverse effects of increased utilisation rates.

- In considering the *spelling priority* for different paddocks, areas of relatively poor pasture condition should always be spelled first. While a spelling system is important to ensure that all paddocks receive an occasional spell, the system should be flexible so that spelling is targeted at paddocks that will benefit from spelling the most.

- *Dry season spelling* is generally regarded as having no beneficial impact upon land condition or animal production. However, anecdotal evidence from graziers indicates that while wet season spelling is far more beneficial, dry season spelling does have some positive impact upon pasture condition.

- The decision about exactly *when to lock up a paddock for spelling* can be difficult when there is no definite start to the wet season and/or the start is delayed. Experience suggests that paddocks should be locked up immediately after the first storms so as to capture the benefits of this early rain. In the event of the wet season being delayed, spelled paddocks can be opened if required and then locked up later when the first substantial rains occur.

18.2.5 Use of fire

- *Intense, hot fires that cause top-kill of woody species* have the greatest impact upon woodland structure and density. However, these are dangerous and extremely hard to manage. There are also problems associated with obtaining a permit to burn under the conditions required for a hot, intense fire.

- *Fire is not necessarily good for all 3-P species*: while there is some evidence that burning favours *H. contortus*, results from the present trial indicate that important species like *B. ewartiana* are set back to a certain extent by fire.

- Both hot and relatively cool fires can be used to *reduce the cover of Carissa ovata* but this effect is temporary.

- To avoid damage to pastures f*ire must be used with extreme caution* and strong attention paid to seasonal indicators like the SOI. In general, it is probably not a good idea to burn unless the SOI is above +5 or other climate indicators are also favourable.

- *Wet season spelling post fire is essential*. Provision should be made for a full wet season's rest if required, and if seasonal conditions are poor, spelling in the following wet season to aid recovery.

- *Different landtypes have different fire tolerances* with the optimum burning frequency probably being lower on less fertile landtypes like Ironbark. In contrast, more fertile landtypes like the heavy clays are possibly more tolerant of fire and may possibly be burnt more frequently.

18.2.6 Area selective grazing and management of such areas

- Preferred areas e.g. Blackbutt and Brigalow, are often heavily utilised with little grazing occurring of less preferred landtypes.
- Preferred areas that are kept short by continual grazing can often produce large amounts of forage when managed correctly.
- As mentioned above, average utilisation rates can still result heavy utilisation of these areas.

19. Practical principles and guidelines for the northern savannas

19.1. Rainfall, utilisation rate and pasture condition

19.1.1 Principles

Rainfall is the major driver of pasture species composition, ground cover and yield. Management, in particular the level of pasture utilisation, is also critical and buffers or amplifies the effects of rainfall upon land and pasture condition.

High rates of pasture utilisation lead to a decline in species composition, groundcover and productivity. Importantly, the *timing* of the utilisation rate applied relative to climatic conditions like drought or good rains are possibly just as important as the *average* utilisation rate applied.

19.1.2 Management actions

- Apply light utilisation rates to maintain and improve pasture composition.
- Manage for a variable climate using forage budgeting to avoid overstocking in dry years. Where appropriate, use of climate forecasts like the SOI can inform management decisions (Appendix 8).

19.1.3 Guidelines

Apply appropriate pasture utilisation rates:
- Average utilisation rates of around 25 % of annual growth will generally maintain pasture condition.
- Long term average utilisation rates > 40 % lead to pasture degradation and a decline in carrying capacity, at least in the medium term.
- Similarly, application of heavy utilisation rates (>40 %) in the seasons leading into low rainfall years can also lead to pasture degradation.
- Heavier utilisation rates (up to 40 %) can be tolerated in very good seasons, but should not be applied in dry years or immediately preceding these years.

Dry season forage budgeting is an important tool in managing for rainfall variability
- Stocking rate adjustments should be made as early as possible i.e. May/June. Delaying the decision until late in the dry season increases environmental and economic risk, reduces management options and increases the magnitude of the stocking rate adjustment required.
- Assess pasture availability across all land types – remember that estimated dry season stocking rates are imprecise and manage accordingly i.e. monitor pasture and animal condition and adjust stock numbers as required.
- Use long term carrying capacity figures to set upper limits to stocking rates – these upper limits should not be exceeded no matter how good the season (See Appendix 8).
- Be risk averse in adjusting stocking rates i.e. stocking rates should be decreased faster than they should be increased.

Using climate forecasts
- Only use forecasts if the relationship between property rainfall and the index involved is acceptable.
- Remember that climate forecasts are regional and not property level forecasts.
- Forecasts must be integrated with available forage and other factors in making stocking decisions (see Appendix 8).

- Be risk averse: de-stocking should be conducted at a faster rate than re-stocking.

19.2. Pasture species composition and animal production

19.2.1 Principles

Perennial, productive and palatable (3-P) species form the relatively stable matrix of the pasture resource basis within which weaker more transient species fluctuate. These 3-P species are the foundation of the forage resource on properties and buffer seasonal variation in rainfall.

In general, animal production increases with the proportion of 3-P grasses in the pasture, although annuals can provide short term, high quality forage.

19.2.2 Management actions

Manage to maximise the cover, proportion and vigour of 3-P species in the pasture.

19.2.3 Guidelines

- Total LWG over the season increases by 2 kg per beast for every 100 kg of 3-P grass present/ha in the end of wet season yield.
- Dry season LWG increases by between from 1 to 5 kg per beast for every 10 kg increase in daily allocation of 3-P grasses per animal over the dry season.

See other guidelines for setting stocking rates, spelling and fire.

19.3. Rainfall and animal production

19.3.1 Principles

Rainfall is the primary determinant of diet quality and animal performance: in general the *distribution* of rainfall through the season i.e. green days, is more important in determining LWG than the total rainfall through the season.

19.3.2 Management action

Maximise rainfall effectiveness by maintaining a healthy population of 3-P species and maximising ground cover and soil health.

19.3.3 Management guidelines

Animal production:

- Overall, every 100 mm of rain over the season results in a total LWG of *c.* 13.2 kg per beast per annum.
- LWG per hectare also increases with rainfall with production per area increasing by 2.8 kg/ha for every 100 mm of rainfall.
- Dry season (DS) animal performance is strongly dependent upon DS rainfall – overall, DS LWG increases by *c.* 4.4 kg and 3.7 kg for every 10 mm of DS rainfall for urea supplemented and non-supplemented animals respectively.

Pasture condition: See guidelines above

19.4. Pasture utilisation and animal production

19.4.1 Principles

Lower utilisation rates give superior LWG, frame growth and body condition. For steers this leads to better meatworks grades and prices while for heifers, this would presumably increase reproductive performance. Under heavy utilisation individual animal performance is significantly reduced leading to lower weights and poorer grades at the meatworks.

Diet quality is largely driven by rainfall and green leaf availability but management is also important: diet quality is generally highest at lower utilisation rates due to reduced competition for better quality food items.

19.4.2 Management actions

Apply light utilisation rates to maximise diet quality and animal performance.

19.4.3 Management guidelines

Animal production

- Total LWG was generally maximised at utilisation rates of 20 to 30 % and declined at higher levels of utilisation. At very high utilisation rates animals require extra feeding in dry years.
- Total LWG per animal increases by about 4-6 kg/hd for every 1 ha increase in grazing area available per animal. For Wambiana, individual LWG was best at stocking rates of about 8 – 10 ha/LSU.
- Overall, a 10 % increase in pasture utilisation rate results in a reduction in total LWG of about 11.44 kg/hd over the season.

LWG and Dry season fodder budgeting

- Dry season dietary quality declines as utilisation rate increases: in general a 10 % increase in DS pasture utilisation rate results in a 1.24 % decrease in the *in vitro* digestibility of diets selected.

For positive dry season LWG targets for urea supplemented animals are**:**

- Levels of about 2000 kg/ha for start-of-dry and 1000 kg/ha for end-of-dry pasture TSDM.
- Dry season pasture utilisation rates of 30 – 40 % or less.
- Forage disappearance rates of about 40 – 50 kg/ha/day over the dry season.
- A forage allocation of about 140 – 150 kg/ha/day/LSU to allow selection of a diet of sufficient quality.
- A daily allocation of 50 kg/LSU of 3-P grasses.

These guidelines should also ensure adequate ground cover at the start of the next wet season.

19.5. Animal production per unit area

19.5.1 Principles

In the short to medium term heavier stocking rates give better LWG per unit area in most seasons. However, expensive drought feeding is required unless stock numbers are reduced sharply in poorer seasons. Carrying capacity may also decline in the medium term (< 8 years) further reducing total animal performance.

19.5.2 Management actions

This strategy is not recommended except in exceptionally good rainfall years.

19.5.3 Guidelines

- With every 1 ha increase in stocking rate e.g. from 6 to 5 ha/LSU, total LWG/ha increases by 2.2 kg.

19.6. Economic performance

19.6.1 Principles

In the medium term and given normal seasonal variation, overall economic performance with steers is better under light than under heavy stocking. Performance can initially be good under heavy stocking, but is undermined by high production and interest costs and reduced product value, particularly in dry years.

19.6.2 Management actions

In the medium term, running steers at light to moderate stocking rates optimises economic performance.

19.6.3 Guidelines

- Heavy stocking only gives superior economic performance when rainfall is good, interest rates on livestock capital are low (<10 %) and the condition premium for cattle is < $0.20 /kg.
- Drought feeding (molasses) is very expensive and should be sharply avoided, at least with steers.
- Where stocking rates have been increased in response to good seasons, reduce stocking rates early in line with declining forage availability to avoid damage to pastures and the price penalty associated with selling poor condition cattle.

19.7. Runoff and water quality

19.7.1 Principles

Heavy utilisation increases the frequency and intensity of runoff events, particularly from early storms. Aside from the loss of nutrients and sediments this has obvious consequences for the response of pastures to rainfall, particularly in the late dry season.

19.7.2 Management Actions

Manage to maximise the cover, proportion and vigour of 3-P species in the pasture and ensure sufficient ground cover at the end of the dry season to minimise runoff.

19.7.3 Management guidelines

- Aim for minimum residues of 700 – 1000 kg/ha of pasture at the end of the dry season to reduce runoff.
- In most years, groundcover target levels should be in excess of 40 % at the end of the dry to prevent excessive runoff.

- However, these residue and cover levels may not always be achievable on Ironbark, Box and heavy clay landtypes in extended periods of low rainfall; in these years runoff can be reduced by maximising soil health and the proportion of 3-P species.

See other guidelines for setting stocking rates, spelling and fire for maintaining land and pasture condition.

19.8. Spelling and pasture condition

19.8.1 Principles

Wet season spelling maintains and/or improves pasture condition and allows for pasture recovery following fire.

Spelling may buffer the effects of increased utilisation rates on pasture condition in some areas but the exact nature of this relationship on the present landtypes is unclear.

19.8.2 Management actions

All grazing systems should incorporate periodic wet season spelling.

19.8.3 Guidelines

- Paddocks should preferably be spelled for the whole of the wet season and not just the first few weeks.
- Exercise caution in assuming that spelling allows the application of greater pasture utilisation without a decline in land condition.
- Remove stock from paddocks to be spelled at the start of the wet season after the first effective rainfall (about 50 mm).
- The response to spelling depends upon landtype and season i.e. more than one wet season spell may be needed to allow recovery during dry years.
- Spelling frequency depends upon landtype and pasture condition - always spell the area that needs the spelling the most, but *all* paddocks should be spelled occasionally.

19.9. Landtypes and their management

19.9.1 Principles

Landtypes differ markedly in their productivity, forage quality, attractiveness to cattle and resilience to grazing.

19.9.2 Management Actions

If possible, manage landtypes separately according to individual requirements.

If separate management is not possible in mixed paddocks, manage for the most vulnerable or productive landtypes.

19.9.3 Management Guidelines

- The pasture response to rainfall of different landtypes varies from 200 kg/ha per 100 mm of rain from Ironbark and Blackbutt, to 360 and 560 kg/ha for heavy clays and Box soils respectively.
- The proportion of grazeable forage on Ironbark is far lower than on the Box, heavy clay or Blackbutt soils.

- Heavy clay areas, particularly melon hole Brigalow patches, are strongly selected for in preference to Ironbark – they should accordingly be managed for this increased grazing pressure.

19.10. Fire and its use in management

19.10.1 Principles

Fire is important for managing woodland structure and in the longer term is necessary to suppress woody species and native woody weeds like *Carissa ovata*.

The role of fire in improving pasture species composition is unclear, at least in the present environment. Fire can result in severe damage to pasture and land condition if incorrectly applied.

19.10.2 Management action

Fire has a role in all grazing management systems in the savanna woodlands but must be applied with extreme caution.

19.10.3 Burning guidelines

- Hot fires i.e. those with a large fuel load and applied under warm, dry conditions give maximum top-kill of woody species.
- Hot fires result in a major shift in woodland structure to smaller size classes but tree mortality rates are generally low (< 20 %).
- Fires should generally not be applied unless climate forecasts for the approaching season are favourable, e.g. SOI greater than +5. Burning in drier years should particularly be avoided on more vulnerable landtypes like Ironbark.
- Spell paddocks after fire for a full wet season – however in very good seasons, shorter periods of spelling (6 - 8 weeks) may be sufficient to allow recovery.
- Make allowance for the fact that a second wet season spell may be required to allow country to recover if seasonal conditions are poor.
- Burn low fertility areas e.g. Ironbark areas or those in poor condition, less frequently than better condition and/or more fertile areas like the heavy clays.
- Fire is effective in short term control of *Carissa* cover but causes little mortality. Burning is probably needed every six or seven years to keep *Carissa* under control.
- Fire should not be used in an attempt to promote species like *B. ewartiana* or *Dicanthium* spp, although it appears to have some positive effects on *H. contortus* and may assist in reducing *Aristida* densities.

20. A Proposed system for managing stocking rates in a variable environment

20.1. Issue

Stocking rates must be adjusted in line with changing seasonal conditions and feed availability. This critical management decision has to be made given some knowledge of current conditions but with major uncertainty about future rainfall and pasture availability.

20.2. Underlying principles

- Rainfall is the major determinant of pasture condition and animal production on rangelands but is extremely variable in time and space.
- Stocking rate is the single most important factor under direct control of the manager affecting animal production and land condition.
- Stocking rates must be adjusted in line with rainfall variability to reduce pasture degradation and economic losses in dry years and to take advantage of good rainfall years.
- Present climate forecast systems like the SOI are of only moderate accuracy.

20.3. Uncertainty associated with making stocking rate adjustments

Known variables:

- The amount of forage available for grazing at any time (standing feed), is usually known, at least within rough limits.
- Forage quality is difficult to measure but can be roughly estimated using faecal NIRS, greenness, leaf: stem ratios etc
- Potential forage demand can be calculated from stock numbers and their reproductive status etc.
- The average rainfall, seasonal distribution and variability are approximately know from historical rainfall records.
- The potential pasture productivity of different landtypes (long term carrying capacity) can be roughly estimated via modelling or local knowledge.

Unknown variables

- The major unknown is the amount and distribution of rainfall in the coming wet season and hence expected pasture growth and potential carrying capacity.

20.4. Problems associated with current management systems and tools

Long term 'safe' utilisation rates

- While conceptually useful, graziers (and agency staff) find the utilisation concept confusing and difficult apply in day to day management.
- Long term 'safe' utilisation rates are historical averages and of limited use in making tactical stocking rate decisions.
- Long- term 'safe' stocking rates are based upon historical rainfall data and can still lead to overstocking in the event of decadal or longer term climate cycles or climate change.

Dry season fodder budgeting

- Does not account for expected pasture growth in the following wet season. Hence it can easily lead to overstocking, especially when good years are followed by poor rainfall years, as happened in the present trial.

Climate forecasts are a useful tool but:
- Provide only a probabilistic forecast of likely rainfall.
- Have a relatively short lead time.
- Are difficult to integrate into management decisions.

20.5. Proposed management system

The proposed system integrates the above methods into a single management system for making stocking rate decisions in a variable climate.

The system consists of:
(a) *A primary adjustment point* in May or June at the end of the wet season where stocking rates are set for the next twelve months based on standing feed and expected growth for the following season.
(b) *Secondary adjustment points* in the late dry- (November) and early wet-season (March) when animal performance, pasture availability and climate forecasts are assessed and stocking rates adjusted *downwards* if necessary.

20.6. Application of proposed system

The proposed system involves five steps:

Step 1: Use GRASP pasture growth tables and/or local experience to derive long term safe carrying capacities for different landtypes as done in GLM (Chilcott, McCallum *et al.* 2003). Set upper carrying capacity limits for very good seasons - these limits should not be exceeded not matter how good the season is.

Step 2: At the end of the wet season in May/June set stock numbers for the next 12 months using an integrated stocking rate derived from (a) the dry season stocking rate and (b) the expected ‘safe’ stocking rate for the next wet season (*See Appendix 7 for more detail).*

Step 3: In the late dry season (October/November):
(a) Assess cattle performance, pasture condition and yield relative to targets i.e. is the paddock over or under stocked?
(b) Use climate forecast-stocking rate tools (Appendix 8) to check potential stocking rates for the next wet season relative to the current rate being applied.
In both cases reduce cattle numbers if stocking rates are too high but **do not increase numbers if understocked.**

***Step 4*:** In the early to mid wet season (March) reassess available pasture and animal production in the light of the rainfall received to date.
Again, if overstocked or the season is very poor cut stock numbers but do not increase numbers unless the season is exceptionally good.

Step 5: May/June: Assess progress and performance over previous season in terms of animal production, pasture condition and composition and the relative response to rainfall using relevant tools like the ABCD condition standards in Appendix 5.

Apply adaptive management principles, adjust management guidelines and repeat steps 1 – 5 again.

21. Knowledge Gaps – Further issues that need to be addressed

21.1. Production and economics

What is the relationship between production, economics and land condition i.e. how does land degradation effect animal production and what is the cost of land degradation in terms of reduced economic performance?

How do the present results scale up to whole property economic performance? What is the effect of rainfall, interest rates and beef prices on the relative performance of different strategies?

How do the present results with steers relate to breeder performance both at a paddock and whole property level?

To what extent can productivity and economic performance be increased (relative to ‘traditional’ management) using a combination of sustainable pasture management and the best animal and nutritional strategies?

What are the modelled long term outcomes in terms of economics and land condition, of running the different grazing strategies over different long term (50-100 year) rainfall scenarios?

21.2. Runoff

What is the medium to long term productivity cost of increased rates of runoff and sediment loss? What are the short term costs in terms of reduced rainfall efficiency e.g. in terms of a reduced growing season and lower live weight gain?

21.3. Pasture change and condition

Under what rainfall and management conditions does pasture and land condition change to new states? What indicators of grazing intensity, tussock density or basal cover can be used to determine when these changes are about to occur?

To what extent can increased utilisation rates be buffered by wet season spelling? Is this influenced by grazing system i.e. short intense grazing periods versus longer periods of continuous grazing?

Under what conditions does recruitment and mortality of *B. ewartiana* and other 3-P grasses take place? How long do tussocks live and how can seeding be encouraged?

How far can species composition and basal cover change before irreversible transition to another state occurs? What indices can be used to quantify the susceptibility of pasture to change?

What indices can be used to predict the rate and potential of pasture recovery? For example, how is future recovery related to basal cover, 3-P density and soil condition?

What are the long term effects of pasture change on critical processes like nutrient cycling, infiltration and water availability?

21.4. Carissa

Given bans on mechanical and chemical tree control, how can land with a high cover of *Carissa* be reclaimed to increase pasture production?

What is the relationship between *Carissa* density and the quality and quantity of pasture TSDM produced?

What is the competitive effect of grass on *Carissa* and vice versa? Can *Carissa* density be regulated via grazing management?

21.5. Fire

What is the optimum fire frequency and intensity for different landtypes?

Are cooler, slower fires effective in controlling woody species?

Is burning detrimental to soil health, organic matter and nutrients? What are the comparative effects of grazing on these processes?

21.6. Patch/Landtype selection

What determines patch selection within different landtypes? Can patch selection be influenced or manipulated using spelling, fire and/or different grazing systems?

What is the spatio-temporal pattern of degradation in paddocks? How does landscape heterogeneity change as a pasture moves from good condition to a degraded state?

21.7. Land condition assessment

How repeatable and accurate is the ABCD land condition framework? Is it repeatable across observers, space and time?

Do the ABCD condition states represent meaningful differences in pasture condition or landscape functionality?

21.8. Dry season forage budgeting

What are the wastage and pasture detachment rates for dry season feed? How are these affected by pasture TSDM, grazing intensity and environmental conditions like rainfall?

To what extent does dry season utilisation effect pasture production in the subsequent year?

22. Extension of grazing trial results

22.1. Wambiana Grazier Advisory Committee

A grazier advisory committee (GAC) was established in November 1997 before treatments were initiated or the trial fully established (Table 22.1). The GAC played a major role in the selection of stocking rates for the different treatments. The committee has an annual meeting at Wambiana when the site is viewed and results and issues discussed in detail. Important management issues that arise between meetings e.g. drought feeding, are discussed telephonically after a brief synopsis of the problem has been faxed to all members. The GAC has thus had an important role in the management of cattle and pastures at the site and has, for example, been involved in decisions on supplementation, spelling, fire, the use of HGPs, timing of field days, de-stocking etc. This grazier participation has been actively pursued to maximise the potential for adoption of project outcomes and to encourage discussion, debate and ultimately, acceptance, of the 'sustainable management' message. The experience and knowledge that graziers have brought to the project in terms of land and cattle management has also significantly enhanced the overall relevance of the project to the larger grazing industry and, more importantly, provided a valuable learning experience to the project team.

Table 22.1: Present and past * members of the Wambiana grazier advisory committee, property names and relevant land system

Name	Property	Land system
*Edgar Burnett	'Nairana'	Tertiary sediments
*Therese Stewart	'Doongarra'	Tertiary sediments
David Steele	'Liontown'	Tertiary sediments
John & Ronda Lyons,	'Wambiana'	Tertiary sediments
Dan Goodwin	'Lascelles'	Tertiary sediments
David Black	'Pajingo'	Tertiary sediments
Roger Landsberg	'Trafalgar'	Tertiary sediments
*John Healing	'Warrawee'	Grano-diorite
Bill Mann,	'Lockwall'	Basalt & tertiary sediments
Elton Callcott	'Ellenvale'	Basalt
Peter Leggett	'Helenslee'	Tertiary sediments
*Colin & Alison Brett	'Taemus'	Tertiary sediments

22.2. Grazing principles workshop

A workshop was held with graziers on 24 November 2004 at Charters Towers DPI&F to assess a range of principles and guidelines for sustainable grazing management. The workshop was a very valuable exercise in both obtaining a critical assessment of current management recommendations and capturing a large amount of management experience from the grazier community. A summary of workshop outcomes was submitted to MLA for Milestone 6 of this project.

Print 16: Members of the Wambiana Grazier Advisory Committee viewing trial cattle in May 2000. The committee played a very important role in making management decisions throughout the trial.

22.3. Visitors to trial site

There have been a total of 984 visitors to the trial site since its inception in December 1997. These include 140 research and extension staff, 406 University students, 194 graziers, 125 staff from various agencies and boards e.g. QRAA, *AgForce*, and approximately 199 international visitors.

22.4. Presentations

Numerous presentations have been made on the trial and its results to many different forums and meetings. Between 1997 and 2006 the total audience number would exceed of 1000. Presentations have been given to many Landcare and producer groups, research groups at a national and international level and various government and state agencies. Some of these include:

- Beef 2006
- 2003 International Rangelands Conference in South Africa
- Queensland State Landcare Conferences (2001 & 2005)
- Pigeonhole Field Day in September 2005.

22.5. Edge GLM Education package

The majority of the findings from this project have already been incorporated into aspects of the *Grazing Land Management Education* Package which has been delivered in a number of regions in north Queensland e.g. (Chilcott, McCallum *et al.* 2003). In particular, many of the pasture growth tables used in the course are based on the detailed SWYFTSYND data (Chapter 15) collected over a number of years at the trial site. Other project information incorporated into the package includes the effects of fire on woodland vegetation and the effects of the different grazing strategies on animal performance, pasture condition and economic performance.

Data from the trial site is currently also used in the *Edge Nutrition* package (Anon 2002), specifically the NIRS seasonal trends in diet quality, as well as the animal production and pasture condition data.

22.6. Extension programs

Data from the project is being used in a number of other extension programs. These are specifically *GLM-Plus* currently being established in the Gulf (J. Rolfe, *pers. comm., DPI&F, Kairi Research Station*) and the *Research to Reality* project occurring in North and Central Queensland (B. Nelson, *pers. comm., DPI&F, Charters Towers).* The principles and guidelines from the project are also being incorporated into the DEH funded *Coastal Catchments Initiative* which aims to improve water quality from grazing lands of the Burdekin.

Print 17: Bob Shepherd (DPI&F) discussing land management issues during a visit by rural bankers to the Wambiana trial site in February 2005. The field visit was part of the Rural Bankers Forum organised by the North Queensland Beef Research Committee.

23. Success in Achieving Objectives

Quantify the medium-term (8 years) effect of different utilisation rates and grazing strategies on resource condition, animal production and economic return.
The medium term effects of different utilisation rates and grazing strategies were quantified and their effects on animal production (Chapter 7 & 8), resource condition (Chapters 9, 10, 11 & 17) and economic return (Chapter 13) are reported in detail in this report.

Identify key management principles for the sustainable management of tropical savannas.

A range of key management principles for sustainable grazing management in a variable climate were identified and are presented in Chapter 19.

Develop practical management guidelines that allow graziers to manage their natural resources in a sustainable and viable manner.

Practical management guidelines for sustainable and viable management in a variable climate were derived from this study and are listed in Chapter 19. Guidelines developed include those on the use of fire, adjusting stock numbers, spelling and the use of dry season pasture.

Develop practical decision tools that producers can use in pasture condition assessment and forage budgeting, using climate forecasts to adjust stock numbers and adjusting animal numbers in relation to feed supply.

Practical decision tools for use by graziers were derived from data collected, as well as management experience and insights gathered over the course of the trial. These include tools on forage budgeting, the use of climate forecasts in sustainable management (Appendix 7 & 8), land type sheets and rules of thumb to predict pasture growth on different land types from rainfall (Appendix 5).

Develop empirical relationships that relate pasture production, animal production and soil loss to utilisation rate.

A number of empirical relationships were developed to relate pasture and animal production and soil loss to utilisation rate. Most of these relationships emphasised that the timing of a particular utilisation rate relative to seasonal conditions was of greater importance in determining resource condition than the average utilisation rate *per se*. In general, pasture condition and individual animal production declined as utilisation rates were increased. In contrast, runoff and soil and nutrient loss increased at higher rates of utilisation. The application of heavy utilisation rates immediately before or in conjunction with drought was found to be particularly detrimental to resource condition.

Make at least 60% of producers in the Burdekin and Flinders catchments aware of these principles, guidelines and decision tools.

A major effort has been made to communicate the principles and guidelines for sustainable management emerging from this project to the grazing industry (Chapter 21). This has included presentations to a large number of Landcare and producer groups in north Queensland, numerous site visits by different producer groups, radio interviews and many articles and publications in the rural press. Producers have also been made aware of these principles and guidelines through related extension projects, in particular, the Edge Networks GLM package, as well as other projects like GLM Plus, the DEH funded Coastal Catchments Initiative and Regional Bodies like the Burdekin Dry Tropics NRM.

Exposure of the decision tools has been limited, as these have been under development and testing until recently. These will be communicated to the industry and agencies in the near future via publication of a producer booklet, continued GLM courses and ongoing extension like the QDPI's *Research to Reality* project.

24. Impact on Meat and Livestock Industry

24.1. Economics

Delivering a higher value product in a shorter time
The Wambiana project has shown that LWGs can be significantly improved by applying lighter stocking rates along with appropriate supplementation and HGPs. Such animals grow faster, reach turnoff sooner and are in better condition than those run under heavier stocking strategies. These animals accordingly deliver a more consistent, higher grade, better quality carcass that meets market expectations and returns a higher value.

Reduced input costs
Application of sustainable stocking strategies reduces production inputs in terms of drought feeding, supplementation and the interest costs on livestock capital. In the longer term, mortality rates are also likely to be lower due to reduced animal stress, increased feed availability and a reduced tendency to consume toxic plants.

Increased turnover, efficiency and property performance
With faster growth rates, animals reach target weights sooner for marketing or breeding, potentially increasing property turnover. This increased efficiency, along with reduced costs and a greater product value could improve whole property performance. However this needs further verification with whole property modelling.

Data from the trial also indicates an eventual drop in carrying capacity under heavy stocking, at least in the short term. This reduced carrying capacity as well as the reduced individual animal performance will have obvious costs for property productivity, particularly if carrying capacity does not recover in the longer term.

24.2. Environmental benefits

Improved land condition, increase in ecosystem services
Sustainable grazing strategies improve or at least maintain land condition. Land in good condition i.e. with a healthy proportion of 3-P grasses, has a higher productivity through increased rainfall, improved nutrient cycling and greater rainfall use efficiency.

Sustainable management also reduces the frequency and intensity of runoff events, reducing erosivity and minimising soil and nutrient loss. This directly improves water quality locally but also has far reaching consequences for downstream users and the GBR Lagoon.

Lighter stocking strategies have positive effects on a number of bird species which require better ground cover and pasture TSDM for cover, nesting and feeding (Kutt and O'Reagain 2005). Heavy stocking has a negative impact upon these species as well as a number of other faunal groups through its direct effects on soil surface condition, cover, yield and species composition.

24.3. Community

Reduced need for drought assistance
The present study has clearly shown the economic benefits of lighter and/or variable stocking. Adoption of such strategies could reduce drought risk by firstly, eliminating management induced droughts caused by overstocking, secondly, avoiding the costs of excessive drought feeding and potential losses through animal mortality and thirdly, increasing the resilience of both the business and the environment to cope with natural climatic fluctuation.

24.4. Social

Reduced time and inputs, reduced stress

A major advantage for graziers in adopting sustainable strategies is the reduction in the time spent on drought feeding, monitoring and checking cattle away on agistment and other issues. Management decisions would also be easier to make because more options are available in terms of marketing animals, breeding and the use of fire to control woodland weeds etc.

25. Publications

25.1. Popular publications

Reducing sediment and nutrient loss from pastoral lands of northern Australia: Sustainable Grazing strategies for the Seasonably Variable Tropical Savannas. *Reef Research GBRMPA Vol 9 No. 3 1 December 1999, Pp25 to 28*

Managing Stocking Rates: Stocking for Performance. Frontier MLA *Winter 2006, Pp 6-7*

25.2. Newspaper reports and press releases

"Grazing trial aims to help with drought". *Savanna Links 1 March 1998, P5*

"Fire – Cheap, effective management tool". *North Qld Register 25 February 1999*

"Three rivers meet at Ewan". *North Qld Register 25 February 1999*

"Key Beef Research Role for new Charters towers Centre". *DPI News Release 1 September 1999*

"Run-off study targets rivers reaching reef". *Townsville Bulletin 27 September 1999, P2*

"Grazing effects under review". *Northern Miner 28 September 1999, P8*

"Grazier tour looks at land management issues & woody weeds". *DNR News Release 1 November 1999*

"Clermont graziers Research tour targets grazing, woody weeds". *Qld Country Life 6 January 2000*

"Pasture trial needs funding:". *Northern Miner 3 March 2000, P13*

"Livestock: Safe stocking rate benefit". *Qld Country Life 21 June 2001, P33*

"The Wambiana grazing trial: Preliminary Results". *Community Forum on Water Quality in the Burdekin Catchment 1 December 2001, P7-8*

"Smart farming: Grazing trial's funding boost". *Qld Country Life 19 September 2002*

"On-farm: Grazing strategies for a variable climate". *Feedback Meat & livestock Industry Journal Mar-2003, P6*

"On-farm: Stocking rate reviewed". *Feedback Meat & livestock Industry Journal Mar-2003, P7*

"Northern education: Learning tour for MLA chief". *North Qld Register 13 March 2003*

"Research on forage for world stage". *North Qld Register 31 July 2003, P25*

"Less is more on the Land: Study shows cattle grow healthier, faster on lightly stocked pastures". *Townsville Bulletin 8 May 2004*

"Grazing trial points to benefits of sustainable land management". *North Qld Register 13 May 2004, P20*

"DPI&F heavy grazing update". *North Qld Register 20 May 2004, P41*

"Bugging out on a mighty mite". *Rural Bulletin Jul-2004 P4*

"Rainman". *North Qld Register 18 January 2005*

"Livestock: New Research: Rain man's plan provides edge in NQ". *Qld Country Life 10 February 2005, P45*

"Bankers understand the land". *Northern Muster, Autumn 2005, p29*

"QRAA Board meeting visit – Charters Towers". *QRAA Prime Focus 1 May 2005, P2*

"Good land management increases profitability". *Northern Muster, Winter 2005 p12*

"Praise for patch work". *North Qld Register 6 October 2005 , P10*

"GPS Collars track herds". *Qld Country Life 8 December 2005, P101*

"Risky business: Can sustainable grazing management be economic in a variable environment?". *Beef Frontier Forums 1 May 2006, P12*

"Cattle Health & Nutrition: Stocking rates: Desert Upland Plan for Graziers". *Qld Country Life 3 August 2006, P97*

"Bankers understand the land". *Northern Muster Autumn 2005, P29*

"Testing Grazing Strategies for a Variable Environment". *Desert Uplands News Issue 2, 2005, P4*

"Bankers Forum: Bankers take a walk in graziers' boots". Savanna Links: *CRC for Tropical Savannas Management Jan –June 2005 Issue 31 , P3*

"Mites could give early warning on soil health". Savanna Links: *CRC for Tropical Savannas Management Jan –June 2005 Issue 31 , Pp 14-15*

"Wambiana: the big picture on grazing" Savanna Links: *CRC for Tropical Savannas Management November 2006 Issue 33 , P6-10*

"Grazing trial underway to study rainfall variability". *Prime News: Research & Extension March – April 1998*

"Fire Management: Link fire management to rainfall patterns". *Savanna Links March – April 1999, P8*

"Grazing management……what pays?". *Northern Muster Spring 2005*

"Who stopped the rain (from running off)?". Northern Muster Christmas 2006

25.3. Refereed Publications

O'Reagain PJ, McKeon GM, Day KA & Ash AJ 2003. Managing for temporal variability in extensive rangelands – a perspective from northern Australia. Proc. VII th International Rangelands Congress, Durban, South Africa, July 2003, 799-809. Eds. Allsopp N, Palmer AR, Milton SJ, Kirkman KP, Kerley GIH, Hurt CR & Brown CJ.

O'Reagain PJ, Brodie J, Fraser G. Bushell JJ, Holloway CH, Faithful JW & Haynes D 2004 Nutrient loss and water quality under extensive grazing in the upper Burdekin river catchment, North Queensland. *Marine Pollution Bulletin 51, 37-50.*

25.4. Book Chapters

Ash A.J., O'Reagain P.J., McKeon G & Stafford-Smith M. 2000. Managing climate variability in grazing enterprises: A case study for Dalrymple shire, north-eastern Australia. *In: Applications of seasonal climate forecasting in agricultural and natural ecosystems*. Eds: Hammer, G.L., Nicholls N & Mitchell C. Kluwer Academic Publishers, Dordrecht, The Netherlands.

25.5. Conference proceedings

O'Reagain P.J. & Bushell J.J. 1999.Testing grazing strategies for the seasonally variable tropical savannas. *Proc. VIth International Rangelands Congress*, Townsville Australia, July 1999, 485-486.

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27. Appendix 8: Grazing management tools: the Wambiana SOI method

Note: Use *Rainman-Streamflow* (Clewett *et al.*, 2003) and historical rainfall records for the property in question to evaluate the relationship between the SOI and property rainfall – *if relationship is unsatisfactory, do not use either of the SOI methods listed below.*

27.1. A simple method of using the SOI to adjust stock numbers

Objective: Use simple rules of thumb to adjust stock numbers at the end of dry season (November) in line with available pasture TSDM and SOI forecasts for the coming wet season.
The stocking rate applied should:

- Deliver acceptable dry and wet season animal performance.
- Ensure sufficient ground cover and pasture residue to minimise soil loss at the break of season.
- Avoid over-utilisation of the following wet season's growth.

Note: *Because the SOI has a lead time of only 3 months the time of adjustment is assumed to be late in the dry season in October or November. Stocking rate adjustments could naturally be made earlier if this lead time was increased.*

Step 1: Derive sustainable stocking rates
Use local knowledge and/or GRASP pasture growth tables to estimate low, medium and high stocking rates for different rainfall years for the landtypes involved as done in GLM**.** Stocking rates will be based upon expected pasture production for that landtype and a constant utilisation rate of say, 25 %.

Step 2: Assess standing pasture
Use yield standards to classify the amount of pasture into three or four broad yield categories e.g. very low (<1000 kg/ha), low (1000-2000 kg/ha), moderate (2000-2500 kg/ha) and high (>2500 kg/ha).

Step 3: Assess the SOI for the coming wet season.
Classify the SOI or the climate index of choice into three or four broad categories based upon their broad seasonal outlook. For example, three categories for the SOI could be SOI <-5, SOI > +5 or SOI between -5 and +5 relating to poor, good and moderate rainfall years respectively (Appendix Table 8.1).

Step 4: Select the appropriate stocking rate from the SOI-Pasture yield table
Using Appendix table 8.1 as an example, in a year with high end of dry season forage but an SOI value in November of less than -5, the stocking rate selected would be 'moderate'.

Table 8.1: An example of a subjective stocking rate selector based on SOI value and standing forage in the late dry season.

Standing forage	**SOI Value**		
	SOI < -5	*SOI –5 to + 5*	*SOI > +5*
	Stocking Rate Selected		
High (>2500 kg/ha)	Moderate	Moderate	High
Moderate (>2000 kg/ha)	Low	Moderate	Moderate
Low (>1000 kg/ha)	Very low	Low	Moderate
Very Low(<1000 kg/ha)	Very low	Very low	Low

Management Rules

Rule 1: Stocking rates must not exceed the upper limits to carrying capacity

As described in Appendix 7 the stocking rate applied should never exceed the upper limits to stocking rate calculated in Step 1.

Rule 2: Monitor feed availability with time and manage accordingly.

If wet season rains fail and pastures are being over utilised, stocking rates should be reduced in May (or earlier) to avoid pasture damage. Conversely, if the wet season is very good *do not* adjust stock numbers upwards in May. This is a risk-averse approach and avoids the problem of having to cut stock numbers in the late dry if the SOI for the next wet season is unfavourable. As stated earlier this extra pasture can be utilised in November (if SOI outlook is good) when stocking rates are adjusted again. It is preferable to wait until the stocking rate adjustment in October/November as (a) the relatively low grazing pressure will benefit pasture condition and (b) the excess forage will generally still be available as standing feed for use in the coming dry season.

Rule 3: Rate of change

The methodology could be further refined by setting rules about how fast stocking rates could be changed upwards or downwards.

27.2. A more complicated method of using the SOI to adjust stock numbers.

Objective: Use a more precise method to adjust stock numbers at the end of the dry season (November) in line with available pasture TSDM and SOI forecasts for the coming wet season. As before the stocking rate applied should deliver acceptable animal performance and prevent over utilisation of the pasture.

Step 1: Calculate a dry season fodder budget as outlined in Appendix 7. Note that here the length of the dry season budgeted for is from October/November to the start of the wet season.

Step 2: Calculate expected WS forage production

Using GRASP SOI-pasture growth tables for the landtypes in question, obtain predicted pasture growth years when the SOI is negative, positive (> +5) or neutral (< -5). To reduce risk, use the rainfall expected in at least 70 % of years (decile 30). Discount predicted pasture growth production as before for land condition and tree density etc. Calculate total expected pasture production per paddock, weighting by soil type (Fig. 31.1).

Step 3. Calculate sustainable SR for the following season
Calculate sustainable SR for the expected period March to October (SR_{WS}), assuming animals only graze that season's new growth i.e. there is no carryover of grazeable forage from the previous year. For example, if sustainable utilisation rate is 20 % per annum then the utilisation rate for the new pasture growth for March to October is (20 / 12) *8 months = 13.33 %.

Step 4: Calculate total stocking rate
Calculate total SR_{Total} for 365 days, weighting SR for the period using dry feed and the period using new seasons growth as described Appendix 7.

Figure 8.1: Diagrammatic representation of the Wambiana SOI-Variable method (See text for details).

Management Rules
Rule 1: Ensure that animals have sufficient feed for the dry season
Dry season feed must last until at least the first rains otherwise animals will starve and pastures will be over utilised. Accordingly, SR_{Total} cannot be greater than SR_{DS}. In years when DS forage levels are very low always use the lower of the two stocking rates to prevent feed shortages.

Rule 2: Stocking rates must not exceed the upper limits to carrying capacity
As described in Appendix 7 the stocking rate applied should never exceed the upper limits to stocking rate calculated in Step 1.

Rule 3: Monitor feed availability with time and manage accordingly.
If wet season rains fail and pastures are clearly being over utilised, stocking rates should be adjusted downwards in May (or earlier) to avoid damage to the pasture. Similarly, if the wet season is very good *do not* adjust stock numbers upwards in May.