final report

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Prepared by:	Rodd Dyer, Michael Cobiac, Linda Cafe & Tom Stockwell
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Developing sustainable pasture management practices for the semi - arid tropics of the Northern Territory

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Developing sustainable pasture management practices for the semi-arid tropics of the Northern Territory.

Introduction

Background

This is the final report for the Developing Sustainable Pasture Management Practices (NTA 022) project. This work was partly funded by the Meat Research Corporation (MRC) and carried out by the Northern Territory Department of Primary Industry and Fisheries (NTDPIF). The project aims to develop sustainable pasture management strategies for beef production in the semi arid tropics of the Northern Territoty.

Location and seasonal conditions

Project work was carried out mainly in the Victoria River District (VRD) of the Northern Territory between June 1993 and 1997. The majority of research sites were located at the Victoria River Research Station (Kidman Springs), with others located on surrounding cattle stations. Map 1 shows the location of the Victoria River District and pastoral leases within the district.

Seasonal rainfall between 1993/94 and 1996/97 throughout the VRD has been well above average. This has produced excellent growing conditions for pastures and cattle, particularly in the southern areas (Mount Sanford) which are normally associated will lower and more variable rainfall. Rainfall over the last four years in this area has been above the top 30% rainfall decile, will three of the four years being in the top 10%. This sequence of rainfall would be considered as highly unusual. The central VRD (Kidman Springs) has generally had above average rainfall over the last four years, however not as unusually high as southern areas. Rainfall in most years has been very well distributed ensuring excellent pasture growth and animal condition in these areas. Seasonal rainfall in Katherine has been more variable than southern areas during this period. Rainfall in the 1995/96 season was in the lowest 10% of rainfall years, while 1996/97 rainfall was in the top 10% of records. Rainfall observations and associated rainfall deciles are shown for each season in the table below.

Table 1 Seasonal rainfall and rainfall deciles (% chance of rain) for Katherine, Kidman Springs and Mount Sanford between 1993/94 and 1996/97.

	Katherine		Kidman Springs		Mount Sanford	
Season	**Rainfall**	**Decile (%)**	**Rainfall**	**Decile (%)**	**Rainfall**	**Decile (%)**
1993/94	1052	40	762	30	581	30
1994/95	1007	40	735	40	813	10
1995/96	740	90	608	50	828	10
1996/97	1451	10	683	40	789	10
Average	**970**		**690**		**475**	

The pastoral industry and the live export trade

The pastoral industry of the NT is an extensive cattle industry based on native pastures, supplying environmentally clean beef to local and export markets. The industry in the semi-arid tropics is focused on supplying live-export feeder cattle to Asia. The supply of live export cattle from the NT has increased from 45,000 to 80,000 head between 1989 and 1993, with continued subsequent growth to 200,000 head in 1996. The Victoria River District comprises 30 properties with a total cattle population of over 300,000 head and supplies the greatest number of cattle from the NT to the live export market.

With increasing demand for export cattle, both the industry and government agencies recognised the need for increased productivity while ensuring the sustainability of the pasture resource. Sustainability is considered essential to maintain the long term productivity and profitability of the industry and to cater for the needs and well-being of the wider community. Several issues were of concern, the most important including the assessment of sustainable cattle stocking rates and carrying capacity, managing the increasing size and densities of native woody plants and the use of fire in pasture management.

Stocking rates, carrying capacity and seasonal variability

Pastoralists are faced with a variable seasonal climate, fluctuating annual pasture production, and a range of pasture communities in varying conditions. Under set stocking rates this is associated with changing levels of pasture utilisation by grazing animals and fluctuating animal production.

There is a huge range in the potential productivity and carrying capacity of different pastoral land types, determined largely by the pasture community and land condition. The availability of desirable pasture species to cattle will therefore be determined by season, pasture community, land condition, and stocking rate. McCosker *et al* (1988) found the yield of desirable pasture species was positively related to pregnancy rates in cattle. Increasing stocking rates have also been associated with poor breeder productivity in the Victoria River District (Foran *et al*, 1990).

There is a need for pastoralists to be able to better estimate safe and productive stocking rates that account for seasonal variability, pasture community and land condition. This can be achieved by developing models that explain the relationships between season and pasture growth. Alternatively, producers may operate under flexible stocking rates on a seasonal basis, which allows them to maximise production on a land area basis while maintaining safe levels of utilisation.

Fire management

The reduced use of fire on pastoral land has been associated with increasing size and density of woody plants. Fire had been excluded from normal management on Kidman Springs between 1978 and 1989. During this period, photographic and scientific evidence showed massive increases in woody plant biomass, particularly of rosewood (*Terminalia volucris*) on black soils and a range of shrub and tree species on calcareous red earths (Bastin and Andison, 1990). Field inspection by Dr Bill Burrows confirmed this problem and suggested that it was not confined to Kidman Springs but was occurring throughout the semi-arid tropics of the NT. The Burrows report recommended that urgent research into the use of fire be undertaken to address the problem. Research into the effects of fire frequency, season of burn and fuel load on pasture condition and woody plant response was planned. Investigations into tree-grass relations were also recommended to determine the effects that increasing densities of trees and shrubs would have on annual pasture production.

Extension and Communication

The pastoral industry in the VRD is remote and widespread, with individual enterprises surviving largely on their ability to operate independently. Plans were made to establish local best practice groups at three locations throughout the VRD and Sturt Plateau to identify current best practice, identify research and development needs, and to provide a medium for the communication and feedback of research results.

In order to deal with the issues regarding sustainable beef production in the semi-arid tropics a research program with the following objectives was developed in consultation with the pastoral industry and other research agencies.

Objectives

1. Develop relationships between pasture production, carrying capacity and animal production for the major pasture types in the VRD by June 1996.

2. Examine the role of fire in controlling plant numbers of woody species and maintaining pasture condition on pasture types in the semi-arid tropics of the NT, by June 1996.

3. Examine tree/grass relationships on three pasture types in the VRD by June 1996

4. Involve producers in the planning, investigation and learning processes of project objectives to ensure optimal technology transfer and to contribute to the learning process through local best practice group (LBPG) activities by June 1996.

Results and implications presented in this report are generally preliminary in nature. Final statistical analysis in many cases is incomplete, however it is ongoing. Continuing work in NAP3 will complete and utilise unfinished work and aims to incorporate the results into a whole property framework.

A detailed overview of project outcomes can be found in the section titled Discussions and Industry Implications. Details regarding individual methods and results can be found for each project separately.

Project Summary

(i) Predicting pasture production and carrying capacities
Pastoral properties throughout the Victoria River District (VRD) operate within a complex mix of climatic, soil, pasture type, and land condition influences. Correct decisions regarding cattle numbers (stocking rates and carrying capacities) are essential for successful management, as they determine whole enterprise profitability and future resource sustainability.

Pastoral enterprises in the district are extensive. Properties and paddocks engulf areas from tens to hundreds of squares kilometers. The complex mix of country encountered at the paddock level means that estimation of stock numbers is often difficult and made by trial and error over a number of years. The experience and knowledge of good cattleman is often invaluable when considering the productivity and response of different types of country to grazing.

During this project work has been carried out that will quantify the relationships between the type of growing season and pasture productivity for a range of pasture communities, and will contribute significantly to the estimation of "safe" and productive carrying capacities and stocking rates. This information can be used in conjunction with local knowledge to obtain realistic estimates of carrying capacity and stocking rates for pasture types, paddocks or properties. These calculations will account for

(a) Amount and variability of seasonal rainfall
(b) Pasture type and productivity (i.e. quantity, quality, and stability under grazing)
(c) Land condition

Models describing the growth of Mitchell grass, arid short grass, ribbon/blue grass and tropical tall grass pastures have been developed. Additional work involves the investigation of "safe" levels of utilisation. Preliminary estimates of sustainable stocking rates have been made for these pasture types. Calculated rates were similar to those identified by researchers on similar pasture types in western Queensland. Current land condition must be accounted for when determining levels of utilisation and stocking rates as land in poor condition cannot support the same level of stocking as pasture land in better condition. Predicted levels of grazing utilisation estimated using simplistic methods agreed closely with actual levels for a range of stocking rates in a grazing trial. Safe levels of utilisation have been identified from the Mount Sanford stocking rate trial and are estimated between 20-25%.

Work from this project will provide pastoralists additional information when calculating stocking rates, enable the effects of seasonal variability to be quantified and allow the comparison of grazing and stocking management scenarios. Continuing work in NAP3 will be carried out in conjunction with land managers throughout the VRD. This work will record current stocking rates and impacts on land condition and productivity levels, identify "safe" levels of utilisation from producer experience and to incorporate available knowledge and technology such as GIS to provide estimates of "safe" carrying capacities and stocking rates on a paddock and property scale.

(ii) The effect of increasing tree and shrub densities
Anecdotal and scientific evidence suggests that the size and density of several native tree and shrub species is increasing throughout the VRD. Native shrubs such as rosewood (*Terminalia volucris*) and bauhinia (*Lysiphylum cunninghammii*) are becoming more visible and dominating the ribbon/blue grass communities located on gray cracking clays. Eucalypts (inland bloodwood and silver leaf box), conkerberry (*Carissa lanceolata*) and common hakea (*Hakea arborescens*) are increasing throughout arid short grass pastures on the shallow red calcareous earth.

Pasture production on cracking clay soils dominated by rosewood was not affected by stem densities of up to 400 stems/ha and stem basal areas up to $4m^2$/ha. Competitive effects of Eucalypt woodlands around Katherine and the VRD with stem basal areas between 10-15m^2/ha showed significant increases in pasture growth for two years following tree removal. The limitation to pasture growth may be a result of competition from trees restricting the availability of soil moisture in poor rainfall years, and nutrients in years where soil moisture is adequate. Continuing investigation of Eucalypt woodland sites will monitor yield and available nutrients over a number of years following tree removal.

Although shrub invasions on cracking clay soils did not affect pasture growth for the seasons and densities measured, significant effects may be present throughout areas with greater average shrub size and density distributions. From work by Scanlan and McKeon (1993), modeling the effects of tree competition in monsoon woodlands around Katherine, an increase in tree basal area from 5-10m^2/ha decreased potential pasture yield from approximately 85-90% of maximum to 55% in soils of 100cm depth. This suggests that as tree and shrub densities exceed 10m^2/ha significant reductions in pasture production could be expected. This is confirmed by results from Eucalypt woodlands in Katherine and at Kidman Springs.

Unchecked invasion and growth of native trees and shrubs throughout pastoral land will allow woody plant densities to reach levels that will undoubtedly have far greater effects on pasture production than current levels.

The predicted influence of tree and shrub competition in the GRASP pasture growth model will be validated with data collected from Katherine and Kidman Springs. Season and shrub size-density scenarios will be investigated using GRASP to determine whether current or projected woody plant densities in several shrub and woodland communities are likely to have significant effects at the landscape scale. The economic impact of evaluations of several different woody plant management scenarios will also be investigated.

(iii) The effect and management of fire.
Throughout this research project it has become evident that fire is an essential element of pasture management throughout the semi-arid tropics. Fire plays a necessary role in managing woody plant populations, maintaining pasture condition, managing selective grazing by manipulating grazing distribution, increasing the availability of green leaf to cattle and reducing the hazard of uncontrolled wildfires. The use of fire cannot be ignored. If it is, vegetation change will continue and the risk of pasture degradation will increase. Without controlled use of fire, uncontrolled wildfires will cause widespread and unplanned loss of available feed and over time, cause adverse affects on pastures.

The use of fire must be controlled and deliberate to meet the specific objectives of the manager. There are areas and times where the use of fire is not appropriate nor beneficial. An understanding of fire ecology and the interaction of fire and grazing is essential to ensure that fire is used as a sustainable management tool, not one that will do more harm than good.

Evidence has been provided that justifies the use and non-use of fire for the management of pastoral lands. While the use of fire may not provide immediate economic returns, and any benefits may be difficult to measure in financial terms, the cost of not using fire as part of management will be great. Presently the implementation of controlled fire management in many areas, particularly throughout the drier, southern areas of the VRD is low. Implementing fire management at an extensive scale requires a significant input of resources

Continuing work in NAP3 will incorporate the use of fire into normal paddock management at a practical landscape scale in cooperation with pastoral managers. Demonstrations of this nature will identify constraints to the adoption of extensive burning practices, enable the development of economical and safe controlled burning practices suitable for extensive areas and investigate the interactions between season, burning and grazing at a realistic scale.

(iv) Local best practice groups
Local best practice groups have been established at three locations throughout the Victoria River and Sturt Plateau regions. Several meetings of each group recorded land management best practice and identified priority areas requiring further research and development.

Conclusions

Work undertaken throughout the NTA 022 project has assisted the development of sustainable pasture management practices for pastoral lands throughout the semi-arid tropics of the Northern Territory.

Extensive collection of detailed soil and pasture data has enabled the development of pasture growth models (GRASP) for major pasture communities throughout the VRD. This work has led to close and productive working relationship with researchers in Queensland undertaking similar work. These models will assist the estimation of long term stocking rates that will account for seasonal variability, pasture type and land condition. They will also provide a means to investigate the ecological and economic impact of seasonal variability on stocking strategies, burning frequencies, tree and shrub increase and other management scenarios. Preliminary investigations have developed "safe" utilisation rates and stocking rates for Mitchell grass, ribbon/blue grass and arid short grass pastures. A methodology is in place that will allow the estimation of carrying capacity and stocking rates in coordination with station managers, at a paddock, property, land system and regional level

Investigation into the competitive effects of trees and shrubs on soil moisture and pasture production has identified that, at current levels, shrub invasions on black soil pastures may not have any significant effect on annual pasture production. Woodlands with higher densities and tree biomass, particularly in drier areas and in below average seasons, may significantly reduce the growth of pasture. The data collected will be utilised to quantify woody plant influences in the GRASP pasture growth model that will allow the investigation of the impact of tree and shrub invasion scenarios.

The effects of fire on pasture condition and woody plant structure have been examined on black and red soil pasture types. Research has found that woody tree and shrub species are well adapted to fire. Without fire, plants normally suppressed by fire will be allowed to grow and over time significantly increase the biomass of woody vegetation. Regular fire is required to manage woody tree and shrub structure. Recommendations have been made regarding, fire frequency, season, intensity and fuel load required for effective management. Relationships have been identified that allow the prediction of fire effectiveness from fuel (yield and cover) and average plant height inputs. Investigations have identified that fire should not be used as part of land management on pastures in poor condition. Where annual grasses and forbs are recolonising heavily utilised areas, fire can cause significant reductions in yield and cover. The immediate economic benefits of using fire in term of controlling woody vegetation are difficult to demonstrate and may not be significant. There are however, many other benefits that justify the use of fire as part of normal pasture management.

General recommendations

During the life of the project it became obvious that more information and work was required in several areas. Most effort is needed to encourage the implementation of management practices that have been identified as being necessary for sustainable production. It is planned that some of these issues will be covered during continuing work in the MRC NAP3. These are associated with either testing management options in a whole property context or investigating and demonstrating "best bet" management packages, in cooperation with station managers, at a practical scale.

It is important that the investment made in developing GRASP pasture growth models is utilised. Final model validation will provide an opportunity for the estimation of stocking rates and carrying capacities at a paddock and property level, in coordination with land managers and utlising local knowledge, experience and established methodologies. The small number of pastoral leases in the VRD (around 30) means that this can be carried out on an individual property basis. During this process estimation of current stocking rates and relationships between stocking level, land condition and animal production would be determined. Growth models will also allow the investigation of burning frequencies, drought strategies and tree and shrub effects.

The need for economic analysis of management options is seen as being a high priority, and one that is likely to increase the potential adoption of new management strategies, as well as to identify constraints for further investigation. The linking of pasture growth models (GRASP) and whole herd models (Herd Econ) provides a means of investigating the ecological and economic impacts of herd management options. Cooperation with researchers involved with these models is critical and should be maintained. It is also important to work with individual pastoralists and utilise these modeling tools where possible to investigate "real life" management options. Of particular importance is the investigation of the productivity and practicality of various stocking strategies, such as flexible and continuous fixed stocking rates.

There is a requirement that products detailing simple management guidelines are made available to land managers. This would ensure the availability and transfer of research results to the industry. Titles that cover the management of pasture communities in the VRD and sustainable fire management guidelines would be beneficial. Coordination with industry, other researchers and government organisations would ensure a high level of quality and access to the most relevant research results.

It is important that demonstrations of "best bet" fire and grazing management strategies are established on several pastoral properties. The active involvement and feedback of producers in the management of these sites would be essential for identifying opportunities and constraints that such strategies have at a practical scale and would also facilitate action learning. These demonstration sites would provide an opportunity to study and quantify the effect that fire may have on controlling grazing distribution, and assess the potential of fire to minimise localised grazing pressure, particularly on preferred red soil pastures.

Experimental burning during the current project generally took place in either early or late dry season. There is opportunity and potential for burning during the late wet. There is a need to quantify the effect of stage of curing (fuel moisture) on fire behaviour, response of pasture and woody vegetation, and interactions with grazing.

Discussion and Industry Implications

1. Predicting pasture growth and carrying capacity for pastures in the Victoria River District (VRD).

Introduction

Pastoral properties throughout the Victoria River District (VRD) operate within a complex mix of climatic, soil, pasture type and land condition influences. Correct decisions regarding cattle numbers (stocking rates and carrying capacities) are essential for successful management, as they determine whole enterprise profitability and future resource sustainability.

Pastoral enterprises in the district are extensive. Properties and paddocks engulf areas from tens to hundreds of squares kilometers. The complex mix of country encountered at the paddock level means that estimation of stock numbers is often difficult and made by trial and error over a number of years. Experience and knowledge of good cattleman is often invaluable when considering the productivity and response of different types of country to grazing.

Work from this project will provide pastoralists additional information when calculating stocking rates, enable the effects of seasonal variability to be quantified and allow the comparison of grazing and stocking management scenarios.

(a) Estimating carrying capacity and stocking rates

Scanlan *et al* (1994) described a safe carrying capacity as the number of cattle adult equivalents that can be carried on a property without any decrease in pasture condition (reduced basal cover or altered composition) and without accelerated soil erosion. Johnston *et al* (1996) describes the concept of "safe" carrying capacity as a strategic, long term (20-30 years) estimate of stock numbers as opposed to a "safe" stocking rate which is described as a tactical short term (seasonal or annual) calculation of "safe: stock numbers.

Johnston *et al* (1994) identify four factors required to calculate safe carrying capacity for land areas as:

(a) area of land system, land unit or pasture community
(b) intake of cattle over a year (kg DM/head/year)
(c) amount of pasture grown (not standing dry matter) for each land system or pasture community
(d) "safe" level of utilisation

Work has been carried out during this project that will quantify the relationships between the type of growing season and pasture productivity for a range of pasture communities, and will contribute significantly to the estimation of "safe" and productive carrying capacities and stocking rates. This information can be used in conjunction with local knowledge to obtain realistic estimates of carrying capacity and stocking rates for pasture types, paddocks or properties. These calculations will account for :

(a) Amount and variability of seasonal rainfall
(b) Pasture type and productivity (i.e. quantity, quality, and stability under grazing)
(c) Land condition

Continuing work in NAP3 will be carried out in conjunction with land managers throughout the VRD. This work will record current stocking rates and impacts on land condition and productivity levels, identify "safe" levels of utilisation from producer experience and to incorporate available knowledge to provide estimates of "safe" carrying capacities and stocking rates at a paddock and property scale.

Most of the work in this report is directed to estimating pasture growth for productive land systems in the VRD. The areas of pasture communities that have been studied throughout the VRD are shown in Map 2. Models describing the growth of Mitchell grass, arid short grass, ribbon/blue grass and tropical tall grass pastures are nearing completion. Additional work involves the investigation of "safe" levels of utilisation.

(b) Pasture production

Pasture production can be calculated from either simple linear relationships between yield and rainfall (rainfall use efficiencies) or more accurate and complex modeling processes. The use of computer simulation models provides an accurate estimation of annual pasture growth for particular soil and pasture combinations based on seasonal rainfall and climate information. The GRASP pasture growth model has shown to be reliable in estimating annual pasture production for Queensland pasture communities. **Data has been collected that has allowed the calibration and validation of the GRASP pasture growth model for several important pasture communities throughout the VRD, including Mitchell grass, ribbon/blue grass and arid short grass pastures.** Preliminary output of annual pasture growth using GRASP for an arid short grass pasture between 1957 and 1996 has been demonstrated.

(c) Levels of utilisation

'Safe' levels of utilisation are described as the proportion of forage grown that can be safely eaten without causing undesirable changes to pasture condition or animal performance.

Three methods for determining safe levels of utilisation have been described by Johnston *et al*, (1996):

(a) Analysis of grazing trials
(b) Consensus data
(c) Selected benchmark properties and grazier experience.

In this current report we have used results from current and previous grazing trials on similar land systems which are relevant to those in the VRD, and data from Kidman Springs as a selected benchmark property. The Mount Sanford stocking rate demonstration is an important contributor of stocking, utilisation and production information, particularly for Mitchell grasslands.

(d) Predicting carrying capacity and levels of utilisation.

(1) Mitchell grass

The Mount Sanford stocking rate project started in 1993. The project is centered on a large scale stocking rate demonstration, with four stocking rates ranging from 5 to 15 breeders per sq km. These four groups receive year round supplementation. The two lightest stocking rates are also replicated without supplementation. Table 1. summarises the treatments in the project. Each paddock contains 54 breeders, 10 steers, 2 bulls and calves < 100kg. Paddocks are mustered twice a year in May and September. Data on cattle performance and pasture trends are collected. A full report of growth, reproduction and pasture results can be obtained from Neil MacDonald, NTDPIF, Katherine.

Table 1. Treatment details for the Mount Sanford Stocking Rate Demonstration.

Paddock	Size (km^2)	Stocking rate (hd/km^2)	Supplementation
Budgie	4	15	Yes
Pigeon	6	10	Yes
Parrot Creek	8	7.5	Yes
Galah	12	5	Yes
Quarrion	8	7.5	No
Quail	12	5	No

Six 'SWIFTSYND' sites are located within the Mt. Sanford project area. Four represent Mitchell grass pastures between poor and good condition and two represent arid short grass in poor to fair condition. The project site provides an opportunity for predicted values of pasture growth, utilisation and animal production produced by GRASP modeling to be validated against values measured at a realistic scale. The project also allows us to identify what a sustainable level of utilisation may be for Mitchell grass pastures.

Since 1992 the site has enjoyed excellent seasonal rainfall. Rainfall between 1994 and 1997 has been in the top 10% decile of long-term averages. Such a run of seasons has meant that cattle performance has been outstanding, and there have been few stocking rate effects. The annual weaning rate has averaged 86%. Steers have grown an average of 150 kg/head/year.

(i) Observed utilisation rates

Calculated utilisation rates under stocking rate treatments in 1996 ranged between 8-22% (Table 2). Based on observed annual pasture production these levels of utilisation would be typical for each stocking rate over the last four years.

Annual pasture production is estimated from the average yield at the end of the wet season plus the amount of pasture that the cattle would have eaten in the paddock over the wet season. This assumes that pasture growth in the dry season is insignificant (which for some plant species may be far from the truth). If we take 9.0 kg/day as a realistic average intake based on these methods, a percentage utilisation of the different paddocks is shown in Table 2.

Table 2. Annual utilisation of feed in Mount Sanford trial paddocks in 1996.

Paddock	Treatment	T/ha in April	Annual yield (T)	% utilisation
Budgie	15/sq km supp.	2.209	974	22.6
Pigeon	10/sq km supp	1.502	992	22.2
Parrot Ck	7.5/sq km supp	2.212	1860	11.8
Galah	5/sq km supp	1.897	2367	9.3
Quarrion	7.5/sq km unsupp	2.030	1714	12.8
Quail	5/sq km unsupp	2.212	2745	8.0
Average		2.019	1773	12.4

(ii) Predicting levels of utilisation and stocking rates

Observed levels of utilisation were compared with predicted levels calculated from rainfall use efficiency (RUE) values and rainfall deciles.

Using an RUE value of 3.5 kg/ha/mm for Mitchell grass and rainfall deciles based on historical records, predictions of annual pasture production were made for a range of seasonal conditions. By using assumptions of average daily intake of grazing animals, calculations of utilisation and stocking rate were made for each season (Table 4).

Predicted levels of utilisation for stocking rates of 5, 7.5, 10 and 15 head/km^2 for a rainfall season in the top 10% decile, as three of the last four have been, were very close to observed levels of utilisation (Table 3.) There is very close agreement between observed and predicted values for all stocking rates except 10 head/km^2. An explanation of this is given later. These results indicate that even using a simplified approach to estimating pasture production for a range of seasons (i.e. RUE), pasture utilisation and therefore carrying capacity can be estimated with some accuracy.

Table 3. Comparison of calculated (observed) and predicted utilisation rates for four stocking rates treatments at Mount Sanford.

Stocking rate (head/km^{2})	**5**	**7.5**	**10**	**15**
Observed utilisation rate	8.5	12.6	22.2	22.6
Predicted utilisation rate	7.3	11.0	14.7	22.0

(iii) Safe levels of utilisation for Mitchell grass

In the Mount Sanford trial area, most of the paddocks would be considered to be in "good" condition. The pastures are characterised by a dominance of perennial tussock grasses, mainly Mitchell grass species, complimented with a range of annual grasses and forbs in inter-tussock spaces. Since 1994 the proportion of perennial grass across the sites has increased, while annual grasses have generally decreased. The proportion of legumes and forbs has remained steady.

Safe levels of utilisation of Mitchell grass pastures in good condition appear to be between 20% - 25%. Utilisation rates around 22% were calculated for the highest stocking rate paddock (Budgie paddock; 15 breeders/ sq km). Between 1993 and 1997 the proportion of palatable perennial grasses (particularly Mitchell grass) increased under this level of utilisation, while annual grasses and forbs decreased (Figure 1.) This rate of utilisation would then be considered both productive and sustainable. These values agree closely with "safe" utilisation values summarised from grazing trials by Johnston *et al* (1996).

(iv) Determining a safe stocking rate

Although a stocking rate of 15 head/km^2 would be appropriate for recent seasons, long term stocking at this level would result in an average utilisation rates of greater than 40% (Table 4.). At these levels reduced animal production and pasture degradation would be likely.

Table 4. Levels of utilsation rate and stocking rate for predicted levels of Mitchell grass production based on average rainfall deciles for Kalkaringi/Mount Sanford.

Rainfall	Rainfall	Pasture	Stocking rates (head/sq km)					Level of utilisation			
		Production	2.0	5.0	7.5	10.0	15.0	10%	15%	22%	30%
Decile	(mm)	(kg DM/ha)	Level of utilisation					Stocking rates (head/sq km)			
100	145	514.8	4.5%	35.5%	53.2%	70.9%	106.4%	1.4	2.1	3.1	4.2
90	266	944.3	2.5%	19.3%	29.0%	38.7%	58.0%	2.6	3.9	5.7	7.8
80	328	1164.4	2.0%	15.7%	23.5%	31.3%	47.0%	3.2	4.8	7.0	9.6
70	373	1324.2	1.8%	13.8%	20.7%	27.6%	41.3%	3.6	5.4	8.0	10.9
60	405	1437.8	1.6%	12.7%	19.0%	25.4%	38.1%	3.9	5.9	8.7	11.8
50	472	1675.6	1.4%	10.9%	16.3%	21.8%	32.7%	4.6	6.9	10.1	13.8
40	506	1796.3	1.3%	10.2%	15.2%	20.3%	30.5%	4.9	7.4	10.8	14.8
30	575	2041.3	1.1%	8.9%	13.4%	17.9%	26.8%	5.6	8.4	12.3	16.8
20	609	2162.0	1.1%	8.4%	12.7%	16.9%	25.3%	5.9	8.9	13.0	17.8
10	700	2485.0	0.9%	7.3%	11.0%	14.7%	22.0%	6.8	10.2	15.0	20.4
		Average	1.8%	14.3%	21.4%	28.5%	42.8%	4.3	6.4	9.4	12.8

Shaded areas represent years of safe levels of utilisation at a particular stocking rate.

Stocking rates between 7.5-10 head/km^2 provide average utilisation rates between 21.4% - 28.5% respectively (Table 4). Likewise average stocking rates can be calculated for a desired level of utilisation. **A stocking rate of 9.4 head/km^2 will utilise on average 22% of annual pasture production.**

(v) The effect of pasture condition on utilisation and stocking rates

Pasture condition, as well as pasture type will influence safe levels of utilisation and stocking rates. Comparisons made between Budgie paddock (15 breeder/sq km) and Pigeon paddock (10 breeders/sq km) indicate that pasture condition may influence animal production, pasture stability and utilisation rates.

Pigeon paddock and to a lesser extent Parrot Creek and Galah paddocks have large areas which are dominated by annual grasses and forbs, with extremely low basal area of palatable perennial grasses. These areas are generally considered to be in "poor" condition and existed as such prior to the establishment of the trial. They were, and still are, subject to heavy selective grazing pressure.

Statistical comparison of "good" and "poor" condition pastures indicated that, in at least good seasons, there may be little difference in total yield, N concentration and N yield between condition classes. The main difference remains the greater proportions of annual grasses and forbs and lower desirable perennial grass basal area in poor condition pastures. From this it could be concluded that utilisation levels and stocking rates for pastures in poor condition should remain similar to levels considered safe for pastures in good condition. This however does not seem to be the case.

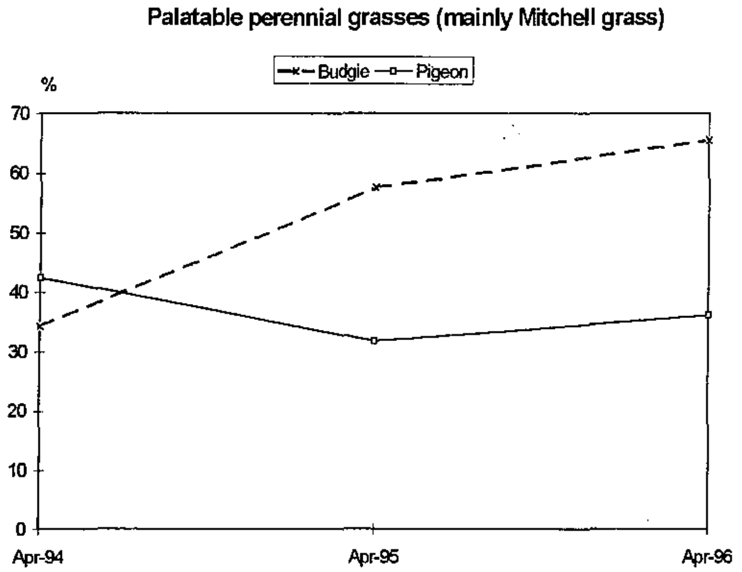
Pigeon paddock is stocked at the second highest rate with 10 breeder/sq km, however utilisation rates of 22%, similar to the highest stocking rate (Budgie paddock) were recorded in 1996. Predicted utilisation rates (Figure 1.) indicate that 14% would be a more likely figure. Analysis of SIWFTSYND site data revealed that the rate of natural detachment and desiccation of pastures dominated by annual grasses and forbs was considerably greater than for sites dominated by perennial grasses. This would then increase the apparent rate of utilisation under a lower stocking rate. Heavy grazing activity would accelerate these processes.

Pigeon paddock, in contrast to Budgie paddock, has shown no increase in the perennial grass component and a significant deterioration in pasture yield, despite favourable seasonal conditions (Figure 1.). The effects of grazing on Pigeon paddock are very obvious from the ground and from the air. This indicates that that a stocking rate of 10 breeders/sq km for this paddock may not be sustainable over a normal run of seasons.

Of interest though, is that steer growth in Pigeon paddock has been significantly higher than other paddocks. This agrees with findings of Ash *et al* (1995), who found that animal production from poor condition pastures in both Katherine and charters Towers regions, was superior to good condition pastures under low levels of utilisation (< 20%). It will be of interest to follow the trend in animal performance and pasture condition over a more normal run of seasons. It would be expected that paddocks with large areas of pasture in poor condition respond poorly to below average seasons compared to paddocks dominated by good condition pastures. During these seasons, utilisation rates would be raised to levels that would significantly depress animal performance and increase the risk of adverse changes in pasture condition.

Animal performance in the short term is therefore not a good indicator of overstocking and declining pasture condition. Managers should therefore be encouraged to observe and

monitor pasture composition when determining stocking rates. The influence of season will have to be accounted for when determining the effect stocking rates are having.



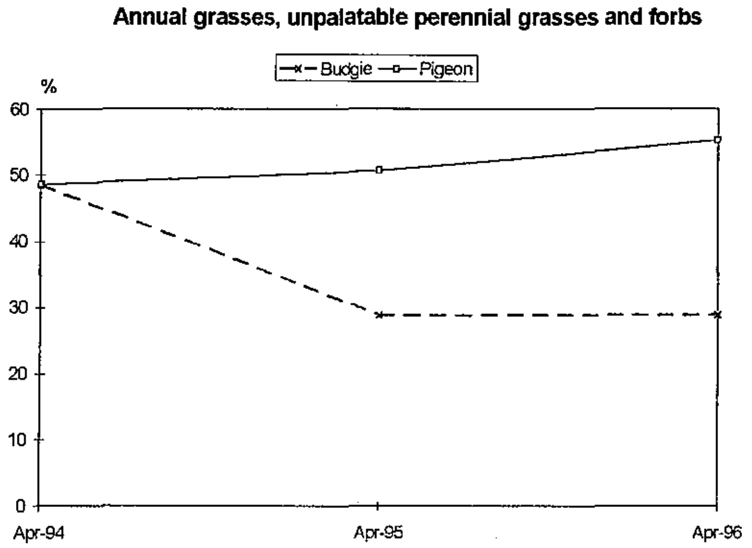


Figure 1 Comparison between two paddocks with a similar utilisation rate of about 22% (high stocking rates)

(2) Ribbon grass and arid short grass

Calculation of safe utilsation and carrying capacity for these pastures is based on expert knowledge and records of pasture condition and animal performance.

Rohan Sullivan was the manager of Kidman Springs between 1987 and 1994. Rohan applied an average stocking rate of between 6-7 head/km^2 on paddocks with a mix of black soil (ribbon/blue grass) and red soil (arid short grass) pastures. During this period cattle productivity increased dramatically under the "best bet" herd management system. This system involved wet season supplementation with P, dry season supplementation with N, early weaning, annual inoculation for botulism and the implementation of paddock burning. Associated with an increase in animal performance, evidence suggests that pasture condition was maintained or improved despite two very poor years. For stocking rates based on individual pasture types alone, Rohan believes that stocking rates of 7-9 head/km^2 for black soil pastures and 5-6 head/km^2 for the more fragile and preferred arid short grass pastures are acceptable and provide long-term, safe levels of pasture utilisation.

Based on these stocking rates, average levels of utilisation were calculated for black and red soil pastures from RUE values for both communities, rainfall deciles and estimations of average animal intake (Table 5).

From Table 5.: **Based on stocking rates between 7-9 head/km^2 for black soil, long term utilisation levels would range between 15% - 18%. For stocking rates of 5-6 head/km^2 for red soil pastures utilisation rates of approximately 12% - 15% would be the long term average.**

These utilisation values can then be applied to similar pasture communities in other locations with different seasonal climates.

Table 5. Levels of utilsation rate and stocking rate for predicted levels of ribbon/blue grass pasture production on black soil based on average rainfall deciles for Victoria River Downs/Kidman Springs. (RUE = 3.55).
(Shaded areas represent years of safe levels of utilisation at a particular stocking rate.)

Rainfall Decile	Rainfall (mm)	Pasture Production (kg DM/ha)	Stocking rates (head/sq km) 2.0	5.0	7.5	9.0	15.0	Level of utilisation 10%	15%	22%	30%
			Level of utilisation					Stocking rates (head/sq km)			
100	242	859	3.7%	21.2%	31.9%	38.2%	63.7%	2.4	3.5	5.2	7.1
90	367	1303	2.5%	14.0%	21.0%	25.2%	42.0%	3.6	5.4	7.9	10.7
80	451	1601	2.0%	11.4%	17.1%	20.5%	34.2%	4.4	6.6	9.7	13.2
70	485	1722	1.9%	10.6%	15.9%	19.1%	31.8%	4.7	7.1	10.4	14.2
60	539	1913	1.7%	9.5%	14.3%	17.2%	28.6%	5.2	7.9	11.5	15.7
50	593	2105	1.5%	8.7%	13.0%	15.6%	26.0%	5.8	8.7	12.7	17.3
40	662	2350	1.4%	7.8%	11.6%	14.0%	23.3%	6.4	9.7	14.2	19.3
30	737	2616	1.2%	7.0%	10.5%	12.6%	20.9%	7.2	10.8	15.8	21.5
20	806	2861	1.1%	6.4%	9.6%	11.5%	19.1%	7.8	11.8	17.2	23.5
10	904	3209	1.0%	5.7%	8.5%	10.2%	17.1%	8.8	13.2	19.3	26.4
		Average	1.8%	10.2%	15.3%	18.4%	30.7%	5.6	8.4	12.4	16.9

Table 6. Levels of utilsation rate and stocking rate for predicted levels of arid short grass pasture production on red soil based on average rainfall deciles for Victoria River Downs/Kidman Springs. (RUE = 2.98)

Rainfall Decile	Rainfall (mm)	Pasture Production (kg DM/ha)	Stocking rates (head/sq km) 2.0	5.0	7.5	9.0	15.0	Level of utilisation 10%	15%	22%	30%
			Level of utilisation					Stocking rates (head/sq km)			
100	242	721	4%	25%	38%	46%	76%	2.0	3.0	4.3	5.9
90	367	1094	2%	17%	25%	30%	50%	3.0	4.5	6.6	9.0
80	451	1344	2%	14%	20%	24%	41%	3.7	5.5	8.1	11.0
70	485	1445	2%	13%	19%	23%	38%	4.0	5.9	8.7	11.9
60	539	1606	2%	11%	17%	20%	34%	4.4	6.6	9.7	13.2
50	593	1767	2%	10%	15%	19%	31%	4.8	7.3	10.7	14.5
40	662	1973	1%	9%	14%	17%	28%	5.4	8.1	11.9	16.2
30	737	2196	1%	8%	12%	15%	25%	6.0	9.0	13.2	18.1
20	806	2402	1%	8%	11%	14%	23%	6.6	9.9	14.5	19.7
10	904	2694	1%	7%	10%	12%	20%	7.4	11.1	16.2	22.1
		Average	2%	12%	18%	22%	37%	4.7	7.1	10.4	14.2

2. The effect of tree and shrub density on pasture production

Anecdotal and scientific evidence suggests that the size and density of several native tree and shrub species is increasing throughout the VRD. Native shrubs such as rosewood (*Terminalia volucris*) and bauhinia (*Lysiphylum cunninghammii*) are becoming more visible and dominating the ribbon/blue grass communities located on gray cracking clays. Eucalypts (inland bloodwood and silver leaf box), conkerberry (*Carissa lanceolata*) and common hakea (*Hakea arborescens*) are increasing throughout arid short grass pastures on the shallow red calcareous earth.

Pasture production on cracking clay soils dominated by rosewood was not affected by stem densities of up to 400 stems/ha and stem basal areas up to 4m ^{2}/ha. Competitive effects of Eucalypt woodlands around Katherine and the VRD with stem basal areas between 10-15m^2/ha showed significant increases in pasture growth for two years following tree removal. The limitation to pasture growth may be a result of competition from trees restricting the availability of soil moisture in poor rainfall years, and nutrients in years where soil moisture is adequate. Continuing investigation of Eucalypt woodland sites will monitor yield and available nutrients over a number of years following tree removal.

Although shrub invasions on cracking clay soils did not affect pasture growth for the seasons and densities measured, significant effects may be present throughout areas with greater average shrub size and density distributions. From work by Scanlan and McKeon (1993), modelling the effects of tree competition in monsoon woodlands around Katherine, an increase in tree basal area from 5 to 10m^2/ha decreased potential pasture yield from approximately 85-90% of maximum to 55% in soils of 100cm depth. This suggests that as tree and shrub densities exceed 10m^2/ha significant reductions in pasture production could be expected. This is confirmed by results from Eucalypt woodlands in Katherine and at Kidman Springs.

Unchecked invasion and growth of native trees and shrubs throughout pastoral land will allow woody plant densities to reach levels that will undoubtedly have far greater effects on pasture production than current levels.

The predicted influence of tree and shrub competition in the GRASP pasture growth model will be validated with data collected from Katherine and Kidman Springs. Season and shrub size-density scenarios will be investigated using GRASP to determine if current or projected woody plant densities in several shrub and woodland communities are likely to have significant effects at the landscape scale. The economic impact of evaluations of several different woody plant management scenarios will also be investigated.

3. The effects and management of fire

(a) Introduction

Throughout this research project it has become evident that fire is an essential element of pasture management throughout the semi-arid tropics. It plays a necessary role in managing woody plant populations, maintaining pasture condition, managing selective grazing by manipulating grazing distribution, increasing the availability of green leaf to cattle and reducing the hazard of uncontrolled wildfires. The use of fire cannot be ignored. If it is, vegetation change will continue and the risk of pasture degradation will increase. Without controlled use of fire, uncontrolled wildfires will cause widespread and unplanned loss of available feed and, over time cause adverse affects on pastures.

The use of fire must be controlled and deliberate to meet the specific objectives of the manager. There are areas and times where the use of fire is not appropriate, nor beneficial. An understanding of fire ecology and the interaction of fire and grazing is essential to ensure that fire is used as a sustainable management tool and not one that will do more harm than good.

While the use of fire may not provide immediate economic returns, and any benefits may be difficult to measure in financial terms, the cost of not using fire as a part of management will be great.

The following summary is a discussion of research results in the context of practical application of fire and pasture management. This information is only preliminary in nature and is based on research results, observations and current available knowledge.

(b) The need for fire

Without fire, woody plant growth will continue unchecked, significantly increasing canopy area and plant height over time. Land managers faced with increasing woody vegetation must maintain, or if necessary reduce, the canopy and height structure of the tree and shrub populations with the deliberate and controlled use of fire.

There is strong evidence that significant changes in vegetation structure have occurred throughout the VRD since the establishment of the pastoral industry. This is most likely a result of changes to long established fire regimes. In some areas, particularly central and southern VRD, a reduction in the incidence of fires has occurred due to lower levels of fuel caused by grazing, and by deliberate policies of fire suppression and exclusion to protect property and feed resources. In the northern tallgrass communities changes to established patterns of burning have occurred.

(c) Woody plant responses

The majority of woody tree and shrub species throughout the arid-short grass, and ribbon/blue grass pasture communities are well adapted to and survive fire.
The response of woody plants following fire is mainly determined by fuel load and fire intensity.

Mortality rates of most species following burning are below 5% over a range of seasons, fuel loads and fire intensities. Conkerberry and bauhinia are slightly more susceptible to higher intensity fires, normally following late dry season fires, which marginally increase mortality rates. Rosewood is particularly resistant to fires of any intensity. Plant mortality remained less than 1% even after extremely hot fires or following successive burning over a three-year period.

The density of individuals subjected to regular burning does not appear to change. Low plant mortality results in insignificant decreases in plant numbers, while plant counts along permanent transects indicated that neither high fire intensity nor early dry season burning seemed to increase the density of rosewood plants by enhanced suckering or germination. Although a few (3) seedlings were observed, fire can be utilised to control seedling establishment events that may occur during favourable seasons.

Regular fire acts on woody plants by suppressing growth and reducing plant height. All of the woody species studied survive fire by resprouting from protected buds in the branches or stem at or below ground level. The response of trees and shrubs following burning is largely determined by the level of plant fire damage.

Plant fire damage and response following burning is determined by fire intensity (fuel load) and plant height. Plants that receive only slight to moderate fire damage, indicated by leaf scorching and some burning of leaves will resprout from the branches the following season. **Moderate to severe fire damage causing complete burning or defoliation of all leaves result in the death of aerial branches or "top kill".**

As the level of fire damage increases so too does the death of aerial branches and the proportion of plant top kill. Smaller plants are generally susceptible to more severe fire damage and will resprout from the base only. As plants become taller they are more likely to incur less severe fire damage and resprout from aerial branches.

As plants increase in height they are more resistant to fire and more difficult to manage. **Once plants exceed 150-200cm in height they require hot to extremely hot fires to achieve adequate top kill of aerial branches.**

Regardless of plant height structure, regular burning with moderately hot fires will at least maintain vegetation structure by suppressing smaller individuals. Areas of uncontrolled regrowth with dense stands of taller plants (>200cm) require hot to extremely hot fires to achieve any change in plant height and canopy area. In all but the most severe fires, significant proportions of plants will escape top kill and resprout from the branches.

(d) Pasture responses

Fire should be only used as a part of management on pastures in good condition. Pastures in good condition have a dominant perennial grass component, are generally higher yielding, and have good ground cover. Soil structure is good, without erosional features and surface sealing.

The main effect of fire on pastures is to cause a reduction in standing yield the season following burning. This is a result of the removal of accumulated material, which in most pasture communities and seasons cattle will not graze. Burning during the dry season has little effect on perennial pastures as they are dormant during this time.

During the above average seasons when response to fire was measured, burning did not adversely affect pasture growth and seemed in some cases to encourage growth. Previously burnt pastures recovered with equal or greater standing pasture yield during the second growing season following burning.

Ribbon/Blue grass pastures on cracking clays are well adapted to fire. Neither single nor successive burning of these pastures resulted in long term reductions of yield or cover. Burning increased the availability of green leaf during the wet season following burning.

Both single early dry season (EDS) and late dry season (LDS) burns promoted an increase in palatable *Dichanthium fecundum* (blue grass), with a reduction in *Chrysopogon fallax* (ribbon grass). From summary data the proportion of *Aristida* spp., an unpalatable undesirable species, was influenced most by season.

Burning during the season measured, does not affect the quantity of annual *Iseilema* spp. (Flinders) and *Dichanthium sericium* (Queensland blue grass). Seed is protected by falling into deep cracks in the dry clay soils and is protected from damage to fire.

In unburnt plots the accumulation of dry matter resulted in large areas of dead or moribund pasture. These areas containing grey, rank pasture and very little current season's growth were distributed throughout the plots in patches of varying size.

Arid short grass pastures with a high component of annual grasses such as *Brachyachne convergens* (summer couch) and *Sporobolus australasicus* (fairy grass) should not be burnt. Burning of these pastures results in large reductions in yield and ground cover, which is slow to recover in the years following. This response would most likely be more severe in below average seasons. The destruction of seed of these species which lies on the soil surface is the most likely explanation. The effect is most severe following complete high intensity fires, which are possible following a favourable season and/or exclosure from grazing.

Arid short grass pastures in good condition and dominated by *Enneopogon polyphyllus* (limestone grass) and with large component of *Heteropogon contortus* (black spear grass) and *Dichanthium fecundum* (blue grass) are more resilient to burning. Apart from the control of increasing woody vegetation, burning of these pasture encourages more even grazing pressure. Cattle generally ignore large perennial tussock grass, especially *Heteropogon* spp, and preferentially graze more palatable annuals and biennials. Cattle were observed to actively select previously ungrazed patches following burning.

Regular burning of perennial based pastures will maintain them in good condition for grazing.

(e) Fuel loads and fire intensity

Effective management of woody plant growth is primarily determined by fire intensity. Fuel load, cover, fuel moisture and weather conditions such as wind, temperature and humidity have the most influence on fire intensity. Increasing fuel loads promote higher fire intensity.

Fuel loads of at least 2000-2500 kg DM/ha are required for effective management of woody vegetation structure. Plant top kill will only be possible if fuel loads and burning conditions support fire intensities high enough to impose moderate to severe damage (complete burning or defoliation of leaves) on aerial branches. Higher fuel loads and ground cover is required for effective management of taller woody plants.

To assist management decisions when controlling woody plant growth with fire, it is possible to predict with some certainty the rate of top kill of trees and shrubs of different heights from fuel load and cover levels.

Fire supported by fuel loads below 2000 kg DM/ha, with ground cover less than 55-60% resulted in cool to moderately hot fires. Such fires cause only slight plant damage to all but the smallest of plants resulting in little top kill and no change in vegetation structure.

Continuous and undisturbed fuel loads promote fires of higher intensity. **Ground cover should be at least 50%, but preferably greater than 60%, to ensure a continuous fire front and fire of**

sufficient intensity. Fragile annual dominated pastures, which are preferentially grazed, often have low yield and cover levels, especially later in the dry season, and therefore only support low intensity patchy fires.

Available fuel loads will fluctuate with season and grazing pressure. In some areas the accumulation of sufficient levels of fuel to ensure effective fires will only be possible after spelling or the exclusion of grazing. This is most simply done by spelling for one good wet season prior to burning.

High fuel loads following favourable seasons should be utilised to achieve significant changes in woody plant structure where tree and shrub heights and densities have increased over the years.

(f) Fire season

The season of burn will be determined by the objectives of fire management.

Late dry season fires are generally more intense than early dry season fires at the same fuel load. Higher fire intensity in late dry season fires is due to lower fuel moisture content, higher temperature and lower humidity.

The response of plants to fire is similar for both EDS and LDS fires of the same intensity. The main influence of burning season (EDS cf. LDS) on woody plants is a result of the higher intensity of LDS fires. EDS burning does not promote increased densities or resprouting in woody plants.

Annual based pastures can generally support effective fires earlier in the dry season than perennial dominated pastures due to their rapid maturity and curing rate which reduce the amount of fuel moisture.

In grazed paddocks the amount of fuel consumed and trampled by cattle increases as the dry season progresses. This reduces potential fire intensity and effectiveness. The optimum time for intense fires will be a trade off between lower fuel moisture and humidity and higher temperatures during the late dry season, and higher and undisturbed fuel loads earlier in the dry.

In some areas, particularly SE Queensland, it is a common practice to burn after early storms at the end of the dry season. Although this reduces the risk of uncontrollable fires and provides some assurance of pasture regrowth from soil moisture, it is not recommended as burning can damage young growing pastures, and fires will be of lower intensity and have a reduced affect on woody vegetation.

Wind strongly influences fire rate of spread and fire intensity, particularly across areas with discontinuous or low fuel loads. Wind speeds of at least 10 km/hr are necessary for fire of higher intensity. Periods during the year when wind speed is constant and predictable should be utilised. Late in the dry season (late September-November) winds become gusty and may constantly change direction making controlled burning difficult. Fire behaviour and effectiveness is less predictable under these conditions.

(g) Fire frequency and extent

Fire frequency is defined as the number of years between burning a particular area of pasture. It will be influenced by pasture community, the average amount and variability of rainfall, and the objectives of burning.

For management of woody plants, burning frequency will be determined by the rate of woody plant growth and fuel accumulation. This is largely determined by rainfall amount and variability associated with particular pasture communities. Pasture communities should be burnt at a frequency and intensity that maintains normally fire suppressed woody plants below 150-200cm.

Burning frequencies should range between 3-5 years in the northern tropical tall grass pasture and decrease to 4-6 years in the semi-arid mid-height pastures of central VRD to 5-10 years in Mitchell grass and spinifex pastures the drier southern areas

(h) Rotational burning - A proposed burning program

The most practical method for implementing a burning program would be on a rotational basis. This would involve burning a different section of each paddock each year. The proportion burnt will depend on the desired burning frequency.

Rotational burning should transfer grazing pressure to previously burnt sections during the following season. This will reduce the disturbance of fuel loads in sections designated for burning during the next season.

(i) Where to burn
Burning should be avoided in pasture communities that are heavily utilised by cattle, or those in poor condition. Burning should be initially directed to areas that are consistently under-utilised by cattle and where native or exotic woody weed problems are emerging or underway.

(ii) How much and how often to burn
Correctly set stocking rates will allow controlled burning of a proportion of most paddocks in most years, without affecting the supply of standing feed to cattle.

It is important to burn substantial areas within paddocks. If burnt areas are too small cattle grazing pressure will be concentrated and potentially cause long-term damage to pastures due to overutilisation.

In wetter northern areas where burning frequencies would be between 3-5 years, paddocks would be divided into thirds or quarters and a section burnt each year. In drier areas, where desired fire frequency is less frequent, 20-25% of paddocks could be burnt in above average years.

(iii) When to burn
The timing of burning during the year will be determined by the objectives of using fire. Burning during the late dry season will promote high intensity fires that will have maximum effect on woody plant structure. Early dry season fires will be cooler and more easily controlled. They can be utilised for the maintenance of vegetation structure and hazard reduction. A combination of early and late dry season burning in paddocks during the one year can be utilised to serve several management objectives. Stored soil moisture during the late wet season can be utilised to provide low yields of nutritious regrowth. This practice can be used in northern, higher rainfall areas, however care must be taken to ensure grazing pressure is transferred to other areas the following season to reduce the risk of plant death due to over grazing. A range of suggested burning conditions for various management objectives are summarised in Table 7.

Table 7 Proposed burning conditions necessary to meet a range of fire management objectives

Objective	Fire Intensity	Fuel Load (kg DM/ha)	Season
Maintain woody vegetation structure	Mod-Hot	2000 – 3000	April-Oct
Change woody vegetation structure	Hot– Extreme Hot	2500 – 4000	Aug-Oct
Hazard Reduction	Cool – Mod.	> 1500	April-June
"Green Pick" + Maintenance of woody veg. + Hazard Reduction	Cool – Hot	> 2000	March-April

(iv) Head fire or back fire?
All controlled burning should be conducted with head fires. Burning against the wind or back burning is necessary for establishing fire-breaks and fire control, however the majority of burning should be with the wind. Head fires are rapid and direct their energy upwards, towards the aerial branches of woody plants and away from the growing bases of pastures.

(v) Fire breaks
Fire breaks are required to contain fires in designated areas. Back burning along fire breaks, especially along down wind sections, is essential to reduce the risk of jump-overs and uncontrolled fires. In many cases current roads and fence lines can be utilised as fire breaks. Additional fire breaks will most likely be needed to divide paddocks into sections that can be burnt each year.

Graded fire breaks are the most effective, however they may be time consuming and expensive to establish in some country. Without run off control, graded fire breaks may also increase the potential of soil erosion. Once established graded breaks are cheaper to maintain

Late wet or early dry season fires, are generally cool and slow moving, and often extinguish at night. These fires could be utilised to produce clean fire breaks ready for burning later in the year. Establishment of these fire breaks early in the season would reduce the risk, time and labour involved with controlled burning late in the year, normally during the busy mustering season.

(vi) Operational procedures
An ongoing burning program in extensive pastoral situations requires considerable time, labour, machinery, organisation and technical resources. The only way the implementation of fire management will be possible at this scale is to develop safe and effective burning procedures that address these constraints. Methods for the construction of cheap and effective fire breaks and the use of aerial ignition in combination with ground based burning are areas that need further investigation for pastoral fire management.

(i) Selective grazing and burning

It was commonly observed that grazing pressure is concentrated on preferred pasture communities (arid short grass), palatable pasture species (*Dichanthium, Brachyachne, Enneopogon* and palatable forbs) and desirable plant parts such as green leaf. These components are the most nutritious and productive within the paddock landscape. The productivity of animals within a paddock may therefore rely on the availability of only a small proportion of the total pasture types, species and plant parts. Therefore, sustainable and productive grazing management should aim to minimise the degradation of these components within the paddock system.

Cattle selectively graze arid short grass pastures in preference to ribbon/blue grass pastures, particularly during the wet season. There appears to be relatively little grazing of ribbon/blue grass pastures during the wet season as they become boggy and difficult to move across. Cattle remain on the drier shallow calcareous red earth which support the more palatable arid short grass species.

High stocking rates or persistent heavy grazing pressure of arid short grass pastures will result in massive and rapid changes affecting pasture yield, cover, species composition and soil erosion (Foran *et al,* 1985). Over time, preferentially grazed areas within paddocks become larger as they become degraded and pasture yields decrease. Animals are forced to shift to new grazing areas, increasing the size and number of overutilised patches.

The formation of patches is associated with a decline in pasture condition as annual grass species and forbs dominate, perennial grass basal area declines and ground cover and yield is often reduced. Animal production from these patches in poor condition may be superior to those in good condition during favourable seasons and if feed quantity is not limiting (Ash and Stafford Smith, 1996). However, due to their limited capacity to remain resilient under a range of seasonal conditions, production from this type of country, under anything but the lowest stocking rates, is extremely variable and susceptible to environmental and economic disaster.

The opportunity of using fires under these conditions is also severely reduced. The decreasing grass component and high levels of grazing utilisation leave insufficient levels of fuel for effective fires. As a result, changes to woody plant structure and exotic weed invasion, which are stimulated by heavy grazing pressure, will proceed without any economical means of control. For pastures already in poor condition, Foran *et al* (1985) demonstrated that exclosure from grazing and favourable seasons would enable the regeneration of pasture condition over a number of years.

Burning affects the normal grazing patterns of cattle as they preferentially grazed post-burn regrowth. Burning also reduces the selectivity of cattle for palatable species, as they were observed to actively graze species normally considered unpalatable. It was observed that burning did encourage grazing of ribbon/blue grass pastures during the wet season. As with arid short grass pasture, pasture species were grazed less selectively compared to unburnt pasture. There was evidence of heavy grazing of usually ignored *Aristida, Eulalia and Chrysopogon* during this period. As grasses matured and dried out grazing pressure was transferred back to the normally preferred species.

Fire may be the key that ensures the effects of selective patch grazing are minimised and patches remain productive. Burning adjacent areas of ribbon/blue grass pastures on cracking clay soils should transfer some of the grazing pressure from red soil pastures, at least during the growing season. Alternatively, burning arid short grass areas that are not normally grazed, which are a greater distance from water or generally less utilised by cattle, and are still in good condition may transfer grazing pressure from the areas that are heavily utilised on a regular basis.

To determine whether such a burning strategy would be successful, it is necessary that burning management programs be tested and implemented at the landscape scale in extensive, grazed paddocks.

(j) Fire management and management of exotic weeds

Regular controlled use of fire can be used to indirectly control the establishment and spread of exotic weeds.

The establishment of exotic weeds in extensive paddocks will often go undetected until a serious weed problem has developed. If these weed populations are to be confined and managed, expensive control strategies have to be implemented to restrict further spread and reduce current weed infestations.

A rotational burning program that burns large proportions of paddock areas over a number of years will act to disrupt the establishment of exotic herbaceous and woody weeds by killing established juveniles before they mature, set seed and become more resistant to control by fire.

(k) Risks associated with burning

The response of pastures, trees and shrubs to fire during this project were measured in above average seasons. **Pasture recovery may be adversely affected, producing less growth than from unburnt pastures in years with poor wet season rainfall.** This, in some circumstances, could result in shortage of feed for cattle and increase the risk of land degradation over a number of poor seasons. This is an area that requires further investigation.

The risk of these responses can be minimised by burning sections of the paddock after favourable seasons to leave sufficient carry over feed for livestock. **The predictive capabilities of the Southern Oscillation Index (SOI) may also be utilised to assist the decision to burn by reducing the risk of burning prior to a poor wet season.** If burning is delayed untill the late dry season, the SOI during this period can provide some indication as to the success of the coming wet season. The decision not to burn may be made if the SOI is strongly negative, or alternatively, burning may be carried out if the SOI is strongly positive and falling prior to the wet.

Sub-project 1

Modelling and predicting pasture growth and carrying capacity in the Victoria River District (VRD).

Objective

To develop the relationship between season, pasture production, carrying capacity and animal production for the major pasture types in the Victoria River District (VRD).

Introduction

Responsible resource management is greatly facilitated by the availability of relevant information to the land manager. For managers of cattle stations in the VRD, information on productivity of native pasture communities and appropriate stocking rates has been patchy. With increasing community concern regarding the sustainability of rangeland use and the effects of season and grazing on land condition, comes increasing pressure for rangeland managers to utilise country in a responsible way. The calculation and implementation of "safe" carrying capacities and stocking rates is central to sustainable pasture management.

The primary resource of the pastoral industry are the extensive native pasture lands. The climate, pasture type and state (or 'condition') of these lands will determine the productivity of the pastures which grow upon them, and in turn, the productivity of cattle utilising the pastures.

(a) The influence of climate and season

The weather experienced throughout the VRD is strongly seasonal in nature, with the year being divided into two distinct seasons: a hot summer period, characterised by intermittent rainfall (October to April); and a warm dry winter period from May to September. Short transition periods serve to merge the major seasons (Slatyer, 1960).

The variation of rainfall amount and reliability and therefore the variation in annual pasture production throughout the VRD is great. Annual rainfall averages decline steadily as distance from the coast increases (Figure 1.1). As rainfall declines, so too does rainfall intensity and reliability. Rainfall deciles from north to south at Katherine, VRD and Kalkaringi are shown in Figure 1.2. The chance of receiving higher annual rainfalls is considerably higher in Katherine compared to Kalkaringi. Even in the driest 20% of years Katherine will receive over 600mm of rainfall, however Kalkaringi will only receive 300mm. The number of wet days however, changes more slowly with distance from the coast. Thus, the amount of rainfall per wet day is highest in regions of greatest rainfall and decreases with declining rainfall (Slatyer, 1970).

While annual rainfall totals provide a useful frame of reference, seasonality of the rainfall pattern, effective rainfall during the growing season, and the duration and effect of the dry season are of greater importance for pasture and animal production (Johnson and Tothill, 1985).

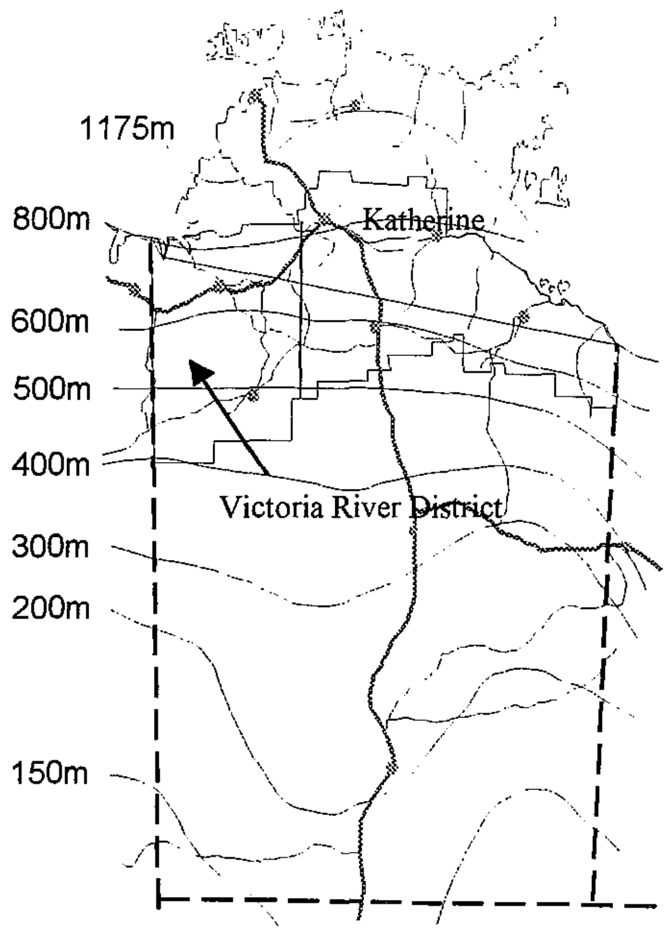


Figure 1.1 The distribution of average annual rainfall throughout the Northern Territory

The major determinant of annual animal performance in the region is season. This is due partly to the highly seasonal wet and dry periods of the year restricting pasture quality and quantity, and also to the sizeable variability in the amount and distribution of rainfall across the growing seasons and its effects on pasture growth. Many attempts have been made, (Fitzpatrick and Nix, 1970; M^{c}Alpine, 1970; M^{c}Cown, 1974; and M^{c}Cown, 1981) with varying success, to quantify the effects of variation in amount and distribution of rainfall on subsequent pasture growth and animal production. These methods have been somewhat broad, and lose reliability in a rather variable environment (worst year 15-20% of best year).

Quantifying the relationships between 'type of season' and subsequent pasture growth will allow a much more informed assessment of the likely amount of biomass a pasture community has available for utilisation by cattle. Since a level of pasture utilisation by grazing animals above a "safe" threshold can have detrimental effects on the pasture, restricting the utilisation to levels that are considered "safe" can greatly reduce the risk of pasture and land degradation. This is the basis of the calculation of a "safe" carrying capacity for areas of pastoral land.

Rainfall deciles at three seasonally different locations in the Katherine/Victoria River districts.

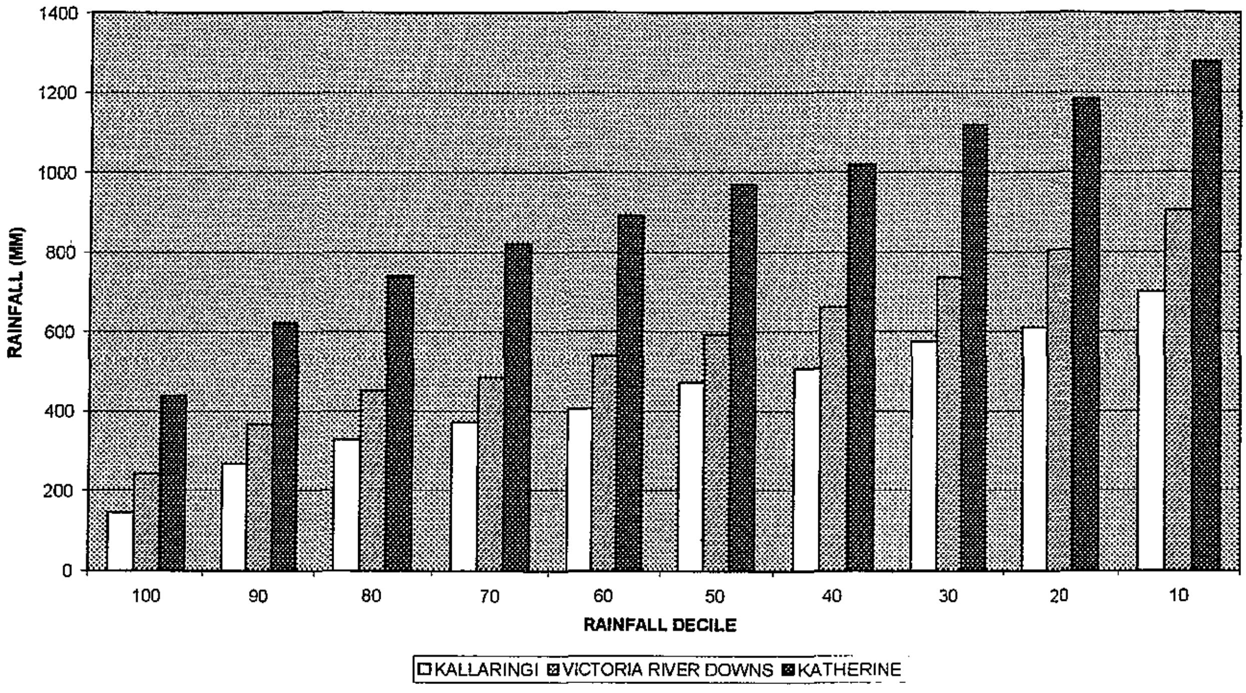


Figure 1.2 Distribution of average rainfall deciles for a north–south transect (Katherine, Victoria River Downs and Kalkaringi) in the VRD.

(b) Distribution of pasture communities

A survey by CSIRO in the early 1950's (Stewart *et al*, 1970) described the Victoria River District in terms of land systems. They classified and mapped the 118 758 km^2 VRD into 41 land systems. These vary from saline estuarine plains around the Joseph Bonaparte Gulf in the north, to desert scrubland in the south.

In the high-rainfall area (1000mm +) of the north, the country is rugged, hilly, and broken by valleys of tropical tallgrass and bluegrass plains. Soils of the tallgrass plains vary from leached sandy to leached loamy soils and carry the tussocky tall perennial grasses, kangaroo grass (*Themeda triandra*), perennial sorghum (*Sorghum plumosum*), ribbon grass (*Chrysopogon fallax*), white grass (*Sehima nervosum*) and black spear grass (*Heteropogon contortus*). The upper-story is mainly *Eucalyptus* box or bloodwood community, averaging 10-13m in height. The bluegrass plains of perennial *Dichanthium* spp. and *Chrysopogon* spp. consist of flat to gently undulating county with cracking clay soils developed on basalt or alluvium. The upper-story of these plains are scattered *Terminalia* spp. (rosewood and nutwood).

In the central section (500-1000mm rainfall), the hilly country persists with larger areas of less rugged and more undulating country than in the northern portion. Tall perennial grasses dominate the lower country of loamy soils with some areas of Mitchell grass (*Astrebla* spp.) on the basalt soils. Smaller pockets of erodible calcareous soils carry arid short grass species mainly *Enneapogon* spp. (eg. limestone grass), and *Aristida* spp. (eg. kerosene and wire grasses). The hilly country supports poor quality soft spinifex (*Plectrachne pungens*) and low woodlands of Snappy gum (*Eucalyptus brevifolia*).

The southern low-rainfall area (less than 500mm) is mainly open undulating country or soft spinifex plains on sandy or gravelly soils. This is broken by plains of cracking clay soils carrying the more productive Mitchell grass species and constitutes some of the best grazing land of the area.

A report into the relative land condition of various pasture communities in the VRD and elsewhere has been prepared by Condon (1986) and Tothill and Gillies (1992). Generally pasture condition throughout the district is good, however there are several pasture communities and areas within landscapes susceptible to continuing land degradation. Management strategies that enable sustainable grazing are required.

Carrying capacity and "safe" levels of utilisation will be largely determined by seasonal influences (rainfall amount and variability), pasture type and productivity, land condition, and the stability and resilience of the pasture under grazing.

Methods

Estimating carrying capacity and stocking rates

Scanlan *et al* (1994) and Johnston *et al* (1996) have outlined methods for the estimation of safe levels of utilisation and carrying capacity. Central to the calculations is the prediction of annual pasture growth for various pasture types and the determination of "safe" levels of utilisation.

(a) Predicting pasture production - SWIFTSYND sites and GRASP modeling

Data has been collected that has allowed the calibration and validation of the GRASP pasture growth model for several important pasture communities throughout the VRD, including Mitchell grass, ribbon/blue grass and arid short grass pastures.

In 1993 and 1994, a total of 21 'SWIFTSYND' exclosures were established at five locations throughout the VRD. SWIFTSYND is the name given to the sampling methodology outlined by Philp and Day (*unpubl.*) which aims to collect a basic data set for the development of the GRASP pasture growth model. Sites were selected to represent, where possible, land systems that are considered important for cattle production in the district, and therefore covered a range of productive pasture communities in various land conditions, across a range of rainfall zones. Map 2 displays the area that selected land systems represent across the VRD. Table 1.1 describes the location, pasture community and approximate condition of each 'SWIFTSYND' exclosure.

These exclosures represent a considerable number of pasture communities throughout the VRD as defined by Tothill and Gillies (1992). The allocation of pasture condition to sites was based subjectively on the condition assessment matrix described in Tothill and Gillies (1992). The relative composition of desirable and undesirable pasture species largely dominated the selection criteria. For future analysis it is planned to calculate condition scores using the method described by McIvor *et al* (1995) as a legitimate and objective means to compare sites.

Over a two-year period, intense pasture, soil and climate measurements at each exclosure were made on four occasions during the growing season and once at the end of the dry. The methodology is outlined in detail by Philp and Day (*unpubl.*).

Data collected from SWIFTSYND sites was used to calibrate and validate the GRASP pasture growth model for pastures in several soil and condition types. Data was also used to investigate the effect of soil type, pasture type, and land condition on basic productivity parameters such as yield, nutrient content etc that influence levels of utilisation.

Table1.1 Description of SWIFTSYND Exclosures.

Site	Location	Land System	Pasture Community	Condition	Main Species	Latitude	Longitude
1	Mount Sanford	Antrim	Arid Short Grass	B	Brachyachne convergens Sporobolus australasicus	17o 10' 50.3" S	130o 37' 25.1" E
2	Mount Sanford	Antrim	Arid Short Grass	B	Sporobolus australasicus Brachyachne convergens	17o 12' 17.1" S	130o 36' 40.8" E
3	Mount Sanford	Wave Hill	Mitchell Grassland	A	Astrebla pectinata Chrysopogon fallax	17o 11' 15.0" S	130o 36' 8.0" E
4	Mount Sanford	Wave Hill	Mitchell Grassland	B	Astrebla pectinata Brachyachne convergens	17o 13' 12.1" S	130o 38' 20.5" E
5	Mount Sanford	Wave Hill	Mitchell Grassland	A	Astrebla pectinata Chrysopogon fallax	17o 13' 22.7" S	130o 34' 56.2" E
6	Mount Sanford	Wave Hill	Mitchell Grassland	B	Astrebla pectinata Brachyachne convergens	17o 13' 10.0" S	130o 33' 49.4" E
7	Kidman Springs	Argyle	Ribbon/Bluegrass	B	Chrysopogon fallax Eragrostis tenellula	16o 05' 8.0" S	131o 0' 54.0" E
8	Kidman Springs	Argyle	Ribbon/Bluegrass	A	Chrysopogon fallax No sub-dom. grass	16o 05' 7.9" S	131o 1' 0.0" E
9	Kidman Springs	Argyle	Ribbon/Bluegrass	B	Chrysopogon fallax Aristida latifolia	16o 04' 11.0" S	130o 59' 40.1" E
10	Kidman Springs	Argyle	Ribbon/Bluegrass	A	Chrysopogon fallax Aristida latifolia	16o 04' 31.6" S	130o 59' 39.8" E
11	Kidman Springs	Humbert	Arid Short Grass	A	Enneapogon polyphyllus No sub-dom grass	16o 05' 4.3" S	130o 56' 58.7" E
12	Kidman Springs	Dinnabung	Mid Height Grass	B	Chrysopogon fallax Brachyachne convergens	16o 05' 24" S	130o 55' 15.3" E
13	Kidman Springs	Humbert	Arid Short Grass	B	Brachyachne convergens Tragus australianus	16o 06' 27.1" S	131o 0' 22.6" E
14	Kidman Springs	Dinnabung	Mid Height Grass	A	Sehima nervosum Eriachne spp.	16o 08' 3.0" S	130o 55' 19.6" E
15	VRD	Ivanhoe	Mitchell Grassland	B	Astrebla spp. Chrysopogon fallax	16o 23' 23.9" S	130o 58' 48.0" E
16	VRD	Ivanhoe	Ribbon/Bluegrass	A	Chrysopogon fallax Aristida latifolia	16o 24' 2.0" S	130o 57' 39.5" E
17	Rosewood	Wave Hill	Mitchell Grassland	B	Dichanthium fecundum Aristida latifolia	16o 24' 23.6" S	129o 2' 57.0" E
18	Rosewood	Wave Hill	Mitchell Grassland	A	Astrebla pectinata Panicum decompositum	16o 26' 55.9" S	129o 2' 28.6" E
19	Rosewood	Antrim	Arid Short Grass	A	Sehima nervosum Enneapogon polyphyllus	16o 28' 40.1" S	129o 8' 14.7" E
20	Auvergne	Ivanhoe	Tallgrass	B	Sehima nervosum Panicum decompositum	15o 42' 44.5" S	129o 57' 38.9" E
21	Auvergne	Ivanhoe	Ribbon/Bluegrass	A	Chrysopogon fallax Brachyachne convergens	15o 47' 19.1" S	129o 59' 49.8" E

(b) Determining safe and productive levels of utilisation

This report makes some preliminary comparisons of productivity parameters between broad pasture types and land conditions to determine whether there is justification for adjusting utilisation rates according to pasture type and condition.

Results

1. Pasture types and land condition

Basic pasture and soil productivity data for each SWIFTSYND site is summarised in Tables 1.2, 1.3 and 1.4. At this stage data is only in summary form. Complete analysis is planned in cooperation with Greg McKeon and Ken Day. Differences in the basic productivity between pasture types (quality, quantity and resilience to grazing) and land condition will influence levels of utilisation and carrying capacity.

Data for only 12 sites was analysed over two years (1994 and 1995) to investigate differences between sites allocated to A (good) and B (poor) land conditions, and black and red soil types (Mitchell/ribbon grass and arid short grass respectively). A complete data set is not yet available for the remaining sites.

(a) Soil and pasture type

(i) Species composition and basal area
Comparison by soil type reveals that red soils, regardless of condition, yield a higher proportion and higher total yield of annual grasses and forbs than do black soils (Figure1.4b). Most of the grasses are very palatable. Some of the forbs are moderately palatable and nutritious species (*Neptunia* and *Rhyncosia* spp) while many are woody and are rarely grazed by cattle *(Waltheria, Sida, Heliotropium, Hibiscus, and Gossypium* spp.). Some forb species are thought to have potential toxicity under certain conditions (*Crotolaria* and *Indigofera* spp.). The greater proportion of annual grasses and forbs could be a reflection of the greater representation of poor condition sites on red soil pastures. At the time of selection sites, meeting the criteria for good condition were difficult to find due to seasonal conditions and the preference of this soil/pasture type for grazing.

Pasture basal area was greater for black soil sites but only significantly ($P < 0.05$), during the 1993/94 season. This is no doubt attributed to the greater proportion of perennial grasses on black soil sites and an increase in perennial grass yield on red soil pastures with continued favourable seasonal conditions in 1994/95.

(ii) Pasture yield
Pastures on black soils (Vertosols) consistently yielded higher, although not significantly, than those on red soil (Dermosols, Kandosol, and Calcarosol) (Figure 1.3). This is likely to be due to black soils being deeper and having a much higher available water storage capacity in the plant rooting zone (0-50cm, Table 1.4). The higher productivity of black soil pastures compared to red soil pastures, in terms of total yield, was also evident from the calculations of rainfall use efficiency (RUE).

(iii) Pasture quality
There was no significant difference in %N between black and red soil pastures, however total N yield was significantly ($P < 0.05$) greater in black soil pastures during 1994/95.

(b) Land condition

Declining pasture condition is normally associated with an increase in undesirable pasture species, an increase of annual grasses and forbs (reduced perennial grass basal area), a reduction in herbage yield and ground cover, increase in woody vegetation and increased signs of soil erosion.

Table 1.2 Summary of Values for Pasture Community Variables at the End of the Growing Season

Site	Year	Rainfall (mm)	Total Yield (kg/ha)	RUE (kg/ha/mm)	PGBasal (%)	WtdBasal (%)	Cover (%)	N Yield (kg/ha)	P Yield (kg/ha)
1	1	543.1	1951.1	3.59	0.00	0.00	84.1%	19.50	0.82
	2	740.7	2951.8	3.99	0.00	0.00	69.8%	25.54	1.64
2	1	530.7	1977.4	3.73	0.00	0.00	89.6%	23.26	0.84
	2	756.9	2424.3	3.20	0.00	0.00	56.6%	19.08	1.35
3	1	543.9	1860.6	3.42	4.50	3.97	37.5%	11.89	1.19
	2	816.4	2543.8	3.12	3.75	3.31	55.6%	28.70	2.44
4	1	592.0	2342.7	3.96	1.00	0.78	74.4%	31.53	2.34
	2	806.0	2672.2	3.32	1.00	0.89	84.1%	36.42	2.84
5	1	595.1	2737.7	4.60	3.63	3.12	53.4%	22.09	1.25
	2	752.3	3470.9	4.61	3.75	3.27	67.5%	33.22	2.63
6	1	632.4	2013.5	3.18	1.50	1.25	52.3%	12.87	1.34
	2	674.0	3330.3	4.94	1.13	1.00	74.4%	26.50	3.39
7	1	748.9	2553.4	3.41	2.25	1.39	55.6%	16.61	1.08
	2	836.1	3660.8	4.38	3.25	1.93	72.5%	30.54	1.64
8	1	748.9	3425.8	4.57	6.00	3.60	69.4%	19.79	1.14
	2	836.1	4281.7	5.12	4.25	2.55	88.1%	36.61	1.75
9	1	785.3	1862.3	2.37	0.88	0.54	41.9%	11.13	0.66
	2	707.5	2526.6	3.57	2.13	1.10	61.3%	22.55	1.02
10	1	780.2	2665.6	3.42	4.25	2.58	52.5%	14.37	0.78
	2	701.9	2762.6	3.94	3.50	1.94	65.3%	20.84	1.02
11	1	800.9	2707.2	3.38	2.88	2.30	43.8%	14.40	0.84
	2	739.3	2344.6	3.17	2.75	2.20	53.1%	16.35	0.76
12	1	819.1	2417.6	2.95	1.25	0.76	46.5%	15.51	1.08
	2	746.5	3032.2	4.06	2.13	1.43	70.0%	20.86	1.53
13	1	825.5	2592.7	3.14	0.00	0.00	90.3%	17.91	1.27
	2	561.2	854.4	1.52	0.00	0.00	24.8%		
14	1	809.0	2395.5	2.96	2.88	0.89	50.0%	11.28	0.68
	2	636.7	1531.4	2.41	2.13	0.61	23.4%		
15	1	870.1	2695.8	3.10	0.75	0.61	73.8%	56.41	2.64
	2	1036.6	2679.8	2.59	1.50	1.23	89.4%		
16	1	870.1	3092.8	3.55	1.63	0.83	76.3%	23.91	1.29
	2	1036.6	2682.1	2.59	1.50	0.84	68.8%		
17	1	786.2	2315.0	2.94	3.00	1.98	50.0%	11.42	1.41
	2	618.2	1761.6	2.85	1.13	0.63	30.0%		
18	1	786.2	3359.2	4.27	2.38	2.09	87.5%	20.34	2.74
	2	618.2	2253.6	3.65	2.13	1.84	53.8%		
19	1	786.2	1872.7	2.38	1.88	1.25	43.6%	9.22	1.08
	2	618.2	736.5	1.19	0.63	0.30	19.6%		
20	1	813.9	2620.8	3.22	0.88	0.35	78.4%	18.34	1.14
	2	893.0	3972.7	4.45	2.00	0.95	73.8%		
21	1	813.9	2030.8	2.50	3.25	1.80	72.5%	18.33	0.84
	2	893.0	1588.2	1.78	1.63	0.91	54.4%		

Data Fields:
RUE = rainfall use efficiency
PGBasal = basal area of all perennial grasses
WtdBasal = PG basal area weighted for pastoral importance
Cover = area of ground covered by plant material
N & P Yield = total amount of N & P in pasture

Table 1.3 Summary of Values for Pasture Yield Variables at the End of the Growing Season

Site	Year	Total Yield (kg/ha)	PerennialGr (kg/ha)	% PG (%)	AnnualGr (kg/ha)	% AG (%)	Forbs (kg/ha)	% Forbs (%)	GrassLeaf (kg/ha)	% GrLeaf (%)
1	1	1951.1	1.5	0.1%	1892.5	97.0%	57.1	2.9%	650.2	33.3%
	2	2951.8	62.8	2.1%	1908.2	64.6%	980.9	33.2%	648.8	22.0%
2	1	1977.4	15.5	0.8%	1882.4	95.2%	79.5	4.0%	669.3	33.8%
	2	2424.3	367.8	15.2%	1605.7	66.2%	450.8	18.6%	873.8	36.0%
3	1	1860.6	1736.8	93.3%	38.7	2.1%	85.2	4.6%	1099.7	59.1%
	2	2543.8	1470.7	57.8%	106.4	4.2%	966.8	38.0%	795.7	31.3%
4	1	2342.7	385.4	16.4%	335.4	14.3%	1621.9	69.2%	313.0	13.4%
	2	2672.2	513.4	19.2%	263.1	9.8%	1895.7	70.9%	330.0	12.4%
5	1	2737.7	2516.5	91.9%	26.5	1.0%	194.7	7.1%	1371.6	50.1%
	2	3470.9	2493.0	71.8%	207.6	6.0%	770.3	22.2%	1517.6	43.7%
6	1	2013.5	1740.8	86.5%	135.8	6.7%	136.8	6.8%	609.9	30.3%
	2	3330.3	996.8	29.9%	1188.5	35.7%	1145.1	34.4%	661.2	19.9%
7	1	2553.4	2080.2	81.5%	73.2	2.9%	400.1	15.7%	1955.5	76.6%
	2	3660.8	2366.7	64.6%	711.9	19.4%	582.2	15.9%	2811.2	76.8%
8	1	3425.8	3016.3	88.0%	63.3	1.8%	346.3	10.1%	2934.1	85.6%
	2	4281.7	2751.4	64.3%	74.2	1.7%	1456.2	34.0%	2664.7	62.2%
9	1	1862.3	993.2	53.3%	343.7	18.5%	525.4	28.2%	1011.5	54.3%
	2	2526.6	1395.5	55.2%	271.3	10.7%	859.8	34.0%	1225.5	48.5%
10	1	2665.6	1898.7	71.2%	418.0	15.7%	348.9	13.1%	1496.7	56.1%
	2	2762.6	1890.7	68.4%	245.6	8.9%	626.3	22.7%	1668.3	60.4%
11	1	2707.2	2583.5	95.4%	0.0	0.0%	123.7	4.6%	1359.0	50.2%
	2	2344.6	1994.5	85.1%	48.5	2.1%	301.6	12.9%	863.1	36.8%
12	1	2417.6	1679.3	69.5%	173.8	7.2%	564.6	23.4%	1503.0	62.2%
	2	3032.2	2240.7	73.9%	391.5	12.9%	400.0	13.2%	1705.8	56.3%
13	1	2592.7	138.7	5.3%	2191.3	84.5%	262.7	10.1%	1025.1	39.5%
	2	854.4	156.9	18.4%	362.7	42.5%	334.8	39.2%		
14	1	2395.5	2183.2	91.1%	51.6	2.2%	160.8	6.7%	1100.6	45.9%
	2	1531.4	1325.2	86.5%	26.8	1.8%	179.4	11.7%		
15	1	2695.8	503.6	18.7%	108.1	4.0%	2084.0	77.3%	390.9	14.5%
	2	2679.8	858.2	32.0%	131.8	4.9%	1689.8	63.1%		
16	1	3092.8	680.2	22.0%	1787.1	57.8%	625.4	20.2%	1703.5	55.1%
	2	2682.1	473.1	17.6%	1536.4	57.3%	672 7	25.1%		
17	1	2315.0	1249.7	54.0%	419.5	18.1%	645.9	27.9%	1052.8	45.5%
	2	1761.6	890.9	50.6%	386.9	22.0%	483 8	27.5%		
18	1	3359.2	1846.7	55.0%	302.6	9.0%	1209 9	36.0%	1295.0	38.5%
	2	2253.6	1552.1	68.9%	159.1	7.1%	542 4	24 1%		
19	1	1872.7	1649.7	88.1%	197.4	10.5%	25 6	1 4%	1437.9	76.8%
	2	736.5	380.8	51.7%	87.7	11.9%	268 0	36.4%		
20	1	2620.8	1950.6	74.4%	357.1	13.6%	313.0	11.9%	2104.8	80.3%
	2	3972.7	3454.3	87.0%	457.5	11.5%	60.9	1.5%		
21	1	2030.8	622.3	30.6%	477.7	23.5%	930.8	45.8%	1081.8	53.3%
	2	1588.2	650.4	41.0%	129.0	8.1%	808.8	50.9%		

Data Fields:
PerennialGr = yield of perennial grasses
% PG = fraction of total yield made up by perennial grasses
AnnualGr and % AG = as above, but for annual grasses
Forbs and % Forbs = as above, but for forbs
GrassLeaf and % GrLeaf = as above, but for grass leaf.

Table 1.4 A summary of soil characteristics at each exclosure site

Site	SoilClass	Origin	Depth (m)	BD 0-10cm (g/cc)	pH 0-10cm	AWSC 0-50 (mm)	Total N (%)	Total P (%)	OrganicC (%)
1	Dermosol	Basalt	0.65	1.44	7.5	90.9	0.05%	0.022%	0.73%
2	Dermosol	Basalt	0.35	1.48	7.8	91.1	0.04%	0.025%	0.51%
3	Vertosol	Basalt	1.42	1.18	8.3	170.5	0.03%	0.013%	0.53%
4	Vertosol	Basalt	1.10	1.35	8.5	164.3	0.03%	0.013%	0.45%
5	Vertosol	Basalt	1.25	1.39	8.3	183.7	0.02%	0.012%	0.37%
6	Vertosol	Basalt	0.75	1.26	8.0	198.5	0.02%	0.012%	0.48%
7	Vertosol	Alluvial	2.00	1.50	8.3	153.1	0.02%	0.010%	0.55%
8	Vertosol	Alluvial	2.00	1.54	8.3	145.3	0.04%	0.014%	0.59%
9	Vertosol	Alluvial	2.00	1.52	8.1	127.9	0.02%	0.007%	0.45%
10	Vertosol	Alluvial	2.00	1.58	8.2	148.8	0.02%	0.005%	0.45%
11	Calcarosol	Limestone	0.40	1.59	8.3	77.0	0.06%	0.020%	0.97%
12	Dermosol	Limestone	0.60	1.46	7.6	66.4	0.05%	0.021%	1.10%
13	Dermosol	Limestone	0.40	1.70	7.3	84.3	0.02%	0.022%	0.42%
14	Kandosol	Limestone	0.85	1.57	7.3	105.2	0.03%	0.018%	0.87%
15	Vertosol	Alluvial	2.00	1.50	8.7	228.1	0.04%	0.017%	0.67%
16	Vertosol	Alluvial	2.00	1.32	7.9	159.3	0.04%	0.008%	0.70%
17	Vertosol	Basalt	2.00	1.35	7.3	187.8	0.03%	0.014%	0.64%
18	Vertosol	Basalt	2.00	1.29	7.8	162.4	0.03%	0.012%	0.55%
19	Dermosol	Basalt	0.30	1.58	7.3	87.3	0.03%	0.031%	0.67%
20	Vertosol	Alluvial	2.00	1.68	8.0	88.4	0.03%	0.011%	0.58%
21	Vertosol	Alluvial	2.00	1.52	6.9	111.6	0.02%	0.010%	0.48%

(i) Species composition and basal area

As mentioned previously, land condition was allocated to exclosures on the basis of species composition and perennial grass dominance. As expected, sites in poor condition have significantly higher yields of annual grasses ($P < 0.05$), lower yields of perennial grasses ($P < 0.05$) and lower perennial grass basal areas ($P < 0.05$).

Data summarised for later years indicates that the effect of favourable seasons on the relative proportions of pasture components was considerable (Figure 1.4a). By 1996, following several good seasons there was little difference in perennial grass, annual grass, and forb proportions between pasture conditions, while in 1994 there was considerable difference between good and poor conditions.

(ii) Pasture yield

For the seasons measured, land condition had no significant effect on annual peak yield. Fig.1.2 shows total pasture yield at the end of the growing season (May) for sites classified as condition A and condition B, with no account taken of the soil type. Although for this chart, a different combination of sites are summarised for each year, the absence of a trend indicates that total yield is not a good indicator of land classified in either "good" or "poor " condition.

(iii) Pasture quality

For the 12 sites analysed there was no significant difference in % nitrogen (%N) and total N yield in May between good and poor condition exclosures. Of interest is that total N yield on average increased significantly ($P < 0.05$) for the second year of measurements.

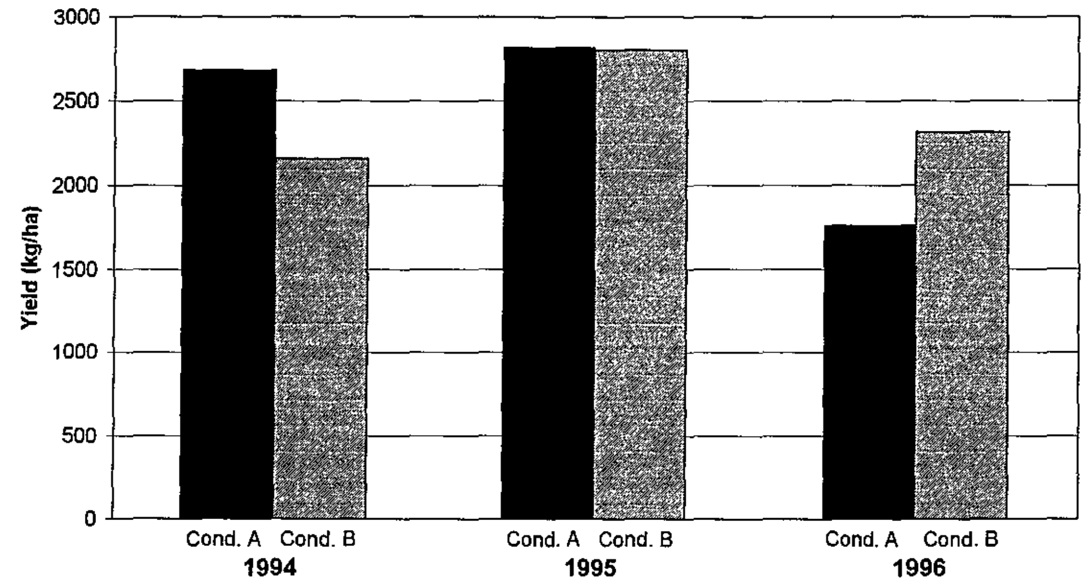


Figure 1.2 Pasture yield at the end of the wet season – by pasture condition

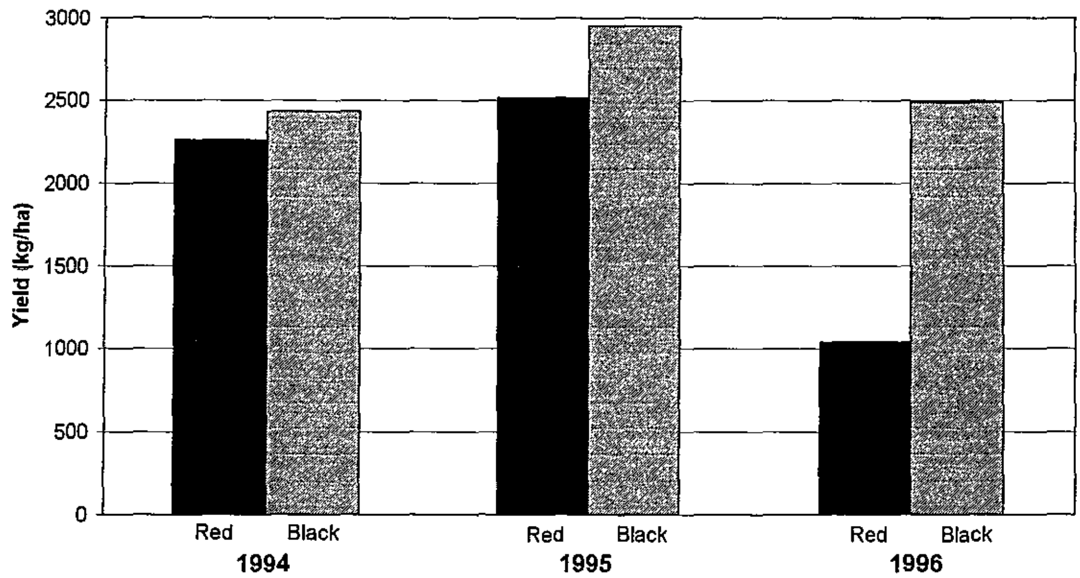


Figure 1.3 Pasture yield at the end of the wet season – by soil type

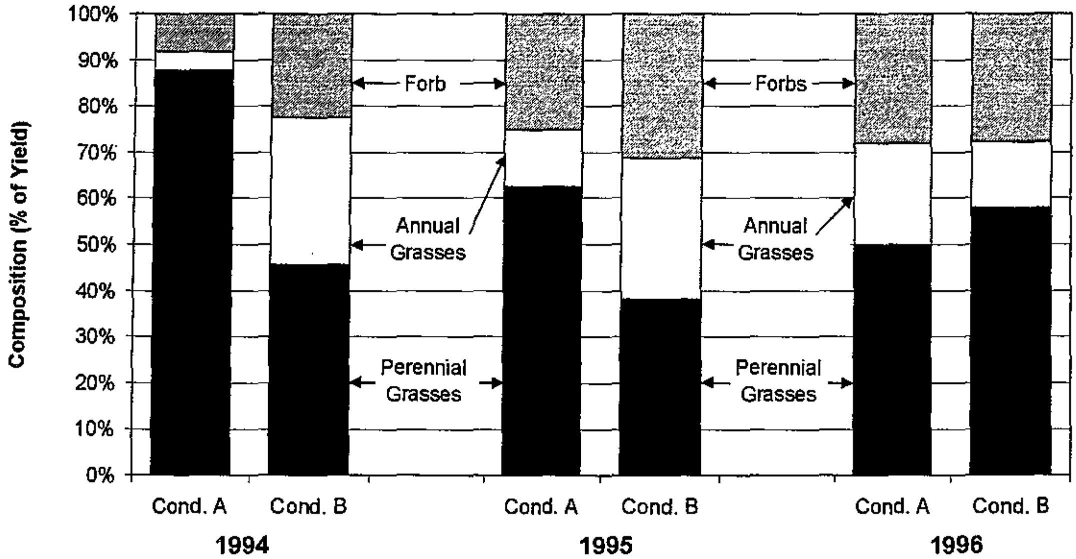


Figure 1.4a Composition in pasture of perennials, annuals, and forbs – by pasture condition

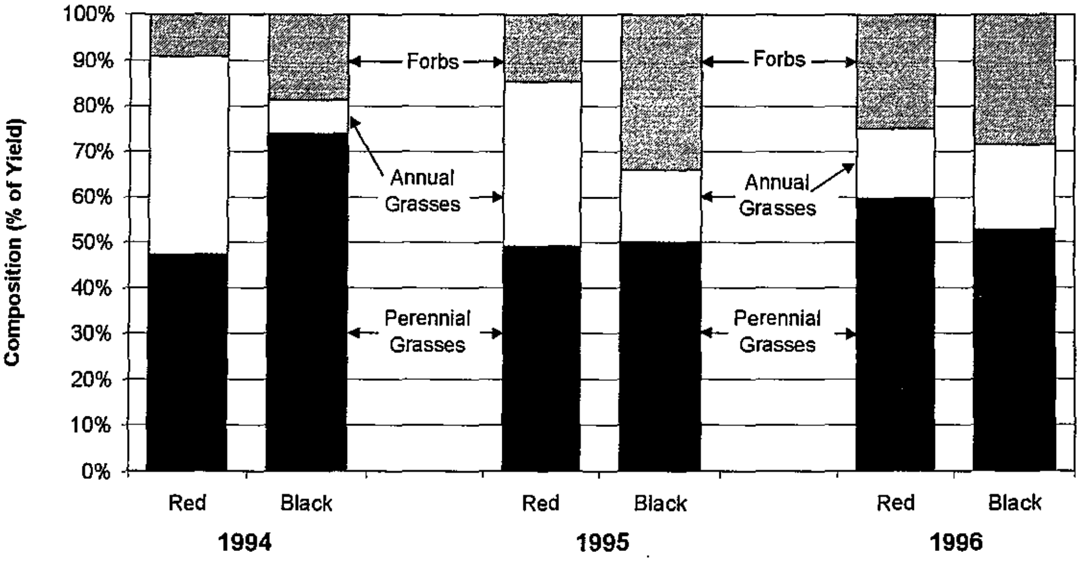


Figure 1.4b Composition in pasture of perennials, annuals, and forbs – by soil type

2. Predicting pasture growth with GRASP and Rainfall Use Efficiencies (RUE)

(a) GRASP

SWIFTSYND data collection is complete and final GRASP model validation is underway with the cooperation of Greg McKeon and Ken Day of QDNR. Unfortunately GRASP model output cannot be utilised for the analysis of carrying capacity and utilisation in this report as validation is incomplete. Until GRASP models for pasture communities are validated satisfactorily, preliminary investigations of carrying capacity can be made using rainfall use efficiencies (RUE) to predict annual pasture growth.

An example of the completed GRASP model output is shown in the figures below for an arid short grass site within the Mount Sanford stocking rate project. Figures 1.5 to 1.8 show a good comparison between observed and predicted values for volumetric soil moisture (0-50cm and 0-100cm), green yield and standing dry matter over a two year period. Historical rainfall records were used to predict annual pasture production between 1957 and 1996 (Figure 1.9). It is from long term production estimates and a knowledge of utilisation rates that annual animal carrying capacity can be estimated (Figure 1.10). Under a fixed stocking strategy, annual levels of utilisation and animal live weight gain would also fluctuate. This is represented between 1957 and 1996 in Figures 1.11 and 1.12. These relationships are an example of how predicted pasture production values may be used. Absolute values for carrying capacity and live weight gain are not accurate, as they are yet to be validated however the general trend between years is of central importance.

As data from all sites is validated, annual production can be simulated for a range of pasture communities and land conditions. This will be utilised to investigate property carrying capacities and stocking rates, levels of utilisation, animal production and burning frequencies throughout the VRD.

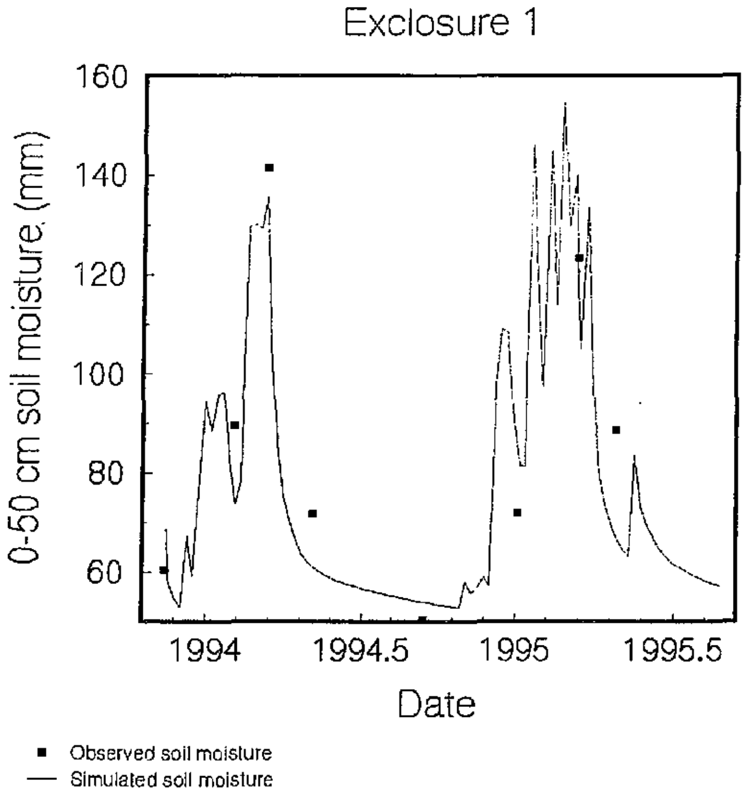


Figure 1.5 Observed and predicted volumetric soil moisture for 0-50 cm depth in an arid short grass pasture

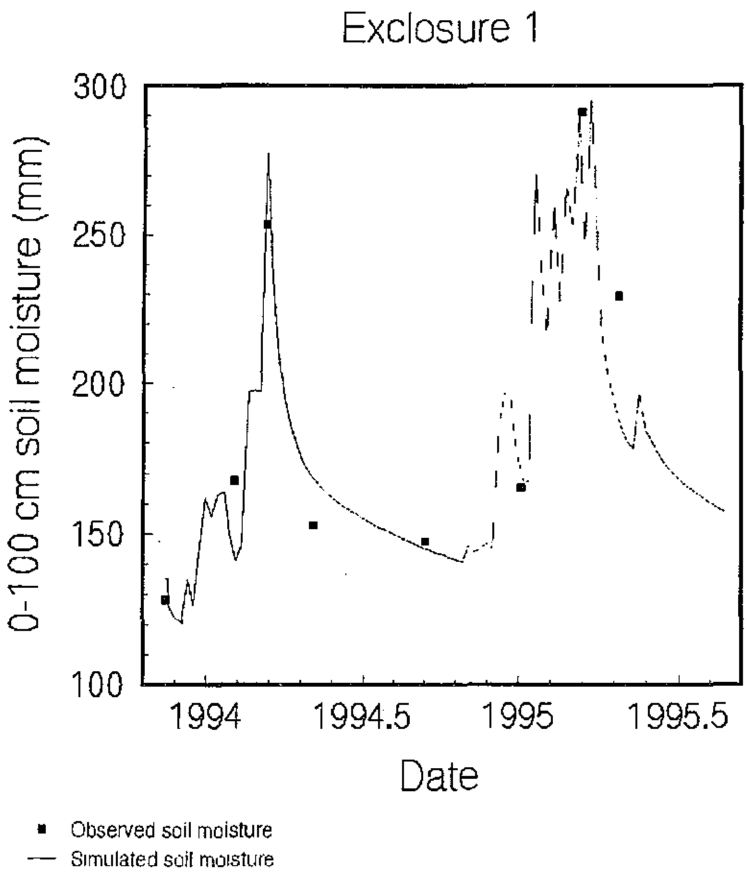


Figure 1.6 Observed and predicted volumetric soil moisture for 0-100 cm depth in an arid short grass pasture

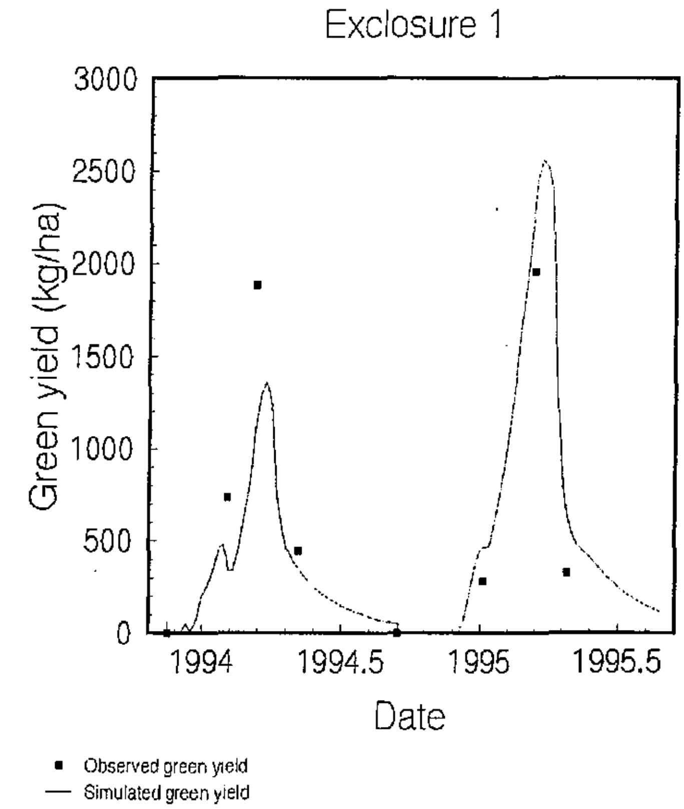


Figure 1.7 Observed and predicted green yield values for an arid short grass pasture

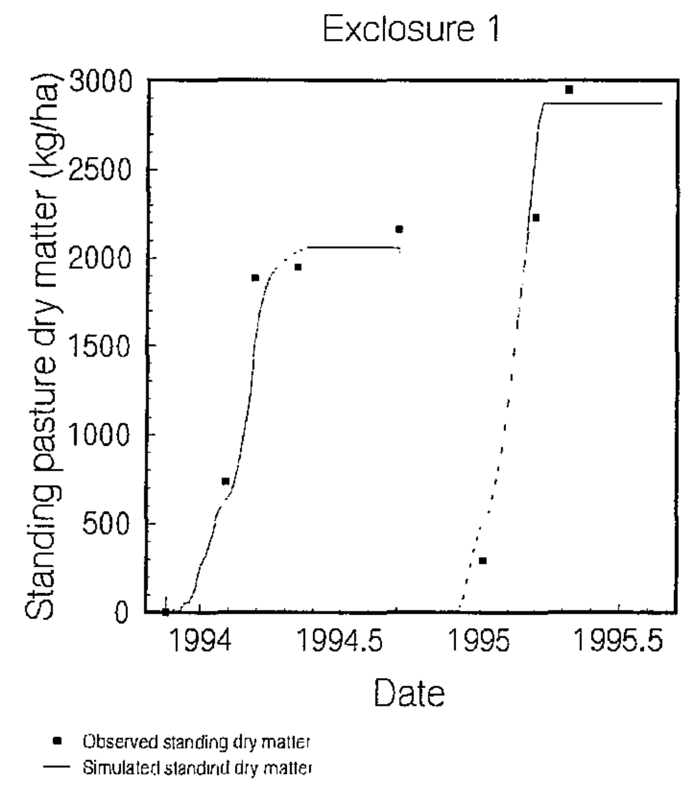


Figure 1.8 Observed and predicted values for standing pasture dry matter for an arid short grass pasture.

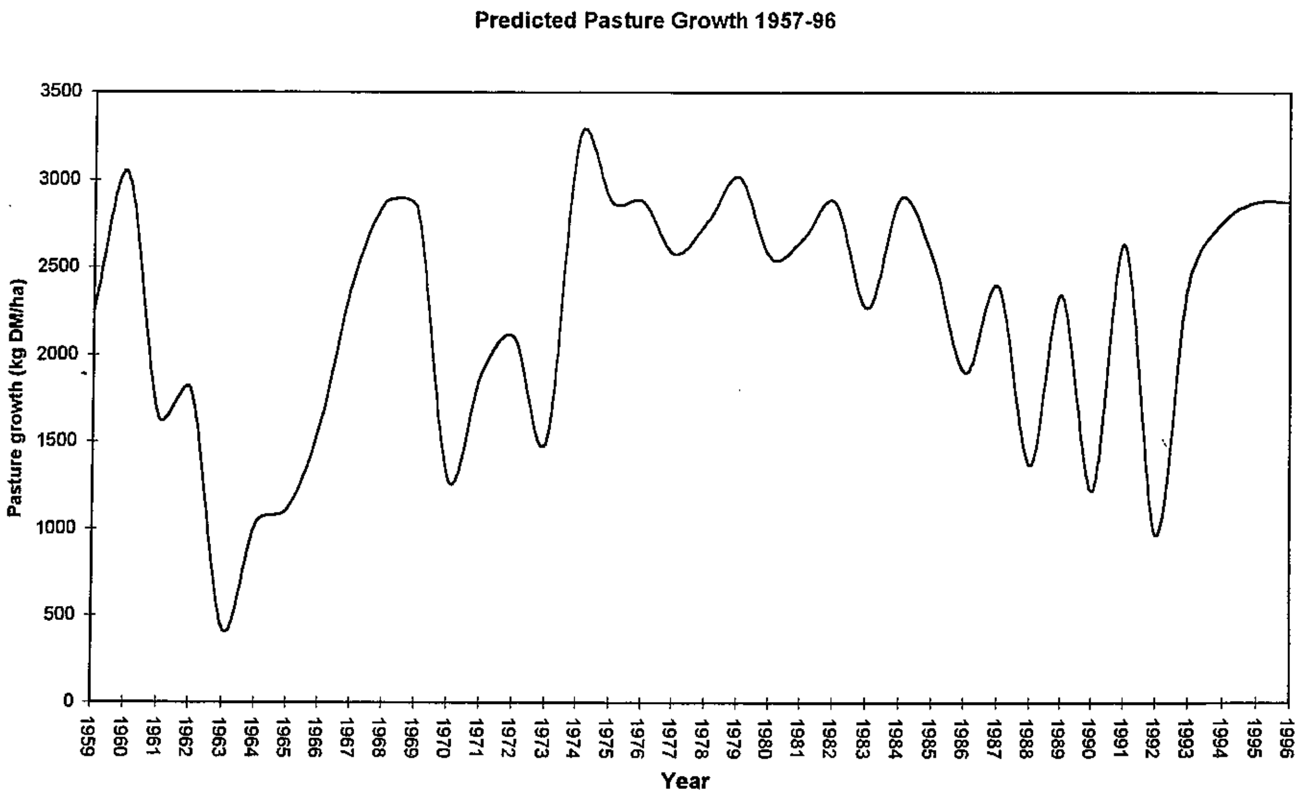


Figure 1.9 Predicted level of annual pasture growth for arid short grass pasture at Mount Sanford between 1957-96.

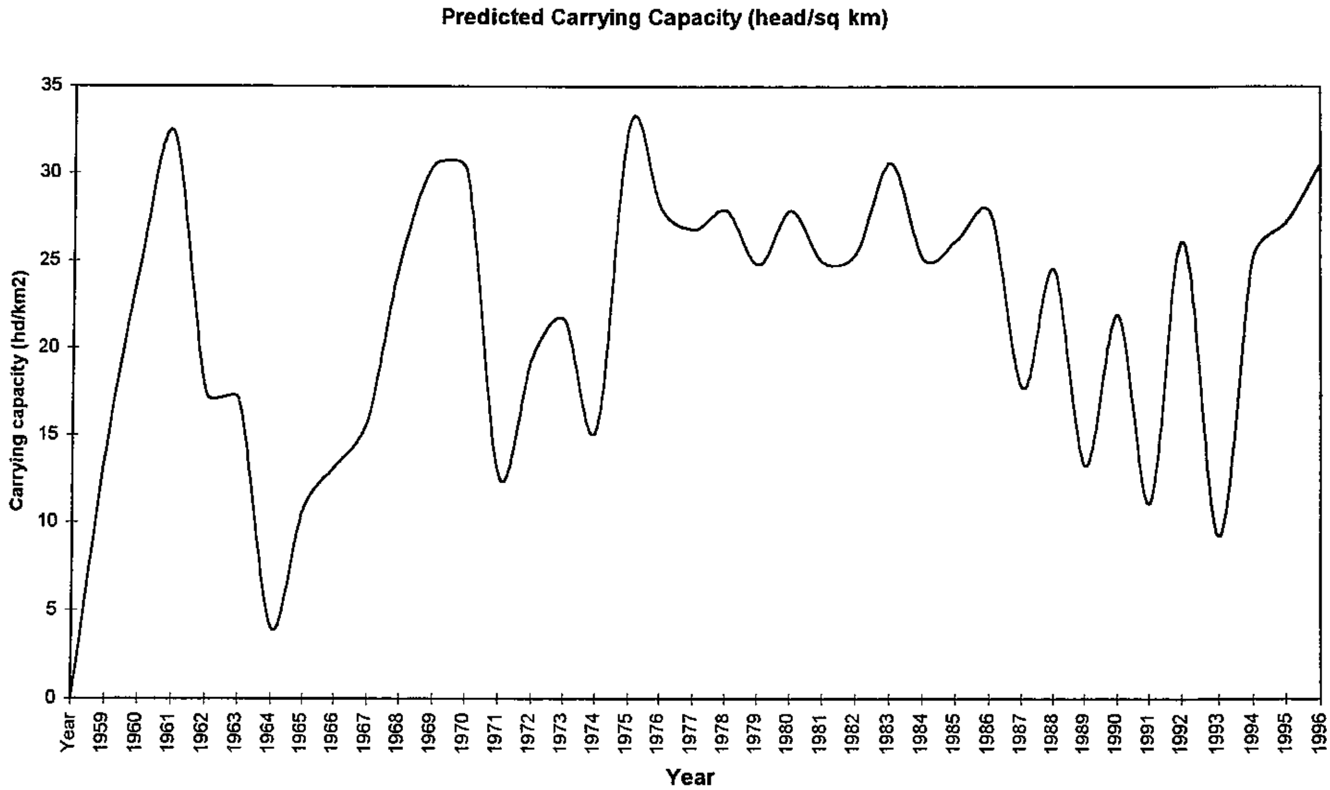


Figure 1.10 Fluctuations in carrying capacity based on annual pasture production between 1957 –96

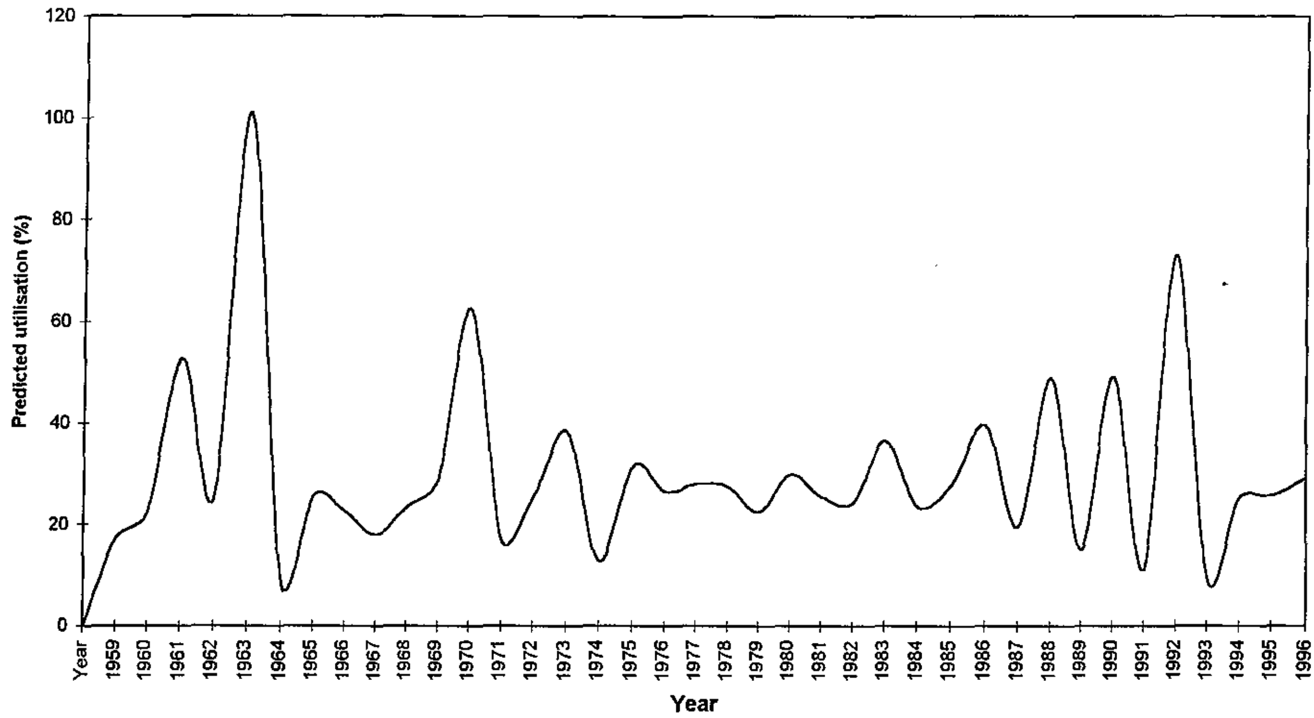


Figure 1.11 Fluctuation in utilisation level with predicted pasture production between 1957-96

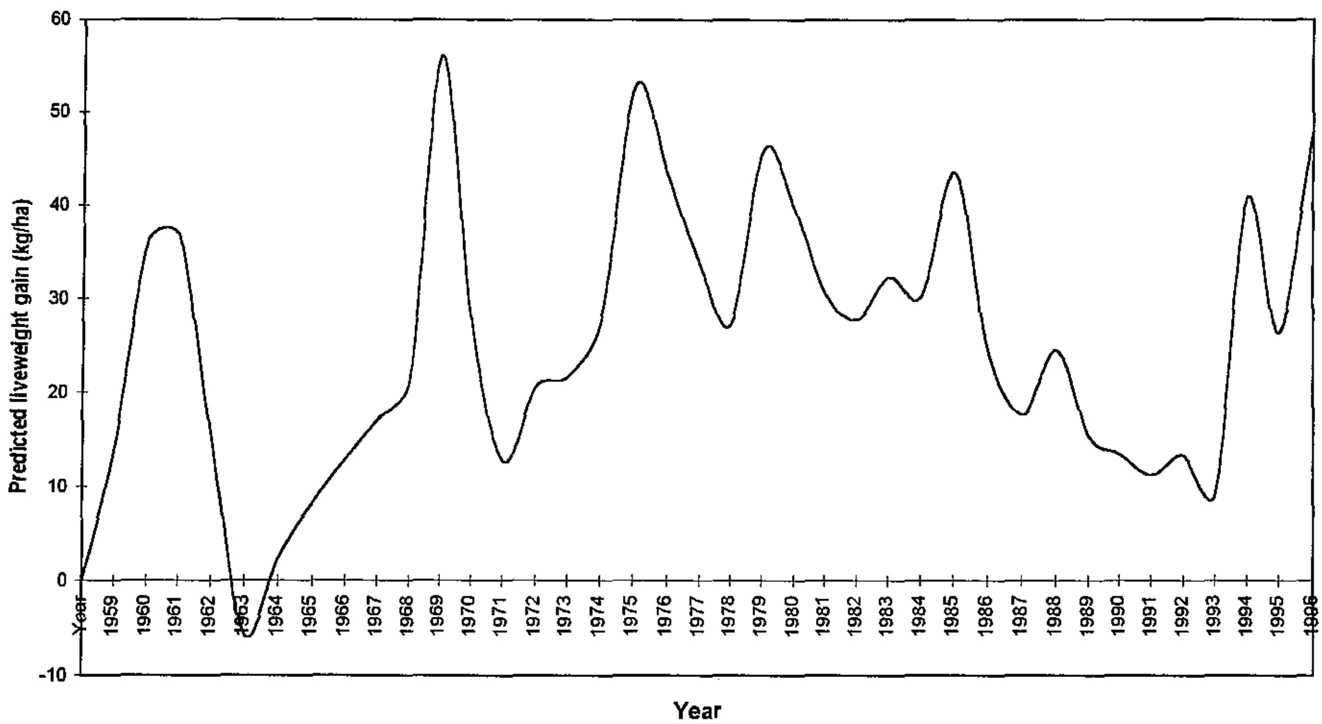


Figure 1.12 Fluctuation in predicted live weight gain (kg/ha) between 1957-96

(b) Rainfall Use Efficiencies (RUE)

The use of RUE is a very simplistic approach to predicting yield from seasonal conditions. RUE calculations assume a linear relationship between rainfall and pasture production and do not account for factors such as seasonal run-off in high rainfall areas and limitations to growth due to nutrient availability.

RUE values were calculated for pastures grouped by soil type (Table 1.5), land condition (Table 1.6), pasture communities (Table 1.7) and season of measurement (Table 1.8a and 1.8b). Calculations were made from peak yield and rainfall data at 21 SWIFTSYND sites.
The only significant difference between RUE was between the black (Mitchell and ribbon/blue grass) and red soil (Arid short grass) pasture communities. There was no difference in the gross productivity between land condition, individual pasture community, or season. These calculations of RUE are only a preliminary indication of growth potential.

Table 1.5 Calculated rainfall use efficiency (RUE) values for black and red soil pasture communities.

Soil type	RUE (kg DM/ha/mm)	Stdev	N
Black soil	3.55 [a*]	0.84	28
Red soils	2.98 [b]	0.85	14

* Different supercripts represent significant difference between groups at the P< 0.05 level.

Table 1.6 Calculated rainfall use efficiency (RUE) values for good and poor land conditions pastures.

Land condition	RUE (kg DM/ha/mm)	Stdev	N
"Good "	3.33 [a]	1.01	20
"Poor"	3.38 [a]	0.75	22

Table 1.7 Calculated rainfall use efficiency (RUE) values for individual pasture communities.

Pasture community	RUE (kg DM/ha/mm)	Stdev	N
Arid short grass	2.92 [a]	0.93	10
Mitchell grass	3.61 [a]	0.74	14
Ribbon/blue grass	3.43 [a]	0.99	12
Mid grass	3.09 [a]	0.69	4
Tropical Tall grass	3.83 [a]	0.86	2

Table 1.8 Calculated rainfall use efficiency (RUE) for soil types over 1994/95 and 1995/96
(a) Sites measured in 1994/1995

Season/soil type	RUE (kg DM/ha/mm)	Stdev	N
1994 Black	3.61 [a]	0.74	8
1994 Red	3.41 [a]	0.34	4
1995 Black	4.12 [a]	0.75	8
1995 Red	3.60 [a]	0.48	4

(b) Sites measured in 1995/1996

Season/soil type	RUE (kg DM/ha/mm)	Stdev	N
1995 Black	3,26 [ab]	0,64	6
1995 Red	2.67 [a]	0.41	2
1996 Black	2.98 [a]	0.93	6
1996 Red	1.80 [ab]	0.85	2

3. The influence of seasonal climate on reliability of pasture production

The reliability of annual pasture production will be determined greatly by seasonal climate. The variation in quantity of pasture grown will influence utilisation rates at particular locations.

By using the RUE values for black and red soil pasture communities, the effect of season on annual pasture production can be described for three different locations (Katherine, VRD and Kalkaringi) from rainfall deciles (Figures 1.13 and 1.14). Based on quantity alone, utilisation rates in the wetter northern areas would expect to be higher. The reliability of getting a least 2000 kg DM/ha in Katherine is very high (9 out of 10 years), however at Kalkaringi annual production at these levels may only occur in 5 out of 10 years. Higher rates of annual production however, are associated with pastures of poorer quality (nutrient content and digestibility) and lower stability under grazing. Utilisation rates and animal production from these pastures are generally considered to be lower than better quality pastures in southern areas.

Black soil pastures such as mitchell grass and ribbon/blue grass are generally more productive in terms of yield compared to arid short grass pastures. Carrying capacities on arid short grass pastures would be expected to be lower based on yield alone.

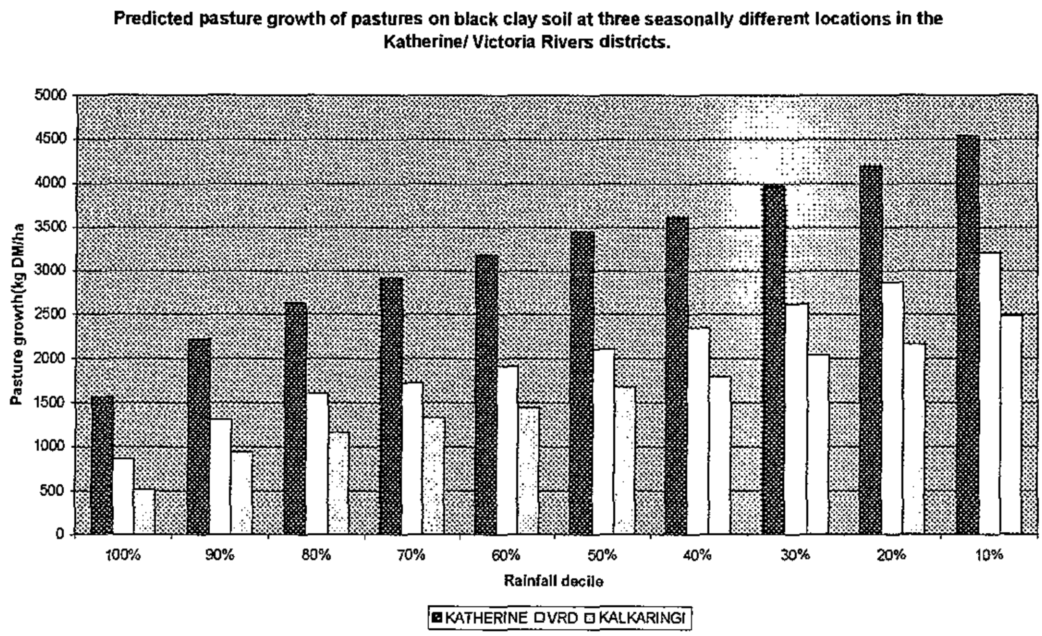


Figure 1.13 The predicted pasture growth of pastures on black clay soils for normal annual rainfall deciles, at three seasonally different locations in the Katherine/Victoria River districts.

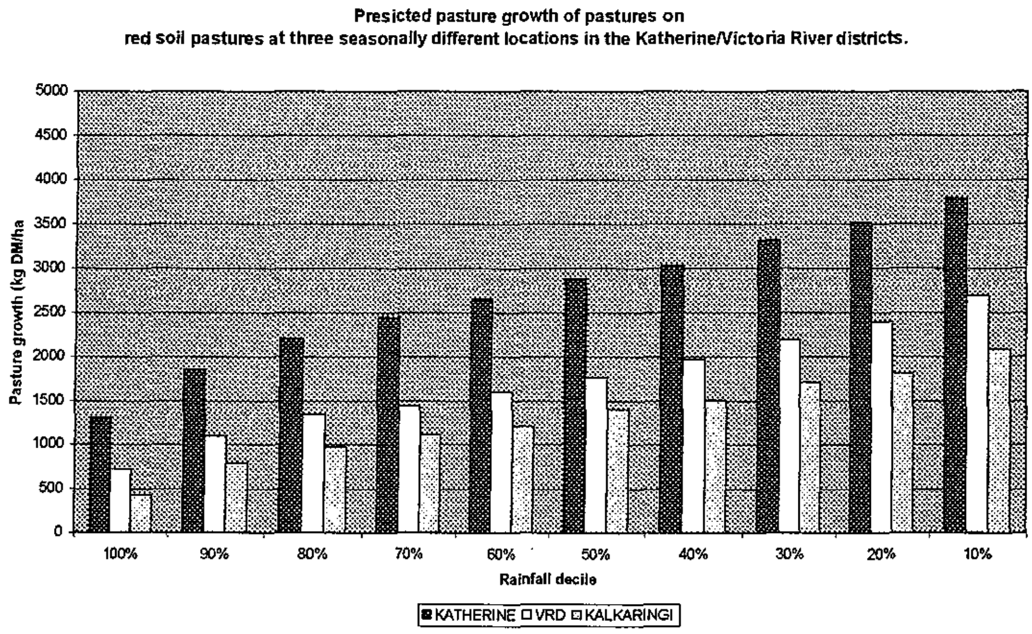


Figure 1.14 The predicted pasture growth of pastures on red earth soils for normal annual rainfall deciles, at three seasonally different locations in the Katherine/Victoria River districts.

Sub-project 2

The effect of tree and shrub density on pasture production.

2.1 The shrub-grass relationships in a semi-arid topical grassland dominated by the woody shrub *Terminalia volucris* (rosewood).

Objective

To determine whether current densities of *Terminalia volucris* (rosewood) on cracking clay soils significantly affect soil moisture and pasture production.

Introduction

Pasture, shrub and tree growth are determined by plant available moisture and available nutrients. Plant available moisture is primarily determined by annual rainfall, soil texture and soil depth. Increasing densities and competitive influences from the overlying tree and shrub layer may utilise significant amounts of soil moisture or nutrients otherwise available for pasture growth.

Tree clearing and tree or shrub invasions are two sources of disturbance to the natural tree-grass equilibrium, and both have the potential to cause considerable, but opposite, effects, on plant available moisture and pasture production.

An increase in tree and shrub canopy cover, resulting from the encroachment of native overstorey species into open savannas, is occurring throughout the northern rangelands. Within grazing lands, this increased overstorey competition for soil moisture has the potential to significantly reduce herbage production. Lower pasture production can lead to increasing grazing pressure and over-use of grazing lands in lower rainfall areas and during periods of below average rainfall.

A trial was established to determine if single plants, or a range of plant densities, had any measurable effect on soil moisture and plant production. In 1989 the CSIRO, Division of Tropical Crops and Pastures established a range of 'artificial' shrub densities in a grassland dominated by rosewood, on cracking clay soils at Kidman Springs. In the immediate area existing plant density was approximately 400 stems/ha. The existing shrub community was manually thinned with a chain saw to leave plots with 40, 200 and 400 stems/ha. Cut stumps were poisoned with herbicide (Tordon) to prevent regrowth. Each shrub density treatment was replicated in two blocks. Preliminary results suggested there was no effect of existing tree densities on pasture production, and further investigation of soil moisture levels and harvested yields would confirm this.

Methods

Experimental site and design

In the current trial, five rosewood plants were identified in each block within the CSIRO experimental area. Plant height, canopy cover and distance to the nearest shrub were measured for each individual. Pasture yield, pasture regrowth and soil moisture were measured at increasing distances from individual plants in each shrub density treatment. Single plant effects were measured around shrubs in the 40 stems/ha plot. It is assumed that at this low density, individual plants would have no effect on those surrounding. The effect of plant density was measured in plots containing 40, 200 and 400 stems/ha.

Pasture production
The biomass of perennial, annual and forb species was measured in March 1994. For each density all current season's growth contained in a $1m^2$ quadrat placed at 1.0, 2.5 and 4.0m from the base of each identified plant was harvested using hand shears. Samples were separated into perennial grass, annual grass and forb components. Dry weight was determined following oven drying at 80°C for 48hrs.

Pasture regrowth
Pasture regrowth was measured from previously harvested quadrats in June 1994. Differences in regrowth yield with distance from single plants or between shrub density treatments would be attributed to underlying soil moisture effects. All standing biomass was harvested with hand shears and dry weight determined.

Soil moisture
Soil samples were collected using a hand auger in March, May and June 1994. Samples were collected at 1.0, 2.5 and 4.0m distances from the base of identified plants within the 40 stems/ha plot and at 2.5m from the base of identified plants in the 200 and 400 stems/ha plots. Moist samples were sealed in plastic bags. Moist soil weight was measured. Dry soil weight was measured following drying at 100°C for 48 hours. Gravimetric soil moisture was determined at 10cm intervals from each soil core. Volumetric soil moisture will be calculated from gravimetric soil moisture using soil bulk densities collected in nearby plots.

Shrub effects in the GRASP model
The GRASP pasture growth model (McKeon & Rickert, 1982; McKeon *et al* 1990) will be used to determine the influence of woody plants for a range of seasons, plant densities and stocking rates.

Results

Rainfall at Kidman Springs during the 1993/94 wet season was 762 mm and evenly distributed between December and March. Average rainfall is 690mm.

Shrub basal areas at this site are in the range of 2-4m^2/ha. Neither single plants nor increasing shrub density up to 400 stems/ha had any significant effect on available soil moisture or pasture growth.

A summary of rosewood shrub data for each block in the three shrub density treatments is shown in Table 2.1.

(a) The effect of increasing plant density on soil moisture and plant production
No effect of increasing shrub density was identified in volumetric soil moisture levels. This was also reflected as no significant differences in perennial, annual and forb yields between shrub density plots.

A significant decrease in volumetric soil moisture over three soil depths (0-10cm, $P<0.01$; 10-50cm, $P<0.01$ and 50-100cm, $P<0.01$) occurred between March and May as the soil profile dried out following wet season rainfall. Further decreases between May and June were slight and not significant. The change in soil moisture between dates, densities and blocks at 10-50 cm depth is shown in Figure 2.1. A significant block effect was identified, with one block having consistently higher volumetric soil moisture levels than the other. This is most likely due to it receiving and holding greater amounts of run-off.

Table 2.1 Shrub summary data (mean and standard error of the mean 'sem') in shrub density treatment plots.

	Shrub density (Stems per hectare)					
	40		200		400	
	mean	sem	mean	sem	mean	sem
Block 1						
Count (n)	4		5		5	
Height (cm)	357.5	(85.0)	452.0	(50.7)	442.0	(39.6)
Canopy area (m)	14.7	(5.1)	7.0	(1.7)	8.1	(2.7)
Distance to nearest shrub (m)	8.5	(4.0)	5.8	(2.9)	3.5	(1.8)
Block 2						
Count (n)	5		5		5	
Height (cm)	352.0	(54.5)	388.0	(91.5)	440.0	(40.6)
Canopy area (m)	5.3	(3.7)	8.8	(5.5)	8.5	(5.4)
Distance to nearest shrub (m)	8.9	(2.7)	4.3	(1.2)	3.6	(1.1)
Total						
Count (n)	9		10		10	
Height (cm)	354.4	(64.8)	420.0	(77.5)	441.0	(37.8)
Canopy area (m)	9.5	(6.4)	8.2	(3.9)	8.3	(4.1)
Distance to nearest shrub (m)	8.7	(3.1)	5.0	(2.3)	3.5	(1.4)

(b) The effect of single plants on soil moisture and pasture production
Volumetric soil moisture differed significantly at all soil depths between dates and blocks but not with increasing distance from shrub base. This is shown for the 10-50 cm depth in Figure 2.2. There was also no significant difference in perennial, annual and forb yields with increasing distance from shrub bases, measured in March. Likewise there was no significant difference in yields of regrowth measured in June.

These results suggest that neither single shrubs nor shrub densities up to 400 stems/ha provide significant competition for soil moisture to cause reductions in pasture yield. This is not unexpected given the relatively low basal areas and shrub densities that existed on the experimental site.

Three factors may explain this result. From work in Queensland (Scanlan and McKeon, 1993) tree basal areas of 2-4m^2 are not considered to be sufficiently high enough to result in significant competition. The strong seasonal rainfall distribution in the semi-arid tropics may provide sufficient soil moisture for tree and pasture growth during the short growing season. The data was collected in a year with well above average rainfall. This would have reduced the competition for moisture which may be apparent in more average seasons.

The dominance of rosewood (*Terminalia volucris*) on grey cracking clays is widespread throughout the VRD. The size and density of the stand measured in the experimental site on Kidman Springs is considerably lower than rosewood populations found across significant areas. It is therefore possible that although no effect on pasture production was measured at this site, higher densities may have a competitive influence at other sites, particularly in seasons of below average rainfall.

It is currently thought that the competitive influence of the pasture layer is lowest in areas with high seasonal rainfall, and limitations to herbage growth may be the result of nutrient deficiency. Predicted pasture yields from preliminary GRASP output comparing Kidman Springs and Katherine rainfall suggest that low tree basal areas may reduce pasture yields in some years with below average rainfall at Kidman Springs however there would be no significant effect around Katherine where rainfall is higher.

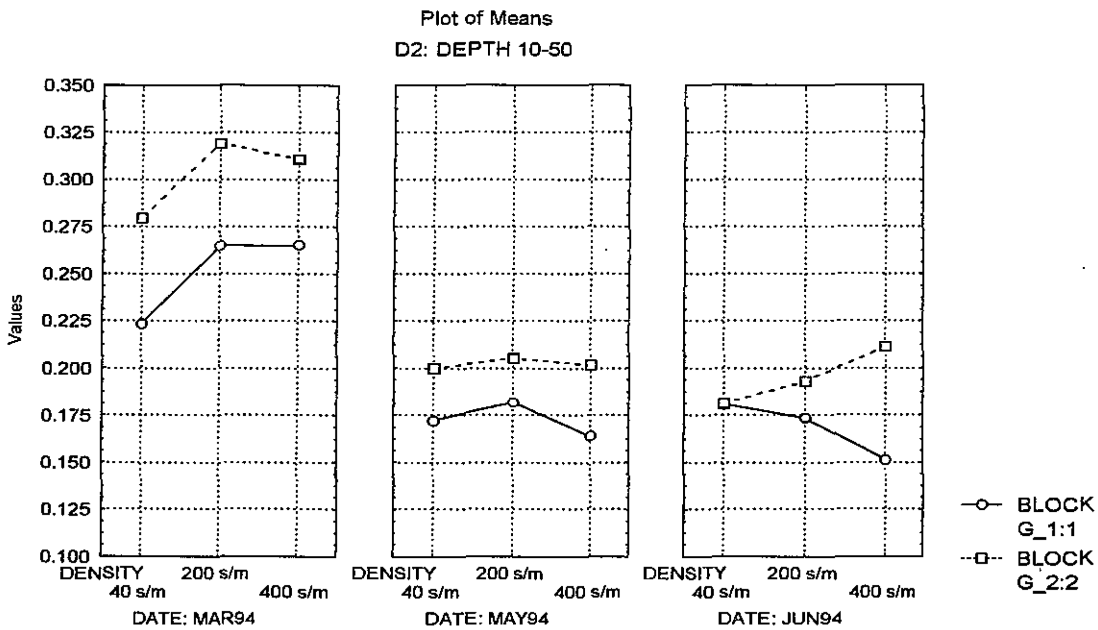


Figure 2.1 The change in volumetric soil moisture (mm) at a depth of 10-50 cm between March and June for 2 blocks in shrub density plots of 40, 200 and 400 stems/ha.

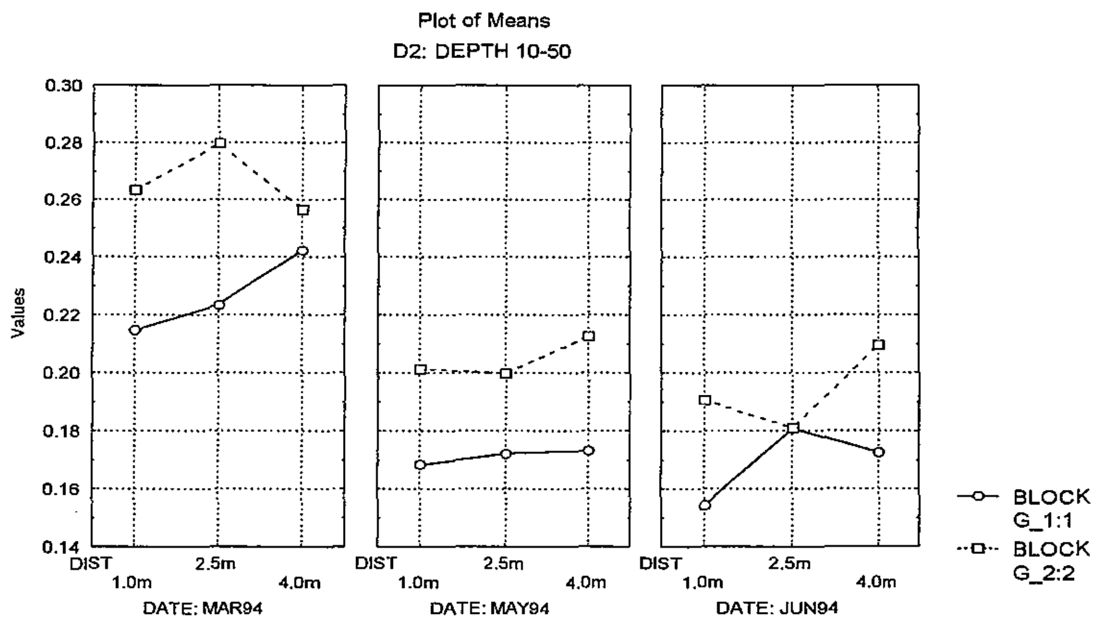


Figure 2.2 The change in volumetric soil moisture (mm) at a depth of 10-50 cm with increasing distance from stem base (1.0, 2.5 and 4.0m) between March and June for 2 blocks.

Further investigations into tree effects will be made using the GRASP pasture growth model to examine tree and shrub effects at higher tree basal area and density levels. This will enable a number of vegetation increase scenarios to be tested in a range of climatically different locations.

2.2 Tree-grass relations at two locations along a rainfall gradient.

Objective

To investigate the effects of competition for soil moisture between overstorey and understorey components of eucalypt woodlands at two locations along a rainfall gradient.

Background

The competitive effects of individual trees and tree communities on soil moisture and pasture production have been investigated on cracking clays at Kidman Springs, which support a range of rosewood (*Terminalia volucris*) plant densities (Table 2.1). Results seem to suggest that neither single trees, nor increasing shrub density to the levels measured, had any significant effect on pasture production.

This experiment aims to examine soil moisture and pasture growth throughout the growing season on naturally densely treed, and adjacent cleared areas at two locations along a rainfall gradient.

The first year of data collection for this experiment was conducted as part of a final year research project for Jillian Heywood, a Bachelor of Land Resource Management student at the University of Queensland.

Aim

The aim of this trial is to:

- quantify the effects of tree density on plant available moisture and pasture production at two locations with distinctly different annual average rainfall.
- provide sufficient data to calibrate and validate tree effects within the GRASP pasture growth model for the pasture communities sampled.
- utilise GRASP to extrapolate tree effects across a range of climate, soil and vegetation systems.

Materials and Methods

Site location
Experiments were established to investigate the relationships between tree density (or cover), plant available moisture and pasture production on two sites each at Katherine Research Station (KRS) and Victoria River Research Station (VRRS). One site at each location was set up prior to the 1995/1996 wet season, with replicate sites for each being ready for the 1996/1997 season. All sites are Eucalypt woodlands on red earth soils and so are comparable in soil, overstorey, and understorey attributes. However, the two locations receive significantly different amounts of annual rainfall in an average year (Table 2.2).

At each site, a uniform area of high tree and shrub density was selected and excluded from grazing. Plots were burnt to remove standing dry matter and litter prior to sampling.

Treatments
Soil moisture and pasture production parameters have been measured over one and a half growing seasons for two tree treatments, to identify any existing overstorey competitive effects.

The tree treatments are: 1. Trees intact
2. Trees removed

Prior to the removal of trees and shrubs, the variables of species, height, basal area, diameter at breast height, and stem number were measured for all plants. These parameters were also measured within the 'trees intact' plot (Table 2.2). Description of pasture composition at each site will be made using BOTANAL.

Table 2.2 Site and woody vegetation characteristics in treed plots for the tree grass relationship trial areas at Katherine Research Station and Victoria River Research Station.

Location	KRS	VRRS
Annual avg. rainfall	970mm	690mm
Understorey type	Tropical tallgrass	Tallgrass
Soil type	Red earth	Red earth
Overstorey type	Eucalypt woodland	Eucalypt woodland
Tree density (stem/ha)	1500 and 2100	2622
Tree basal area (m^2/ha)	12.4 and 17.2	11.2
Overstorey	22%	9%
Understorey	10%	5%

Pasture parameters have yet to be summarised, but the four plots are comprised predominantly of perennial grasses, with variable quantities of annual grasses and forbs.

Site preparation
1.Trees intact
A 30 x 30m sampling area was established within the tree plot

2.Trees removed
All trees and shrubs within a 60 x 60m area adjacent to the treed plot were cut with a chainsaw at breast height, and the stumps killed with herbicide (Tordon). In the centre of this area a 30x30m sampling plot was established. This allows a sufficient buffer zone to reduce the influence of surrounding trees.

The SWIFTSYND sampling methodology was used to collect soil and pasture parameters from each plot on 5 occasions throughout the growing/wet season.

1. weeks after 1st storms - December
2. early wet - January
3. mid wet - February
4. late wet - March
5. peak yield - April
6. end of dry - October

Soil parameters

Regular measurements of volumetric soil moisture were taken from three access tubes within each treatment plot using a neutron moisture probe (NMP). These will be calibrated with gravimetric soil moisture estimations taken at three stages of soil wetness throughout the year. Total N and P and organic C will be measured at 0-10cm and 10-30cm depths.

Pasture parameters

Total grass and forb DM yield, moisture content, pasture height, and component cover, were determined from 10 randomly located 1m^2 quadrats harvested in each treatment plot. All harvested samples were oven dried at 70^{o}C for 48 hours to determine moisture content and DM yield.

Nutrient analysis of grass and forb components from bulked sub-samples of harvested quadrats was carried out to determine total nitrogen and phosphorus levels within each plot.

Weekly pasture heights have been carried out at the two KRS sites throughout the current season. A pasture sample has been collected along with this weekly measurement to determine the pattern of nutrient change on a weekly basis over the growing season.

Results

The 1995/96 wet season was characterised by lengthy dry periods in early January and in late February to March at both KRS and VRRS. VRRS had received its average rainfall by the end of the wet, whereas the KRS season was 180mm less than average. The 1996/1997 season has been very different with constant heavy rainfall from December to February at KRS, and constant falls from Mid January to the end of February at VRRS. Daily rainfall, soil moisture (NMP counts) and pasture production to mid March 1997 are summarised in Table 2.3.

Table 2.3 The rainfall (mm) received at KRS and VRRS over the two seasons of the experiment, compared to the annual average for each location.

Location	1995/1996	1996/1997	Average
KRS	790	1520	970
VRRS	740	680	690

Soil moisture readings using the NMP have been taken at weekly intervals throughout the 1995/96 and 1996/1997 wet seasons at KRS and whenever possible at VRRS. At both locations during the drier 1995/1996 season the treed plot has shown a lower soil moisture content below a depth of 10 cm than the cleared plot (Figure 2.3).

Soil moisture measurements taken over the very wet 1996/1997 season so far have shown a much smaller difference in soil moisture between the treatments. This would be expected during a time when the moisture is being constantly replenished. It can be noted (Figure 2.4) that the lines are beginning to diverge at the end of March when rainfall has eased.

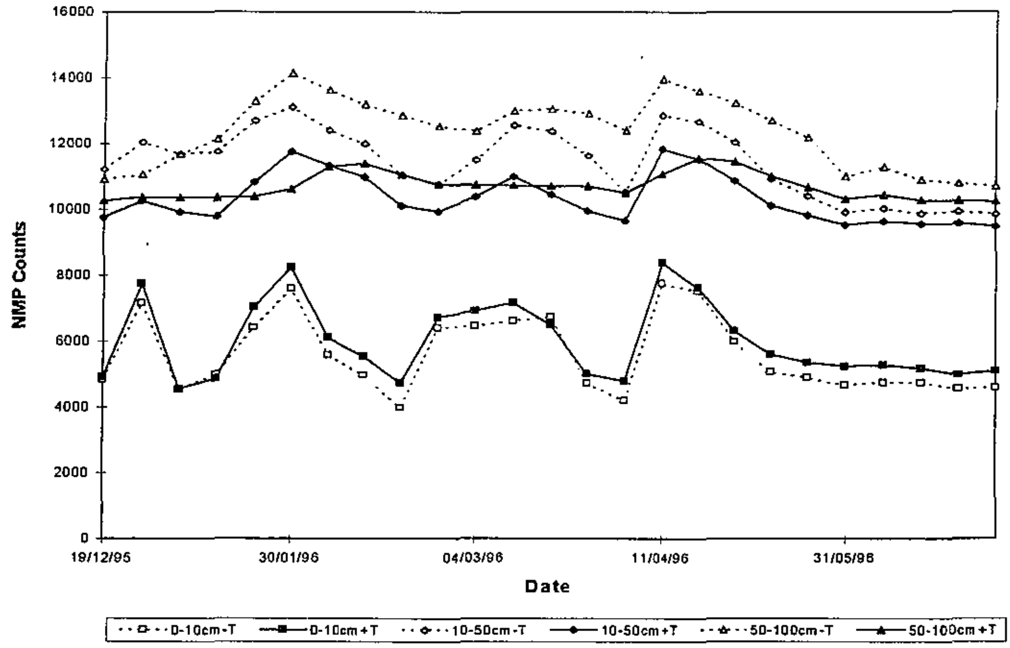


Figure 2.3 KRS Site 1 soil moisture (raw NMP counts) results for treed (+T) and cleared (-T) plots at 3 soil depths (0-10cm, 10-50cm and 50-100cm) for the 1995/1996 season.

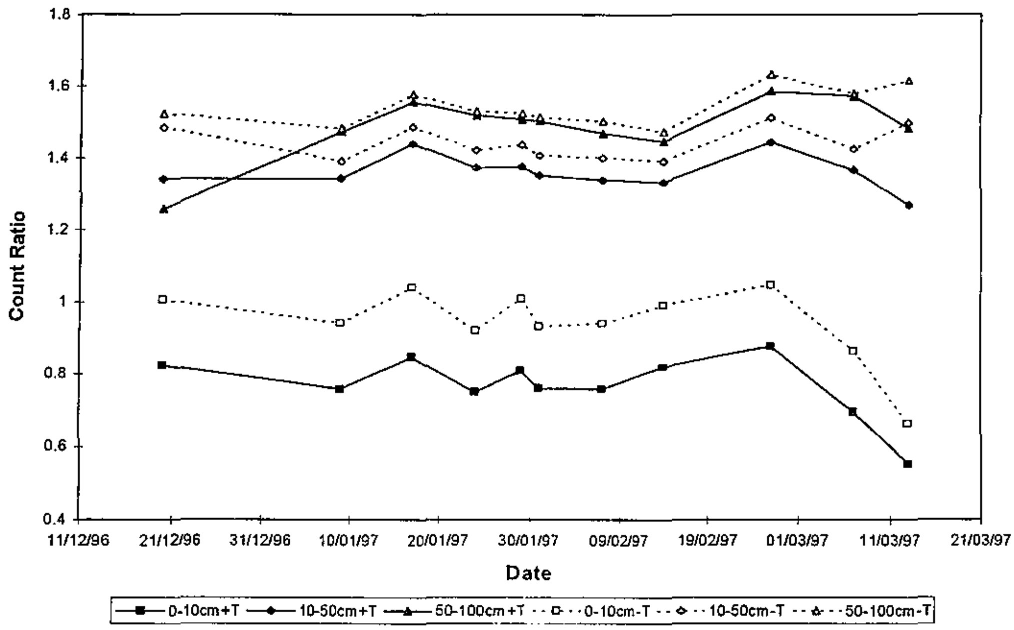


Figure 2.4 KRS Site 1 soil moisture (count ratio) for treed (+T) and cleared (-T) plots at 3 soil depths (0-10cm, 10-50cm and 50-100cm) for the 1996/1997 wet season to March 1997.

Figures 2.5 and 2.6 show that in both good and poor wet seasons at Katherine the cleared plot has yielded higher (160%) pasture than the treed plot (Plate 13). This result appears to be occurring in all plots (Table 2.4), except for Site 2 at VRRS. Six pasture harvests and observations were carried out during 1996 for the two initial sites, and currently three to four have been completed for the 1996/1997 season for the four sites.

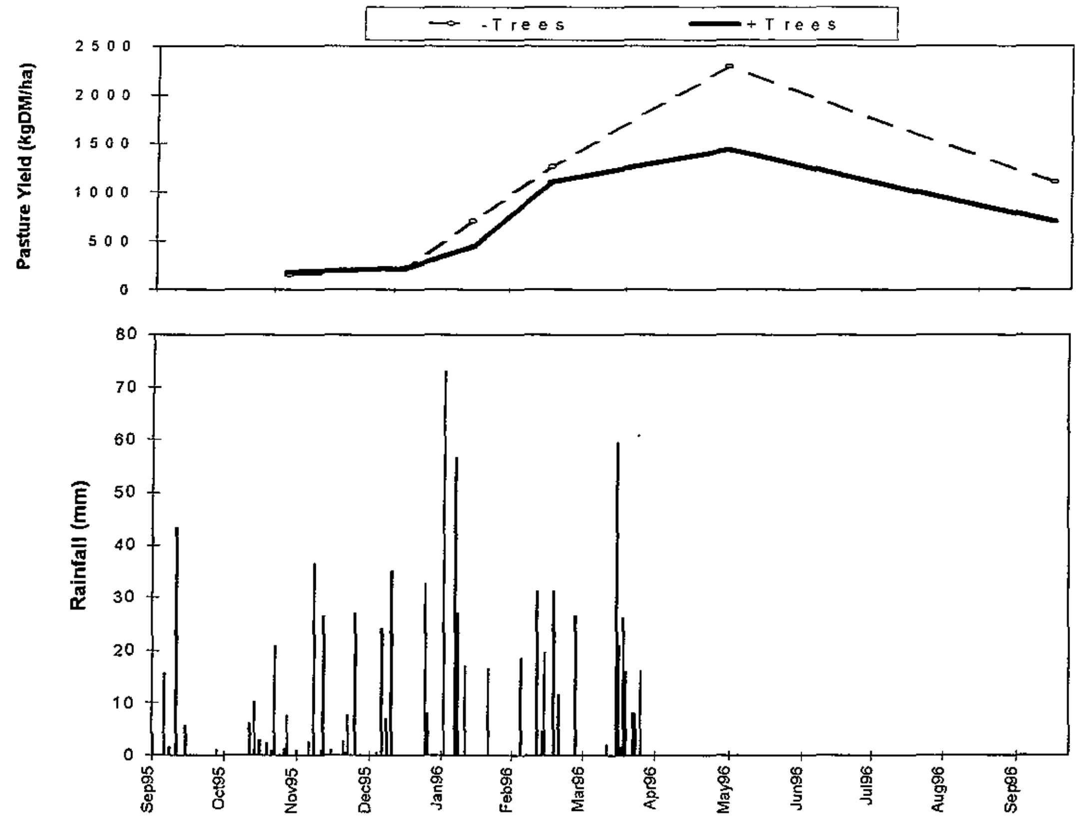


Figure 2.5 Rainfall and Pasture Yields of treed (+ Trees) and cleared (-Trees) plots for KRS Site 1 for the 1995/1996 season.

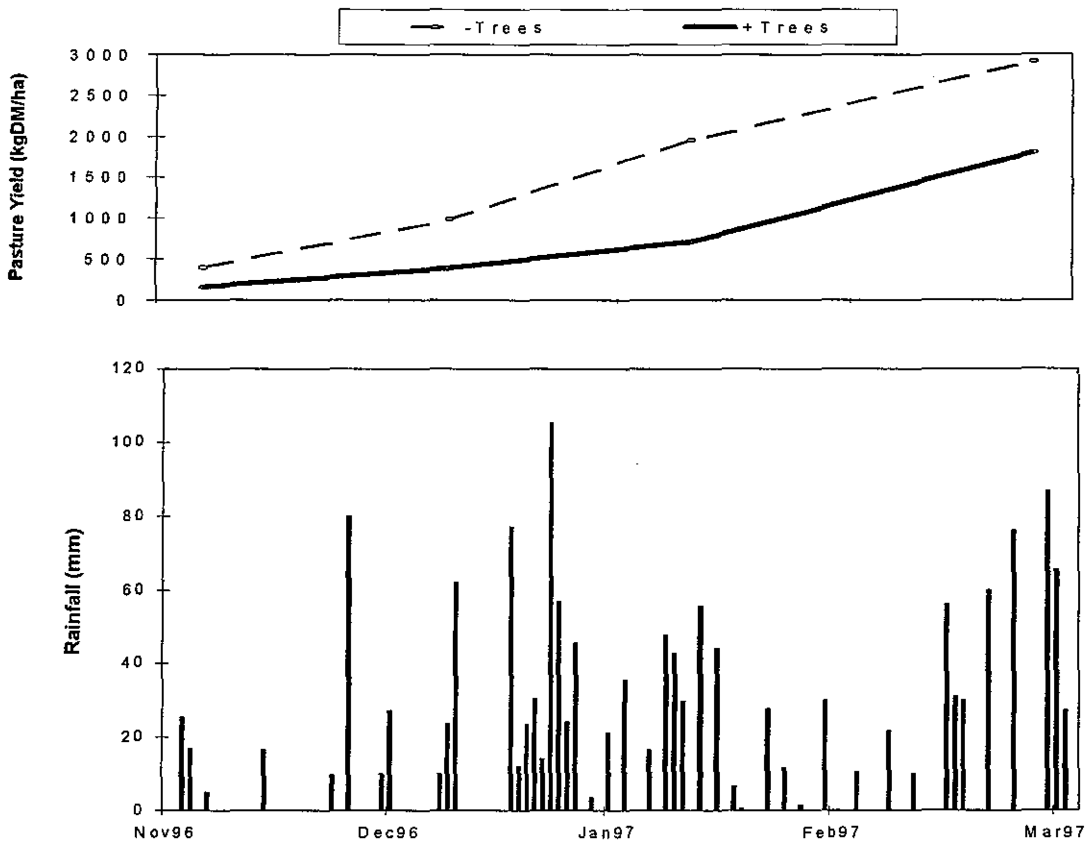


Figure 2.6 Rainfall and Pasture Yield of treed (+Trees) and cleared (-Trees) plots for KRS Site 1 for the 1996/1997 wet season to date.

The higher yields in the cleared plots, even when moisture would not be limiting, show a competition for, and treatment difference in, the levels of nutrients available to pasture.

Table 2.4 Pasture Yields for KRS and VRRS sites for 1995/1996 and 1996/1997 to date.

Location/Site	*Harvest No.*	*Date*	*Minus Trees Yield (kgDM/ha)*	*Plus Trees Yield (kgDM/ha)*
VRRS	1	12/12/95	17.3	20.4
Site 1	2	11/1/96	251.7	284.6
(Lounger's Hill)	3	7/2/96	829.1	550.1
	4	18/3/96	1576.1	1048.1
	5	24/5/96	2078.8	2018.9
	6	15/10/96	1673.0	1345.8
VRRS	1	14/1/97	688.4	493.9
Site 1	2	5/2/97	743.1	534.5
(Lounger's Hill)	3	5/3/97	906.0	803.7
VRRS	1	5/2/97	840.9	929.1
Site 2	2	6/3/97	1809.8	2424.6
(Native)				
KRS	1	7/1/97	255.0	303.0
Site 2	2	28/1/97	695.0	643.0
(Dixon)	3	18/2/97	1035.0	1098.0
	4	12/3/97	2332.0	1489.0

The harvested plant material for the first five harvests in 1995/1996 have been analysed for N and P. The differences in plot N yields are displayed in Figures 2.7 and 2.8 below.

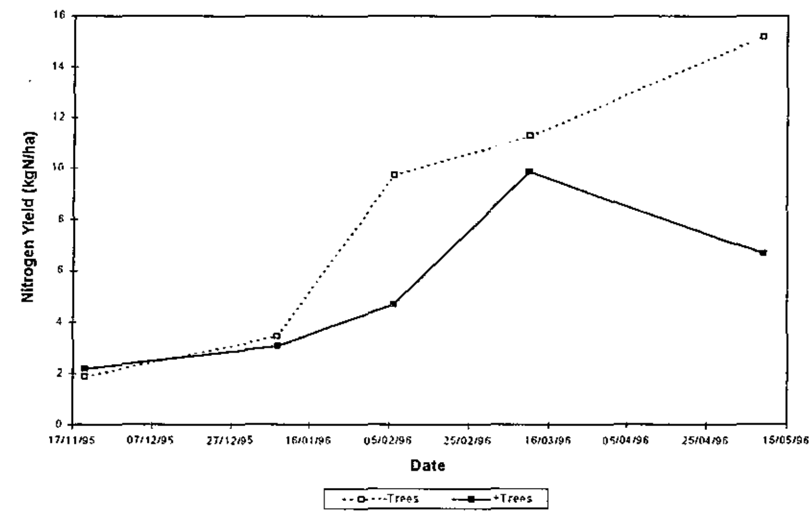


Figure 2.7 Change in pasture whole plot yield of N for treed (+Trees) and cleared (-Trees) plots over five harvests during 1995/1996 at KRS Site 1.

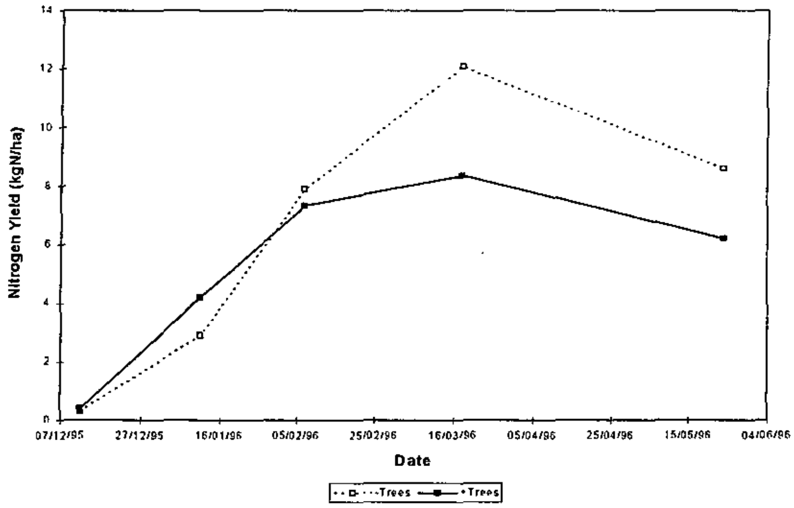


Figure 2.8 Change in pasture whole plot yield of N for treed (+Trees) and cleared (-Trees) plots over five harvests during 1995/1996 for VRRS site 1.

At this stage of the experiment, it is believed that the large differences in N yield between the treed and cleared plots are partly due to the breakdown of dead tree roots in the cleared plots. This results in a higher level of available N. This effect may diminish over time, perhaps resulting in less extreme differences in N yield in future seasons.

This information, though preliminary, indicates that competition from the overstorey has had an effect on soil moisture and pasture growth over the last two wet seasons at the tree densities being studied.

The competition for moisture seems to be the most limiting factor in dry years such as 1995/1996, with competition for nutrients (N) being more important in wet years (1996/1997). This effect is seen in the 1996/1997 pasture yields (Figures 2.5 and 2.6, Table 2.4) where yields are consistently higher in the cleared plots, even though soil moistures at each depth are quite similar (Figures 2.3 and 2.4). This may be a somewhat false result at this stage due to the break down of dead tree roots in the cleared plots leading to a higher pool of available nutrients. If this is the case, the effect of treatment on pasture yield would be expected to reduce over future seasons. Future monitoring of these plots as a part of NAP3 will allow these trends to be measured.

This, and future data, will be used to calibrate and validate the GRASP model for the studied communities and tree densities. The model will then be used to extrapolate tree effects over a range of systems to determine at which tree densities competition is occurring. This information can then be used to assist in management decisions relating to overstorey and pasture competition.

Sub-project 3

The effect and management of fire.

3.1 The effect of fire season and frequency on shrub populations and pasture condition on two soil types in the VRD.

Objective

To determine the effect of fire season and frequency on pasture condition and shrub population in pasture communities on cracking clays and red earth soil types.

Methods

Site Location and Vegetation
Burning trial sites were established on two soil-pasture complexes at Kidman Springs (VRRS) in the central Victoria River District. The cracking clay site (Rosewood), is dominated by mid-height perennial grass species such as *Chrysopogon fallax* (ribbon grass), *Dichanthium fecundum* (blue grass), *Sehima nervosum* (white grass), *Panicum decompositum* (native millet) and the annual *Iseilema* spp. (Flinders grass). Woody vegetation is dominated by low-mid height species such as *Terminalia volucris* (rosewood) and *Lysipyllum cunninghamii* (bauhinia).

The calcareous red earth site (Conkerberry) supports an arid short-grass pasture community dominated by *Enneapogon polyphyllus* (limestone grass) with patches of *Heteropogon contorus* (black spear grass) and *Dichanthium fecundum* (blue grass). *Brachyachne convergens* (summer couch) and *Sporobolus australasicus* (fairy grass) dominate in heavily utilised areas and following poor rainfall seasons. The red earths are shallow and stony with a woody overstorey dominated by *Eucalyptus pruinosa* (silver leaf box), *Eucalyptus terminalis* (inland bloodwood), *Carissa lanceolata* (conkerberry) and *Hakea arborescens* (common hakea).

Experimental design and treatments
At each site 16 plots, each approximately 2.6 ha in area, were randomly allocated into two blocks (8 plots per block). Four plots in each block were allocated to one of two seasons of burning, early dry season (EDS) burns and late dry season (LDS) burns. In each block four burning frequency strategies were allocated to each of the four burning season plots. The four fire frequency strategies are summarised below.

1. Grazed and unburnt control
2. Grazed and burnt every three years.
3. Burnt, spelled and burnt in two successive years. Open to grazing thereafter.
4. As ,above however a third burn will be carried out within four years if seasons permit.

Each site therefore contains 2 block x 2 season x 4 fire frequency burning treatments. As of 1997, plots allocated to frequency strategies 3 & 4 are effectively the same and, therefore, can be treated as one.

Fire measurements
Early dry season (EDS) burns are conducted during June, while late dry season (LDS) burns are carried out in October. Burning began in the late dry season (October) 1993. All plots were

ignited separately (apart from one occasion) and burnt with a head fire following a small safety back-burn on the down wind side. Average fire rate of spread was estimated by timing the progress of each fire across the plot. On some occasions accurate estimations of rate of spread were impossible due to slow and patchy fires. Pasture yields sampled prior to burning provided estimations of fuel load.

Descriptions of fire behaviour shown for ribbon/blue grass are based on fire measurement (rate of spread, intensity and flame height) while arid short grass are based on subjective observations due to difficulties accurately measuring fire rate of spread. Trollope and Potgieter (1985) classified fire into the following categories according to fire intensity.

Fire intensity (kJ/s/m)	
<500	Very cool fire
501-1000	Cool fire
1001-2000	Moderately hot fire
2001-3000	Hot fire
> 3000	Extremely hot fire

Pasture and tree/shrub measurements
Pasture and shrub parameters were collected along four permanently marked 100m transects located in each plot. Pasture sampling recorded yield (double sampling technique), cover and species composition (dry weight rank) in May and October of each year. Shrub and tree measurements recorded species frequency and height at the end of each wet season in May.

Analysis was carried out the season following burning each year to determine fire effects on pasture yield, cover and species composition, and woody species frequency and height distribution.

Results

Fire behaviour

(a) Fuel load and cover
There was a considerable range in fire behaviour (Table 3.2) and vegetation response between treatment burns. Pasture fuel load and cover greatly influenced fire behaviour and the response of the pasture and shrub layers. Across both burning trial sites there was a large range in fuel load and cover available for burning between October 1993 and October 1996 (Table 3.1). The fluctuation of yield and cover between years is mainly due to seasonal rainfall and intensity of grazing pressure.

Pasture yield and cover were consistently higher on ribbon/blue grass pastures compared to the more fragile arid short grass pastures located on red earth. Across the ribbon/blue grass site, pasture yields during this period ranged from 1324 – 3056 kg DM/ha, while cover remained at relatively high values between 62.0 – 74.4%. In comparison, the arid short grass pasture ranged in pasture yield from between 529 – 2635 kg DM/ha, and pasture cover between 44.8 – 68.6%.

Increasing fuel loads and pasture cover promoted higher fire intensity and more complete burns. Undisturbed fuel loads allowed fires to burn on a continuous front, while low cover levels were associated with very cool, patchy fires. In the years between 1993-1996 ribbon/blue grass pasture had sufficient fuel and cover to sustain effective fires.

Low pasture yields and discontinuous fuel, available for the LDS 1993 of arid short grass pastures, were insufficient for effective burns (Plate 1). Selective grazing of the more fragile limestone/couch pasture resulted in large areas of bare, or near bare ground. This patchy and discontinuous distribution of fuel supported fires of only very low intensity which had no significant effect on woody plants.

Plots burnt in October 1994 (LDS) and June 1995 (EDS) were protected from grazing during the wet season prior to burning. In combination with exclosure from grazing, above average seasonal conditions during the 93/94 94/95 wet seasons produced high continuous fuel loads. This provided condition for hot-extremely hot fires (Plate 2). These fires resulted in severe fire damage to woody plants, with defoliation of trees up to 3-4m in height. Such severe fire damage resulted in change in the structure of woody vegetation compared to unburnt plots (Plates 3 and 4)

Table 3.1 Pasture fuel load and cover levels for ribbon/blue grass and arid short grass burning trial sites.

			Pasture Yield (Fuel load) kg DM/ha		Pasture Cover (Fuel cover) %	
Year	Season	Month	Arid short grass	Ribbon/Blue grass	Arid short grass	Ribbon/Blue grass
1993	LDS	Oct	519	1324	44.8	68.8
1994	EDS	Jun	1326	2951	50.3	68.6
1994	LDS	Oct	1405	1964	48.1	62.0
1995	EDS	Jun	2635	3056	68.6	64.6
1996	LDS	Oct	1150	2598	46.8	74.4

(b) Season

Season of burning affects fire behaviour by influencing fuel moisture, ambient temperature, humidity, wind speed and direction. With the progression of the late wet into the early dry season, temperature and humidity decrease. As the season progresses from early dry to late dry, conditions tend to promote fires of greater intensity. This is mainly due to increasing daily temperatures (max and min), lower humidity levels and rapidly falling fuel moisture levels during the late dry season (Figure 3.1).

Table 3.2 Description of fire behaviour from ribbon/blue grass and arid short grass burning trial sites.

Year	Season	Month	Fire intensity		Fire spread and progress		Flame height	
			Arid short grass	Ribbon/blue grass	Arid short grass	Ribbon/blue grass	Arid short grass	Ribbon/ blue grass
1993	LDS	Oct	Very Cool	Cool-mod. Hot	Very slow Very patchy	Slow Patchy	< 0.5m	0.5-1.5m
1994	EDS	Jun	Cool	Moderately-Extremely hot	Slow Very patchy	Fast Continuous	<1.5m	2.0-6.0m
1994	LDS	Oct	Moderately Hot	Moderately hot	Fast Patchy	Very fast Continuous	0.5-2.5m	4.0-6.0m
1995	EDS	Jun	Extremely hot	Extremely hot	Very fast Generally Continuous	Very fast Continuous	4.0-8.0m	2.0-3.0m
1996	LDS	Oct	Moderately Hot	Extremely Hot	Slow Patchy	Fast Continuous	1.0-3.5m	1.5-2.0m

Higher fuel moistures (20-30%) exist in the EDS which results in slower, cooler fires compared to the late dry season when fuel moisture fall to less than 5% (Figure 3.1). Fuel moisture tends to affect fire rate of spread and the proportion of fuel consumed. **Arid short grass pastures cure faster than ribbon/blue grass pastures,** and therefore will support more intense fires during the EDS if sufficient fuel loads are present. Stem material was often left unburnt following EDS fires on ribbon/blue grass compared to combustion of all material during LDS burns.

Controlled burning should aim to be completed prior to the onset of unpredictable wind conditions during the late dry season. A significant climatic factor that influences fire behaviour through the dry is wind. Reasonably constant south-easterly winds dominate throughout the early dry season. These provide predictable conditions for burning. During the late dry season, particularly during late September and October, wind direction becomes more variable with wind changes frequently to northerly. Wind direction and therefore fire behaviour is considerably more unpredictable during these periods.

Season of burn also indirectly affects fuel continuity due to the influence of grazing. **Throughout the year cattle grazing and movement will reduce the amount of available fuel as well as cause disturbance due to trampling.** This will significantly affect opportunities and effectiveness of burning in fragile and low yielding pasture communities, under heavy stocking rates and following poor seasons.

Pasture response following fire

Ribbon/blue grass pastures on cracking clay soils are well adapted to fire. Neither single burns nor burning in two successive years in either the EDS or LDS resulted in major or long term reductions in yield, cover or favourable species. The main immediate effect of burning is to reduce the total amount of pasture biomass and cover the year immediately following burning. This is due to the removal of accumulated standing dry matter. Fire does not affect pasture growth the following wet season and in fact seems to stimulate growth.

Fire on arid short grass pasture, especially complete, high intensity fires, will cause reduction in yield, cover and proportion of perennial grasses.

Yield and cover

Analysis of data in 1994 investigated differences in the following treatments (data not shown):

Treatment	Code
1. Unburnt	0BURN
2. 1993 LDS burn (burnt once)	L1BURN

The LDS 1993 burns resulted in no significant difference in yield or cover compared to unburnt plots on the arid short grass site. This is due to the negligible effect of the fire. There was a significant reduction in both yield ($P<0.05$) and cover ($P<0.05$) for ribbon/blue grass plots.

pp 61 - 62 colour plates

Analysis of data in 1995 investigated differences in the following treatments (data not shown):

Treatment	Code
1. Unburnt	OBURN
2. 1993 LDS burn (burnt once, 2 years recovery)	L1BURN
3. 1993 and 1994 LDS burn (burnt twice, 1 years recovery)	L2BURN
4. 1994 EDS (burnt once, 1 years recovery)	E1BURN

Ribbon/blue grass
Both the early (E1BURN) and late dry season (L2BURN) burns decreased yield in the following year, compared to unburnt plots, although not significantly. Plots burnt in LDS 1993, that remained unburnt in 1994, had recovered with greater yields than control plots, however the difference was not significant. Pasture yield and cover in plots burnt with two consecutive late dry season burns (L2BURN) were lower, but not significantly so, than control unburnt plots.

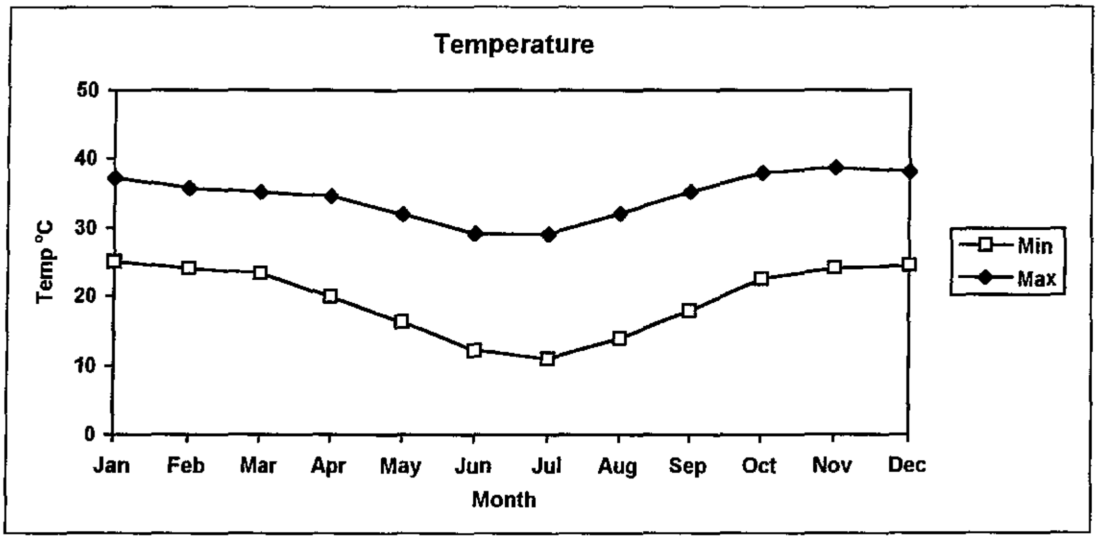
Arid short grass
The second LDS burn in arid short grass plots resulted in a significant decrease in yield ($P<0.05$) compared to unburnt plots. There was also a noticeable decrease in cover, however this was not significant. This is not likely to be an additive effect of two consecutive burns, but rather a dramatic effect as a result of a more intense and complete fire which occurred in LDS 1994. There were no significant differences in either yield or cover between unburnt plots and plots burnt in either the 1993 LDS or the 1994 EDS.

Analysis of data in 1996 examined differences in yield and cover for the following treatments:

Treatment	Code
1. Unburnt	OBURN
2. 1993 LDS burn (burnt once, 3 years recovery)	L1BURN
3. 1993 and 1994 LDS burn (burnt twice, 2 year recovery)	L2BURN
4. 1994 EDS (burnt once, 2 years recovery)	E1BURN
5. 1994 and 1995 EDS burn (burnt twice, 1 year recovery)	E2BURN

Ribbon/blue grass
There was no difference in the yield or cover measured between OBURN, L1BURN, L2BURN and E1BURN plots (Figure 3.2). Plots burnt for the second consecutive EDS had yields and cover significantly lower than all other treatments, however it would be expected that these would recover following another good rainfall season.

Arid short grass
The effect of burning on arid short grass pasture was more evident (Figure 3.3). Even though some plots had up to three years in recovery following burning, all treatments (L1BURN, L2BURN, E2BURN) apart from a single EDS burn in 1994 (E1BURN) had significantly lower yields ($P<0.05$) than unburnt plots. Cover was significantly lower ($P<0.05$) in plots burnt twice (L2BURN, E2BURN). **This suggests that arid short grass pastures, in this condition, are not as resilient to fire as Ribbon/Blue grass pasture.**



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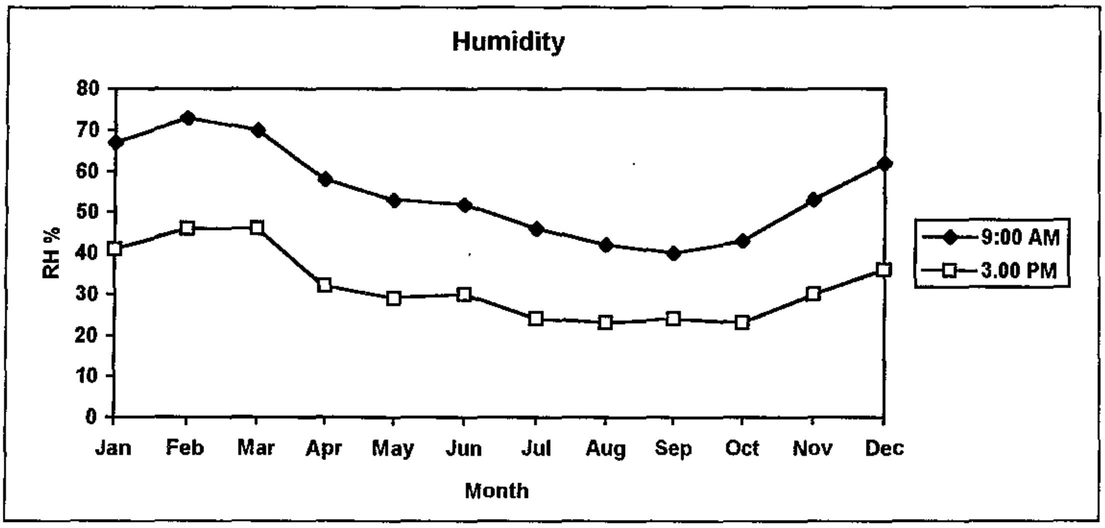

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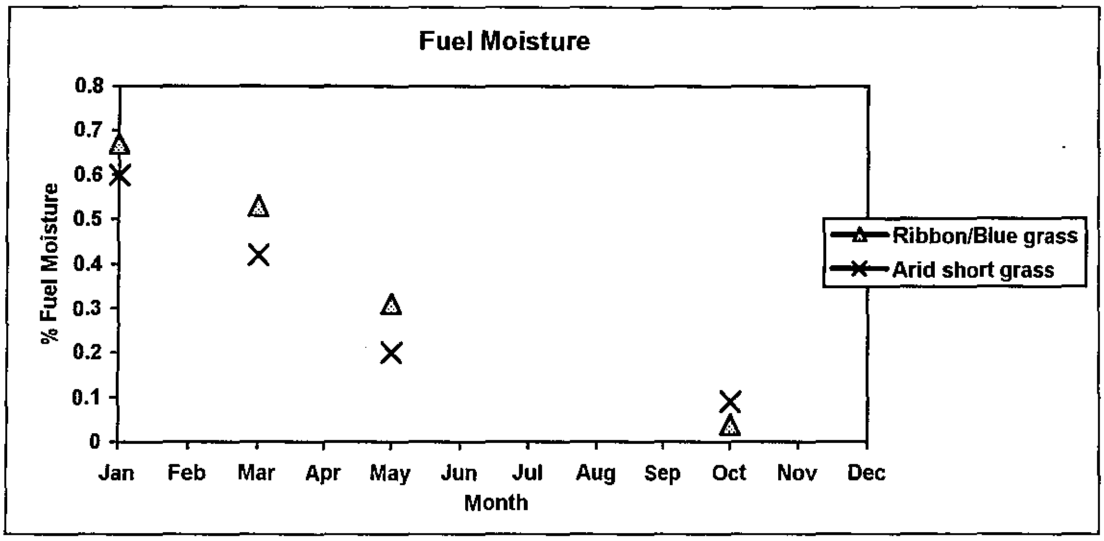


c)

***Figure 3.1*a)** Average monthly temperature (maximum and minimum), **b)** humidity (9.00am and 3.00pm) for central VRD (Victoria River Downs), and **c)**fuel moisture content (%) for Ribbon/blue grass and Arid short grass pastures at Kidman Springs 1994-1996.

Fires in consecutive seasons or single high intensity fires may affect the ability of these pastures to recover to former yield and cover levels. A dramatic reduction in yield, cover, basal area and change in species composition also occurred following burning an exclosure of arid short grass pasture in poor condition for SWIFTSYND measurements (Figures 3.4 and Plates 5 & 6). The high annual species component is the likely explanation. Summer couch (*Brachyachne* spp.) and fairy grass (*Sporobolus* spp), are both fragile annuals, and are classified as increasers as they recolonise over utilised areas. The persistence of these species from year to year relies on rapid maturity and seed set during their growing season,followed by germination from seed the following year. Their abundance is greatly affect by season and fire. Periods of dry weather during a growing season will cause seedling death, while fire appears to destroy all seed laying exposed on the soil surface. These pasture communities and particularly these species, are preferentially grazed by cattle, especially during the wet season. Even under heavy grazing pressure however, these species seem to persist, as seed remains undamaged on the soil surface ready for germination during the next season.

Species composition
The differences in pasture species composition for ribbon/blue grass and arid short grass pasture are shown in Table 3.3 and Table 3.4 for unburnt plots between 1993-1996 and for burning treatments at June 1996. These data are in summary form only. It must also be remembered that these responses are following a sequence of years that are considered above average and favourable for pasture growth. Pasture recovery following burning during poorer wet seasons may not provide the same responses.

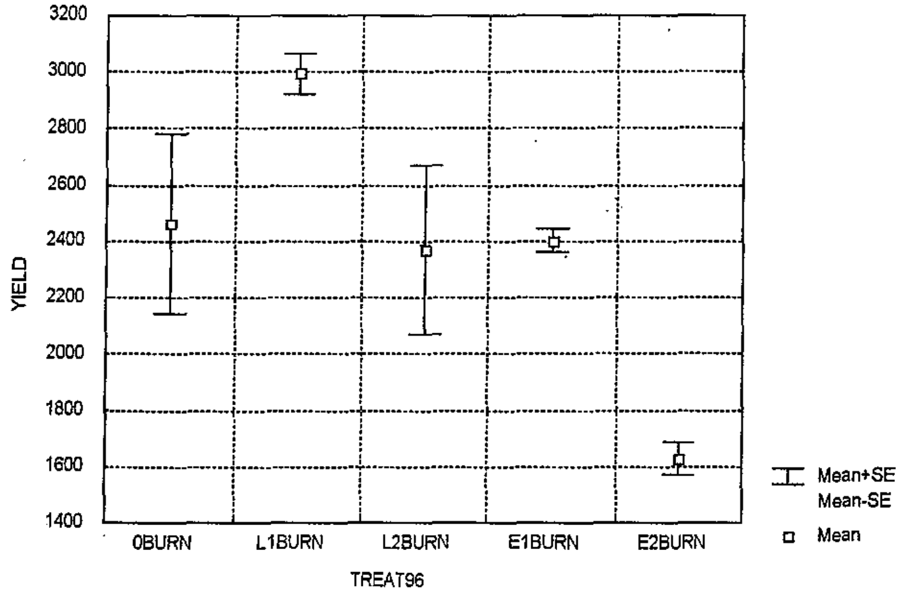
Ribbon/Blue grass
Season and frequency of burning (single and two successive burns) caused no major change to ribbon/blue grass pasture composition. Statistical analysis is yet to be completed, however it is clear that seasonal rainfall has a dominating effect on species composition, particularly affecting the appearance of annuals such has Flinders and Queensland blue grass. A decrease in these species was evident in 1996, probably a result of a lengthy dry period mid-wet. Successive burns over two years in either the EDS or LDS seemed to increase the proportion of Flinders grass.

A single EDS or LDS fire (L1BURN, E1BURN) caused a small increase in blue grass and a decrease is ribbon grass compared to both unburnt and consecutive burnt plots. The relative abundance of Ribbon grass (*Chrysopogon fallax*) and Blue grass (*Dichanthium fecundum*) appear to be related. An increase in one is accompanied by a decrease in the other.

Arid short grass
The favourable seasons between 1993 and 1996 resulted in a large increase in the perennial grass component with an associated decrease in the proportion of annual grasses and forbs (Table 3.4). The main perennial increases were *Enneapogon* (limestone grass), *Heteropogon* (black spear grass) and *Dichanthium* (Queensland blue grass). The abundance of *Brachyachne* (summer couch) and *Sporobolus* (fairy grass) decreased noticeably during this period.

Burning treatments did impact on species composition with *Enneapogon, Brachyachne, Heteropogon* and dicotyledon species displaying the most variation from unburnt plots. Burning, particularly high intensity complete burns (L2BURN and E2BURN) promoted annual grasses and forbs at the expense of the more favoured *Enneapogon.* This response is most likely due to complete and high intensity burns as a result of fuel conditions in LDS94 and EDS95, rather than a response to season or frequency per se. Plots burnt in the EDS seemed to encourage forbs.

Tree and shrub response
Analysis of tree and shrub effects is yet to be completed. Results from the fuel load project provide a more detailed indication of effects.



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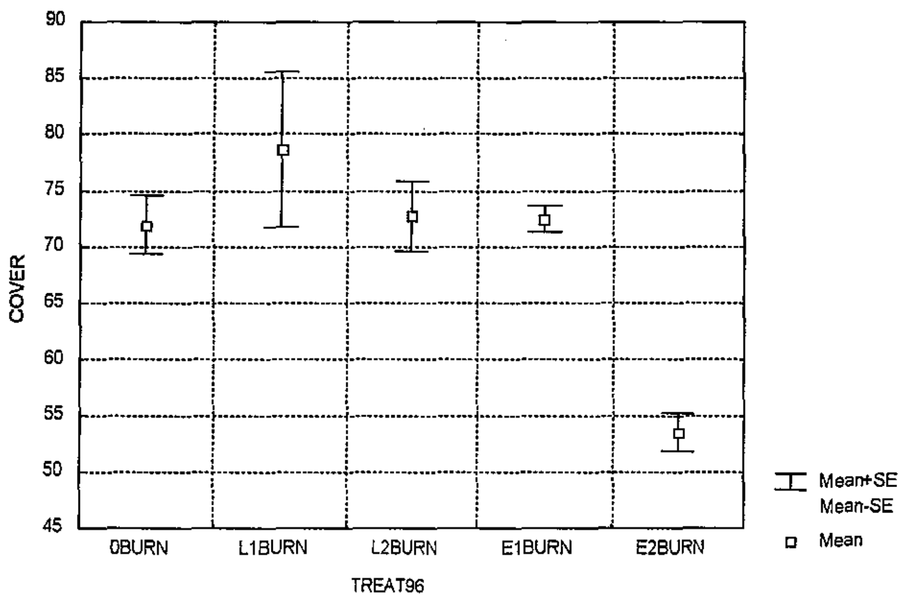
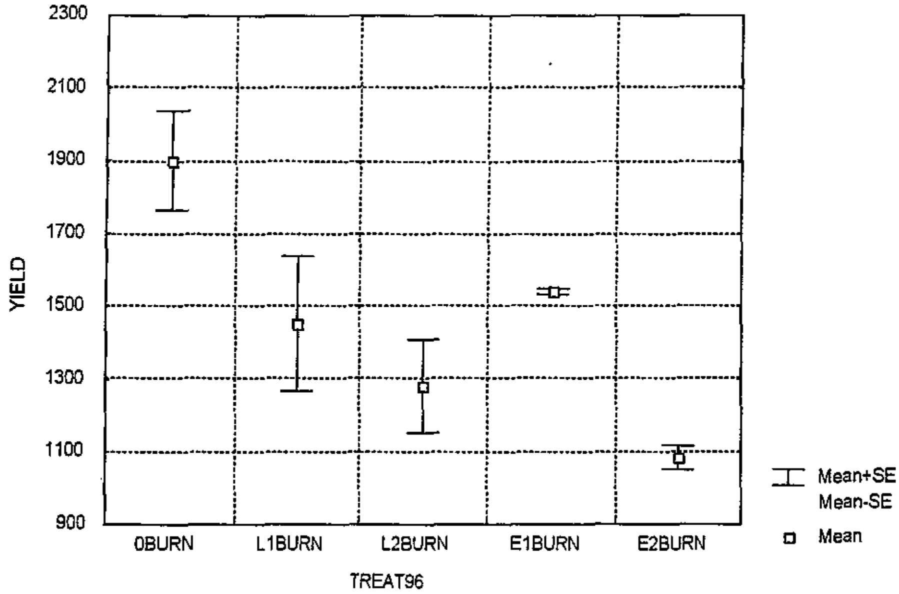
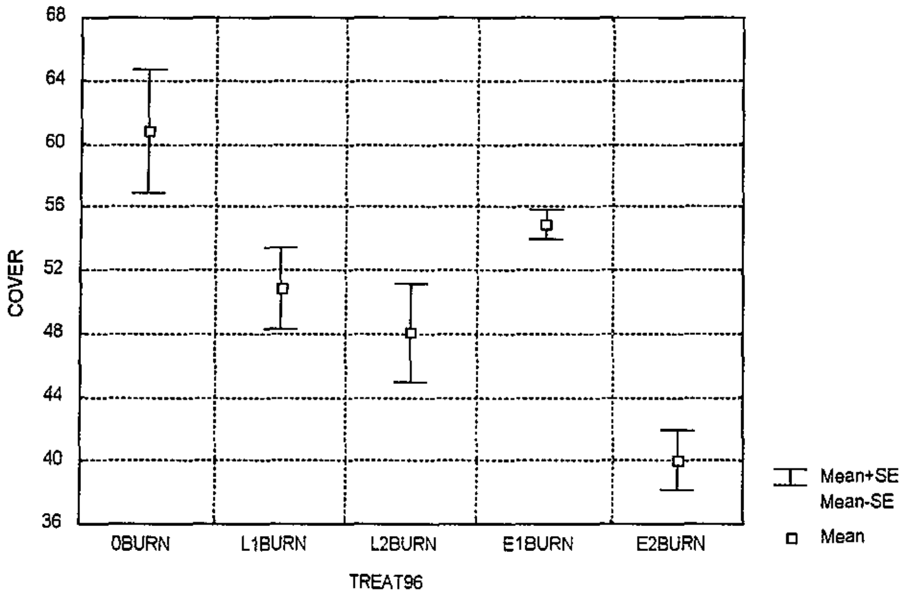


(b)

Figure 3.2 The effect of four burning treatments (0BURN, L1BURN, L2BURN, E1BURN and E2BURN) on subsequent (a) pasture yield, and (b) cover in ribbon/blue grass pastures.



(a)



(b)

Figure 3.3 The effect of four burning treatments (0BURN, L1BURN, L2BURN, E1BURN and E2BURN) on subsequent (a) pasture yield, and (b) cover in arid short grass pastures.

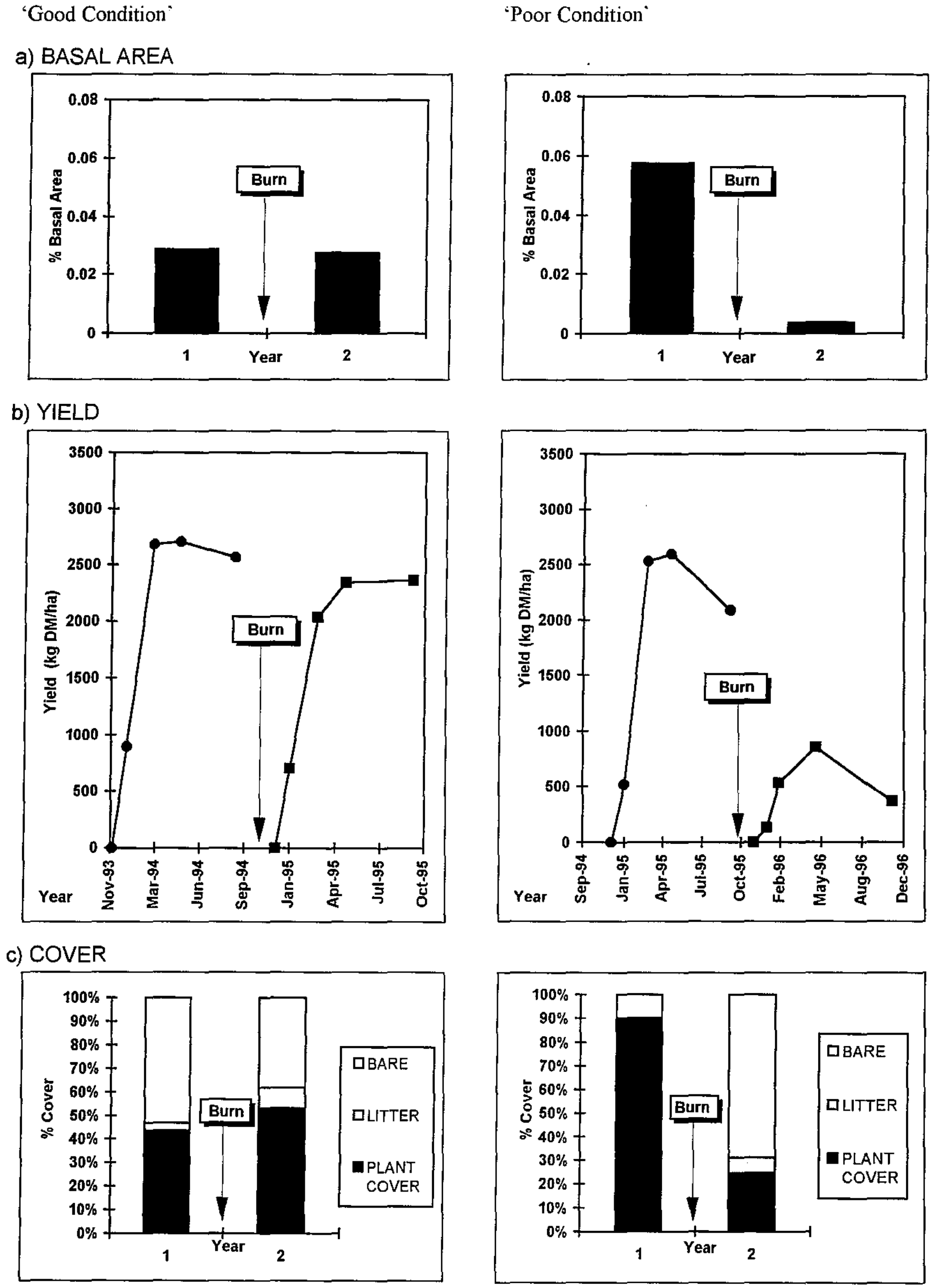


Figure 3.4 The effect of burning on plant basal area, yield and cover for "Good Condition" (Limestone grass dominant) and "Poor Condition" (Summer Couch dominant) arid short-grass pastures.

p69 colour plate

Table 3.3 Mean species composition (%) change for arid short grass pastures

(a) Average seasonal change in species composition in unburnt treatments.

	HETCON		ARILAT		BRCCON		ENNPOL		SPOAUS		DICOT		PERENN		ANNUAL	
	Means	**Sem**	**Means**	**sem**	**Means**	**sem**	**Means**	**sem**	**Means**	**sem**	**Means**	**sem**	**Means**	**sem**	**Means**	**sem**
1993	6.63	1.48	2.00	0.78	18.63	3.09	25.88	3.40	10.63	1.88	23.88	3.38	42.75	2.56	33.13	3.17
1994	10.50	3.06	8.10	2.04	15.00	4.37	34.60	5.60	8.40	1.40	16.40	2.69	61.50	2.69	22.30	2.65
1995	18.75	5.57	2.75	1.11	11.75	4.77	33.50	10.65	0.00	0.00	5.25	2.02	81.75	4.25	11.75	4.77
1996	17.50	4.56	3.75	2.17	3.50	0.87	41.25	10.99	0.00	0.00	10.50	4.84	82.50	4.97	5.00	0.41

(b) Average species composition between burning treatments.

	HETCON		ARILAT		BRCCON		ENNPOL		SPOAUS		DICOT		PERENN		ANNUAL	
	Means	**sem**	**Mean**	**sem**	**Means**	**sem**	**Means**	**Sem**	**Means**	**sem**	**Means**	**sem**	**Means**	**sem**	**Means**	**sem**
0BURN	17.50	4.56	3.75	2.17	3.50	0.87	41.25	10.99	0.00	0.00	10.50	4.84	82.50	4.97	5.00	0.41
L1BURN	16.50	6.50	2.50	0.50	15.50	2.50	46.00	12.00	0.50	0.50	5.00	2.00	76.50	5.50	17.00	2.00
L2BURN	15.00	4.81	5.50	2.22	16.25	9.05	35.50	7.92	0.25	0.25	12.00	2.80	66.00	7.47	17.25	8.75
E1BURN	15.50	2.50	4.50	1.50	4.00	3.00	50.00	3.00	0.00	0.00	18.50	6.50	72.00	1.00	8.00	6.00
E2BURN	25.75	4.61	5.50	1.94	18.00	5.12	19.25	2.93	0.25	0.25	22.50	9.26	56.25	6.45	18.75	5.15

Sem=std error

HETCON=Hetoeropogon contortus, ARILAT=Aristida latifolia, BRCCON=Brachyachne convergens, ENNPOL= Enneopogon polyphyllus, SPOAUS=Sporobolus australasicus, DICOT= Dicots (Forbs), PERENN=Perennial grass, ANNUAL=Annual grass.

Table 3.4 Mean species composition (%) change ribbon/blue grass pastures

(a) Average seasonal change in species composition in unburnt treatments.

	CHRFAL		ARILAT		DICFEC		ISSVAG		GR		DIC	
	Means	**sem**	**Means**	**sem**	**Means**	**sem**	**Means**	**sem**	**Means**	**sem**	**Means**	**sem**
1993	34.50	3.97	14.75	3.54	12.13	4.75	10.63	5.06	95.38	0.80	4.00	0.78
1994	33.00	4.34	13.90	1.96	18.00	4.16	16.60	3.88	97.50	0.40	2.10	0.43
1995	35.25	9.44	6.75	1.55	16.25	7.22	17.00	8.07	98.50	0.50	0.75	0.48
1996	38.00	11.25	9.25	4.21	16.50	7.42	4.25	1.70	93.50	1.55	5.50	1.85

b) Average species composition between burning treatments.

	CHRFAL		ARILAT		DICFEC		ISSVAG		GR		DIC	
	Means	**sem**	**Means**	**sem**	**Means**	**sem**	**Means**	**sem**	**Means**	**sem**	**Means**	**sem**
0BURN	38.00	11.25	9.25	4.21	16.50	7.42	4.25	1.70	93.50	1.55	5.50	1.85
L1BURN	30.50	14.50	5.50	2.50	24.00	12.00	2.00	0.00	95.50	1.50	5.00	1.00
L2BURN	36.75	6.91	10.75	3.47	15.50	3.57	7.75	2.78	91.75	1.60	7.75	1.80
E1BURN	33.00	1.00	15.00	6.00	19.00	6.00	3.00	1.00	89.00	1.00	10.50	0.50
E2BURN	38.00	7.27	15.00	2.86	8.00	3.16	9.75	1.31	88.25	1.65	10.50	1.76

Sem=std error

CHRFAL=Chrysopogon fallax, ARILAT=Aristida latifolius, DICFEC=Dichanthium fecundum, ISSVAG=Iseilema vaginiflorum, GR = Total Grass, DIC = Dicots (Forb)

Pasture condition and seasonal fluctuations

Season has the largest influence on species composition. In arid short grass pastures several above average seasons resulted in increases in limestone grass (*Enneopogon polyphyllus*) at the expense of decreasing proportions of the fragile annuals dominated by summer couch (*Brachyachne convergens*) and fairy grass (*Sporobolus australasicus*). The proportion of forbs also increased over this period. These annual species respond quickly to storms early in the wet season and are actively sought by cattle. They mature and cure rapidly. Areas dominated by these species are frequently left bare by the mid-late dry season, even after a good wet. These annual species are particularly sensitive to the amount and distribution of rainfall. The growth and survival of annual grasses is severely reduced by wet seasons with low rainfall, dry periods or low late wet season rainfall.

Pasture communities on grey cracking clays in good condition are characterised by a strong component of perennial tussock grasses that range in palatability. Species such as ribbon grass (*Chrysopogon fallax*), white grass (*Sehima nervosum*), silky browntop (*Eulalia fulva*) and especially *Aristida* are generally not preferentially grazed. These species are resilient under grazing and burning. Blue grass (*Dichanthium fecundum)*, and native millet (*Panicum decompositum*) species are more favoured and actively selected by cattle. The contribution of annual grass species such as Flinders grass (*Iseilema* spp) and Queensland blue grass (*Dichanthium sericeum*) is greater following seasons with high annual rainfall or uninterrupted growing periods during the wet.

Seasonal fluctuations resulted in changes to the proportions of various species. Of note was the increase of the preferred and palatable blue grass (*Dichanthium* spp.) at the expense of ribbon grass (*Chrysopogon fallax)* during a run of above average seasons between 1994 and 1997. Wire grass (*Aristida* spp.) is generally regarded as an indicator of poor condition, due to its very low feed value and dominance under heavy grazing. It appears that the proportion of *Aristida* may fluctuate with seasons and increase following better years even under low stocking rate conditions.

3.2 The effect of natural fuel loads on response and mortality of woody plants

Objective

To measure the effect of natural fuel loads on the response of woody plants following fires.

Introduction

Individual shrubs were identified within areas of naturally low, medium and high fuel load prior to burning. From this work it is hoped that the requirements of pasture biomass and prevailing weather conditions that will have maximum effect on maintaining shrub populations at manageable levels can be identified

Materials and Methods

The effect of natural fuel loads on fire intensity and woody plant response was measured in two pasture communities. Distinct fuel load areas were located within established burning trials on an arid short grass community (19 fuel load areas) on shallow calcareous red earth (Conkerberry site), and a perennial based ribbon/blue grass community (24 fuel load areas) situated on grey cracking clay (Rosewood site).

Fuel load areas with uniform areas of low, medium and high fuel load were located within plots allocated for both early dry season (EDS) and late dry season (LDS) burning. Approximately 30 trees were identified in each area. A total of 1000 shrubs have been tagged within the LDS and EDS plots. It was decided to concentrate on *Terminalia* and *Lysiphyllum* spp. on the black soil plots (Rosewood pdk) and Eucalypts, *Carissa* and *Hakea* spp. on red soil (Conkerberry pdk) as evidence suggests (Bastin and Andison, 1990) that numbers of these species are increasing. A count of plant species tagged is shown in Table 3.5.

Table 3.5 Counts of tagged plant species in Arid short grass (Conkerberry) and ribbon/blue grass (Rosewood) burning trial pastures.

Arid Short grass

Count of tagged species		LDS1993	EDS1994	LDS1994	EDS1995
Conkerberry	Carissa lanceolata	129	165	92	114
Inland Blood Wood	Eucalyptus terminalis	46		45	
Hakea	Hakea arborescens	42	64	30	54
Silver Leaf Box	Eucalyptus pruinosa	14		14	
Total		231	229	181	168

Ribbon/Blue grass

Count of tagged species		LDS1993	EDS1994	LDS1994	EDS1995
Bauhinia	Lysiphyllum cunninghamii	67	90	38	62
Conkerberry	Carissa lanceolata	15	0	1	0
Rosewood	Terminalia volucris	163	150	148	99
Total		245	240	187	161

Plant species, height, fire damage score and response to burning were recorded for each of the tagged plants. Pasture biomass (fuel load) and species composition was measured using the double sampling technique and the dry weight rank methodology within Tothill *et al* (1992) for 30 quadrats in each fuel load area. Fire damage was assessed several weeks following burning while plant response was scored after the following wet season.

Plots were burnt as part of a larger burning trial investigating the effect of frequency and season of burn (Project 3.1). Plots were burnt either once (L1burn and E1BURN), or twice in successive years (L2BURN and E2BURN), according to treatments summarised in Table 3.6.

Table 3.6 Description of burning treatments for fuel load trial

Treatment	Season of burn	Frequency	Burn Date
L1BURN	Late dry	Single burn	Oct. 1993
E1BURN	Early dry	Single burn	June 1994
L2BURN	Late dry	2 successive burns	Oct 1993 & Oct 1994
E2BURN	Early dry	2 successive burns	June 1994 & June1995

The range of natural fuel loads within each year was not sufficient to enable the analysis of fuel load treatment effects on fire behaviour and plant response. Results were grouped and analysed between years and seasons of burn as well as for fuel load ranges across all years. Data from all fuel loads at each burn was therefore averaged to identify variation in fuel load and plant response that existed between early and late dry season burns and years.

Results

Between LDS93 and EDS95 burns, average fuel loads ranged from 544-3118 kg DM/ha in arid short grass pastures and 1081-3399 kg DM/ha for ribbon/blue grass pastures (Table 3.7). Fuel yield (load) and cover in LDS 1993 were low in both pasture communities, however above rainfall during the 1993/94 and 1994/95 season produced higher levels. Ribbon/blue grass pastures have less variable fuel loads and cover, probably due to their high perennial grass component and lower attractiveness for grazing.

Shrub species such as rosewood and bauhinia, that dominate ribbon/blue grass pastures, display very low levels of plant mortality following burning, and survive fires over a large range of fuel loads. Woody plant species such as conkerberry, hakea and eucalypt species located throughout the arid short grass pastures are also well adapted to fire and suffer only low plant mortality. Fire resulted in plant mortality of between 2.7-5.2% in arid short grass and only 0.7-3.2% on ribbon/blue grass pastures.

Most woody species throughout both pastures survive burning by resprouting, either from the stem base following the death of aerial branches (top kill), from the branches only, or both branches and the stem base. Death of aerial branches, or top kill, is maximised following complete defoliation of leaves (severe damage) at the growing points.

As fuel load and ground cover increase, damage to plants from fire is more severe, which results in greater proportions of plants suffering top kill. The response to fuel load and cover is a result of increasing fire intensity. Increases in the percentage of woody plants in arid short grass pastures receiving severe damage from 4.8, 30.2 to 45.2% in EDS94, LDS94 and EDS95 fires respectively, resulted in subsequent increases in plant top kill from 39.5, 55.5 to 60.9%

respectively. Likewise in ribbon/blue grass pasture, higher fuel loads and cover levels caused greater severe plant damage (92%) which resulted in high degrees of plant top kill (91.4%).

Table 3.7 Fuel, plant damage and plant response characteristics from experimental burning plots in (a) arid short grass and (b) ribbon/blue grass pastures.

a. Arid Short grass

FUEL	**LDS 1993**	**EDS1994**	**LDS1994**	**EDS1995**
yield (kg DM/ha)	544.4	1800.9	1349.7	3118.0
cover (%)	50.4	52.7	58.9	77.4
PLANT DAMAGE (%)				
unburnt	*	17.0	11.0	4.2
slight	*	65.5	39.0	9.5
moderate	*	12.7	19.8	41.1
severe	*	4.8	30.2	45.2
PLANT REPONSE (%)				
mortality	5.1	2.7	5.2	3.8
top kill	53.2	39.5	55.5	60.9
branches and stems +	7.6	16.6	6.9	14.7
branches +	34.2	41.3	32.4	20.5

b. Ribbon/blue grass

FUEL	**LDS 1993**	**EDS1994**	**LDS1994**	**EDS1995**
yield (kg DM/ha)	1081.9	3399.4	2285.3	2757.0
cover (%)	70.5	65.6	63.6	71.2
PLANT DAMAGE (%)				
unburnt	*	0.4	2.7	2.5
slight	*	14.6	2.1	5.0
moderate	*	20.0	3.2	44.1
severe	*	65.0	92.0	48.4
PLANT REPONSE (%)				
mortality	1.7	0.8	3.2	0.7
top kill	69.0	79.5	91.4	82.8
branches and stems+	17.7	10.5	4.3	9.9
branches +	11.6	9.2	1.1	6.6

** Missing data .+Regenerates from*

Conkerberry and bauhinia appear to be more sensitive to fire, however mortality levels remained less than 14%. Plant mortality is higher in some woody species, particularly following more intense fires supported by higher fuel loads. Plant death of rosewood after fire is very low (1%), regardless of fire intensity. The response of conkerberry and bauhinia is variable, and is affected by increased fire intensity during LDS fires. Mortality of bauhinia was very low after EDS fires (1.1 and 0.0%), however increased to 3.4% in LDS93 and to 13.9% following the very intense LDS94 fires. Mortality of conkerberry ranged from 3.8-8.9%, seemingly higher following LDS fires.

Table 3.8 Response of woody plant species arising following from treatment burns in arid short grass and ribbon/blue grass pastures (Percent mortality, top kill, resprout from branch and stem, resprout from stem base).

a. Arid Short grass

PLANT SPECIES	PLANT REPONSE (%)	Treatment LDS1993	EDS1994	LDS1994	EDS1995
Conkerberry	mortality	5.7	3.8	8.9	3.8
	top kill	37.7	32.7	54.4	57.1
	resprout - br & stem	9.4	12.6	3.3	11.4
	resprout - stem	47.2	50.9	33.3	27.6
Inland Blood Wood	mortality	11.1		0.0	
	top kill	77.8		66.7	
	resprout - br & stem	0.0		7.7	
	resprout - stem	11.1		25.6	
Hakea	mortality	0.0	0.0	3.4	3.9
	top kill	87.5	56.3	48.3	68.6
	resprout - br & stem	6.3	26.6	13.8	21.6
	resprout - stem	6.3	17.2	34.5	5.9
Silver Leaf Box	mortality	0.0		0.0	
	top kill	100.0		50.0	
	resprout - br & stem	0.0		14.3	
	resprout - stem	0.0		35.7	

b. Ribbon/blue grass

PLANT SPECIES	PLANT REPONSE (%)	Treatment LDS1993	EDS1994	LDS1994	EDS1995
Bauhinia	mortality	3.4	1.1	13.9	0.0
	topkill	60.3	58.9	80.6	74.1
	resprout - br & stem	12.1	17.8	0.0	11.1
	resprout - stem	24.1	22.2	5.6	14.8
Conkerberry	mortality	10.0		0.0	
	topkill	10.0		100.0	
	resprout - br & stem	20.0		0.0	
	resprout - stem	60.0		0.0	
Rosewood	mortality	0.6	0.7	0.7	1.0
	topkill	75.5	91.9	93.9	87.6
	resprout - br & stem	19.6	6.0	5.4	9.3
	resprout - stem	4.3	1.3	0.0	2.1

Plant height

Burning causes a reduction in the frequency of taller woody plants. Regular fire maintains a suppressing affect on plant height structure. Figures 3.5 & 3.6 show the fire induced reduction in taller height classes, and increase in the frequency of smaller woody plants in both arid short grass and ribbon/blue grass pastures. This is a result of the death of aerial branches of taller plants which resprout from the base as smaller post-fire regrowth. This trend is continued if successive burns are administered. If fire is removed an upward shift in plant height classes occurs with the growth and recovery of plants in the years following burning. If fire is removed from pasture management there is no agent to suppress plant height and increase in plant size will continue.

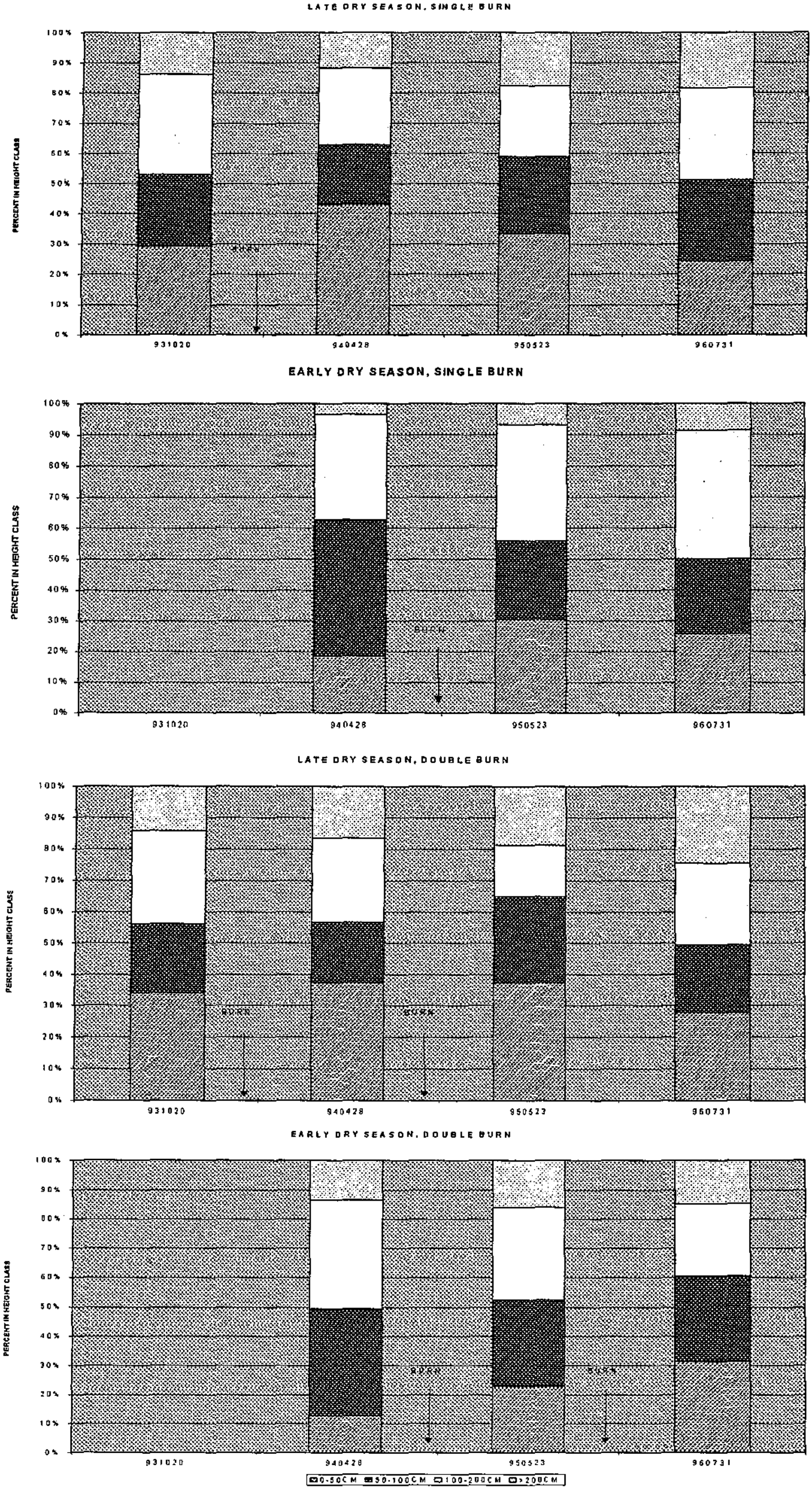


Figure 3.5 The change in woody plant height distribution in arid short grass pastures as a result of single or successive burns

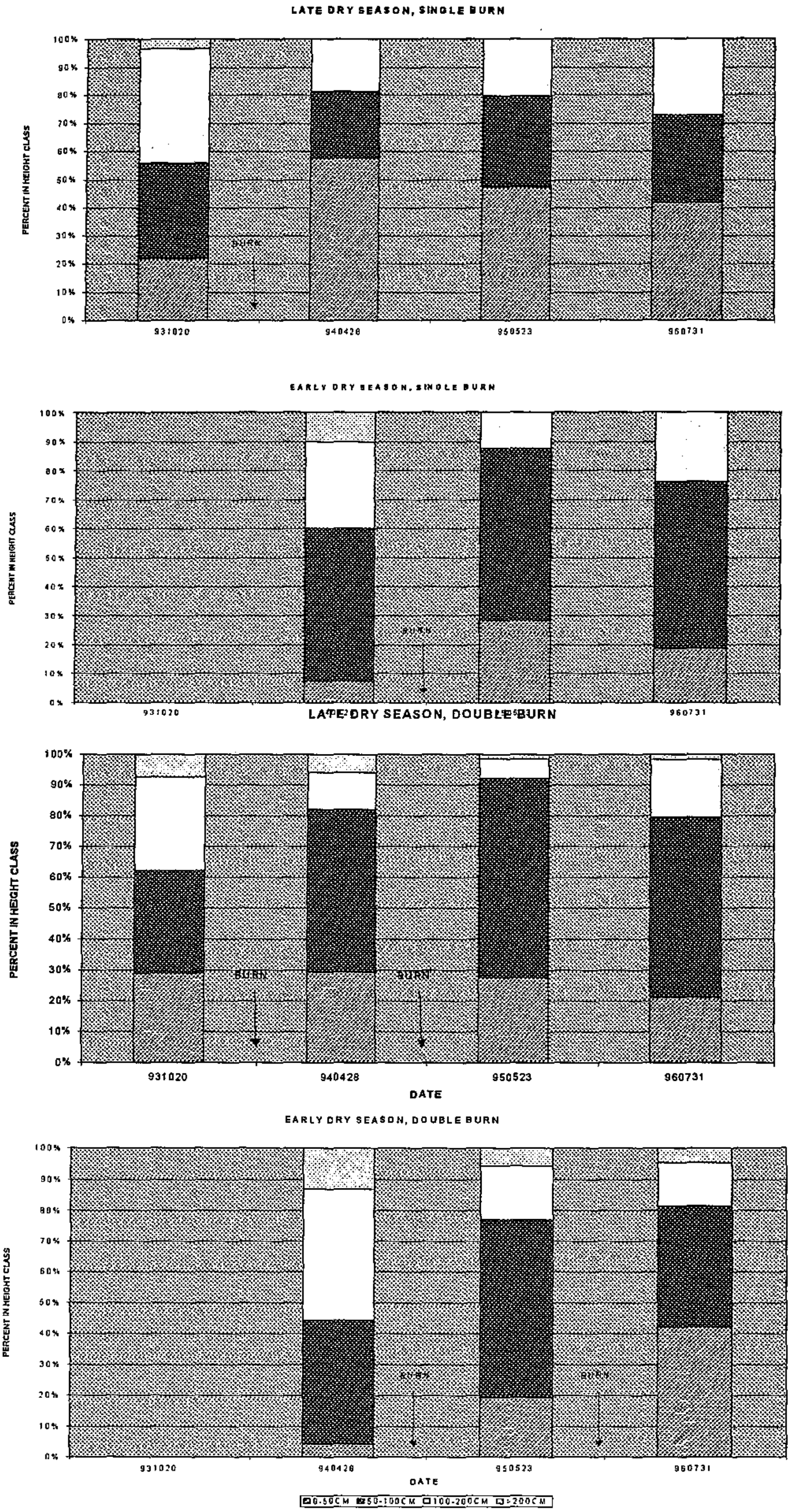


Figure 3.6 The change in woody plant height distribution in ribbon/blue grass pastures as a result of single or successive burning.

Fuel load

The levels of available fuel directly influence fire behaviour and plant response. As fuel loads decrease, fires become discontinuous, patchy and of low intensity. The result is an increase in unburnt plants, lower levels of plant fire damage and less plant top kill.

Table 3.9 shows the level of plant damage resulting from a range of fuel loads from EDS and LDS fires in (a) arid short grass and (b) ribbon/blue grass pastures. The response of woody plants in each community, (a) and (b) to a range of fuel loads from EDS and LDS fires is shown in Table 3.10.

Fuel loads less than 1000 kg DM/ha resulted in over 34% of plants in arid short grass pastures remaining unburnt, while 43.8 received only slight damage. Fuel loads over 2000 kg DM/ha reduced the proportion of unburnt plants to between 8-10% in arid short grass and to below 3% in ribbon/blue grass. .

Late dry season burning increases the level of plant fire damage and top kill compared to early dry season fires with similar levels of fuel. Fuel loads in ribbon/blue grass between 2000-3000 kg DM/ha caused 44.2% severe damage and 76.7% plant topkill during the EDS, however LDS burns at the same levels of fuel resulted in 99.3% of plants receiving severe fire damage and 95% plant top kill.

For effective management of woody vegetation with fire, fuel levels greater than 2000 kg DM/ha are required in both arid short grass and ribbon/blue grass pasture communities. Above this level the proportion of unburnt plants is reduced and a larger reduction in plant height is achieved as a result of greater top kill. Fuel loads less than 2000 kg DM/ha do not support fires of sufficient intensity to maintain an effective impact on any but the smallest of woody plants.

The maximum effect on woody vegetation structure will be achieved by burning during the late dry season.

Table 3.9 The effect of fuel load on plant fire damage from early dry season (EDS) and late dry season (LDS) fire in arid short grass and ribbon/blue grass pastures.

a. Arid Short grass

		Fuel load (kg DM/ha)			
Season	**Plant Damage (%)**	**0-1000**	**1000-2000**	**2000-3000**	**>3000**
EDS	UNBURNT		15.2	12.1	1.4
EDS	SLIGHT		65.2	19.5	30.0
EDS	MODERATE		15.2	33.6	30.0
EDS	SEVERE		4.5	34.9	38.6
COUNT (n)		0	178	149	70
LDS	UNBURNT	34.4	5.8	8.3	
LDS	SLIGHT	43.8	39.1	25.0	
LDS	MODERATE	6.3	21.7	33.3	
LDS	SEVERE	15.6	33.3	33.3	
COUNT (n)		32	138	12	0

Table 3.9 (cont.) The effect of fuel load on plant fire damage from early dry season (EDS) and late dry season (LDS) fire in arid short grass and ribbon/blue grass pastures.

b. Ribbon/Blue grass

		Fuel load (kg DM/ha)			
Season	**Plant damage (%)**	**0-1000**	**1000-2000**	**2000-3000**	**>3000**
EDS	UNBURNT			2.6	0.0
EDS	SLIGHT			11.1	10.4
EDS	MODERATE			42.1	18.5
EDS	SEVERE			44.2	71.1
COUNT (n)		0	0	190	211
LDS	UNBURNT		11.1	0.0	
LDS	SLIGHT		8.9	0.0	
LDS	MODERATE		11.1	0.7	
LDS	SEVERE		68.9	99.3	
COUNT (n)		0	45	143	0

Table 3.10 The effect of fuel load on woody plant response following burning of arid short grass and ribbon/blue grass pastures.

a. Arid Short grass

		Fuel load (kg DM/ha)			
SEASON	**PLANT RESPONSE (%)**	**0-1000**	**1000-2000**	**2000-3000**	**>3000**
EDS	DEAD		3.5	2.9	2.9
EDS	TOP KILL		39.3	54.4	58.6
EDS	RESPROUT - B&S		15.6	17.6	12.9
EDS	RESPROUT – STEM		41.6	25.0	25.7
COUNT (n)		0	173	136	70
LDS	DEAD	6.3	3.4	16.7	
LDS	TOP KILL	41.1	65.5	33.3	
LDS	RESPROUT - B&S	5.3	8.3	8.3	
LDS	RESPROUT – STEM	47.4	22.8	41.7	
COUNT (n)		95	145	12	0

b. Ribbon/Blue grass

		Fuel load (kg DM/ha)			
SEASON	**PLANT RESPONSE (%)**	**0-1000**	**1000-2000**	**2000-3000**	**>3000**
EDS	DEAD			0.6	1.0
EDS	TOP KILL			76.7	84.3
EDS	RESPROUT - B&S			12.2	8.6
EDS	RESPROUT - STEM			10.6	6.2
COUNT (n)		0	0	180	210
LDS	DEAD	3.1	2.7	1.4	
LDS	TOP KILL	55.9	83.1	95.1	
LDS	RESPROUT - B&S	25.2	8.1	3.5	
LDS	RESPROUT - STEM	15.7	6.1	0.0	
COUNT (n)		57.2	31.8	30.4	0.0

Predicting plant response from fuel characteristics
For land managers to optimise the effectiveness and use of fire to manipulate woody vegetation it is necessary to be able to predict the response of vegetation to fire for a range of influencing factors and inputs.

From the results so far, it is clear that fuel load, ground cover and plant height are among a range if influences that will determine the response of woody vegetation to fire. The combined influence of fuel load, cover and average plant height on woody plant response was investigated with multiple regression using percentage top kill as the dependant variable (Figure 3.7).

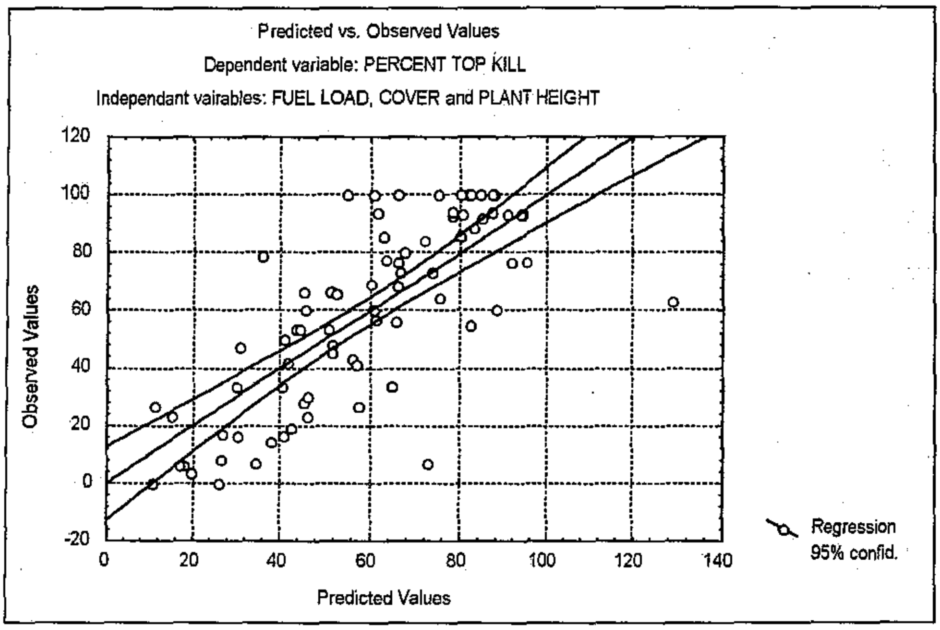


Figure 3.7 Multiple regression of predicted plant top kill (PTC) from a range of fuel load (FL), cover (CV) and average plant height values (APH). From multiple regression eqn. PTC = .0094 FL + .9820 CV + -.3660 APH + 18.259 Adj. $R^2 = 0.52$

This relationship indicated a strong relationship between fuel load, fuel cover, average plant height and the proportion of plant top kill. From this regression equation predicted values for plant top kill can be generated for any combination of plant height, fuel load and cover values. Using these values, predicted top kill was plotted for a range of fuel loads between 500-4000 kg DM/ha, for plants averaging 100, 150, 200 and 250 cm in height and for 40% and 60% levels of fuel cover. (Figures 3.8).

These relationships confirm that effective control of woody plants over 150cm requires fuel loads greater than 2000-2500 kg DM/ha and ground cover of 60%. Incorporation of equations for fire intensity from early and late dry season burns would allow further predictions of plant responses with season of burn.

These relationships can form part of a decision support system that will enable managers to identify necessary amounts of fuel and cover to achieve required levels of plant top kill, or predict the possible plant response from fuel characteristics.

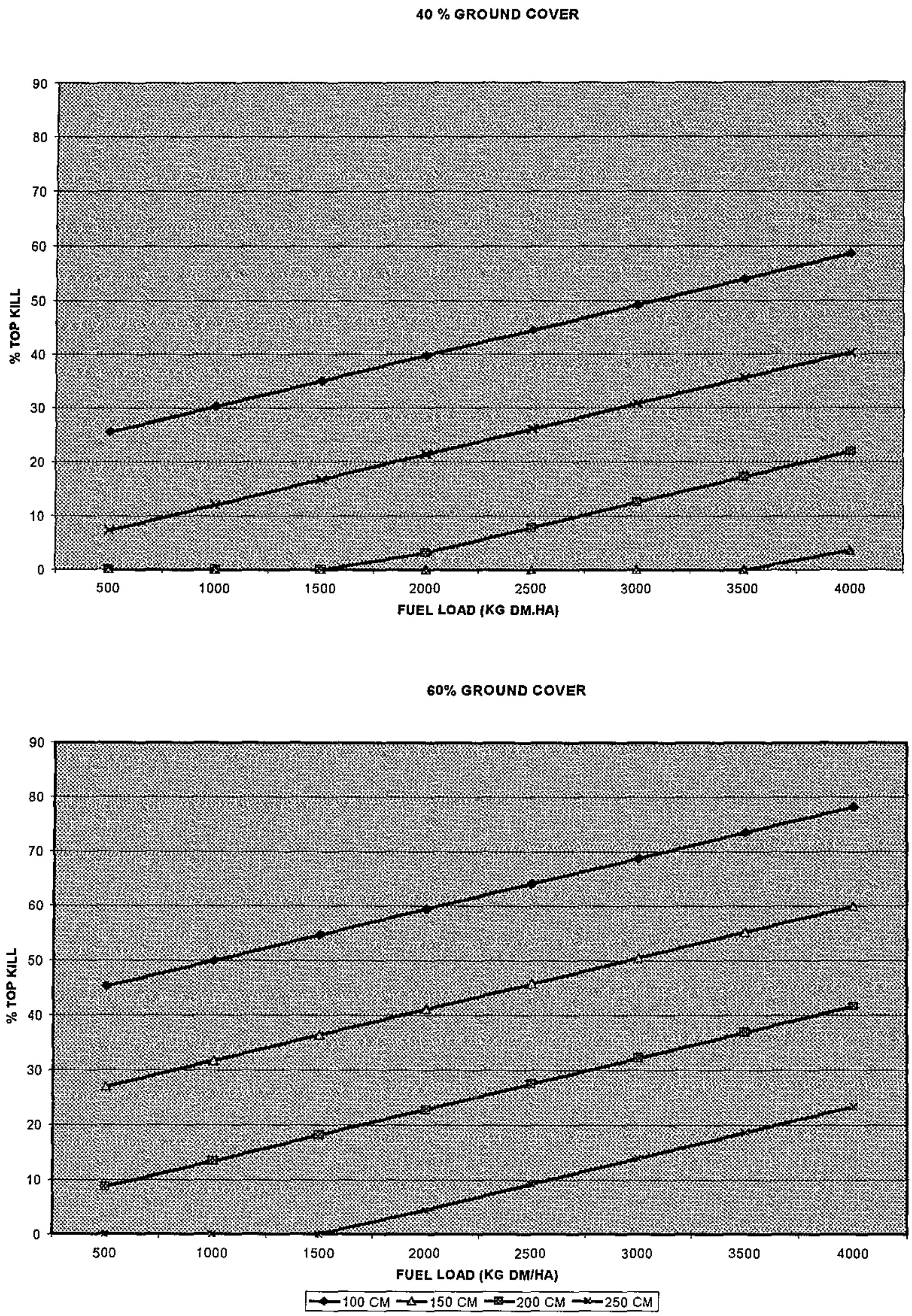


Figure 3.8 The predicted influence of plant height and fuel load on plant top kill following fire at (a) 40% and (b) 60% levels of fuel ground cover.

3.3 The manipulation of fuel loads to determine the effect of fire intensity, temperature, frequency and season on woody plant response.

3.3.1 Fuel load, fire intensity and season of burn.

Objective
Investigate the relationship between fuel load, fire intensity and response of woody vegetation.

3.3.2 Fire residence time and fire intensity

Objective
Measure fire time-temperature profiles over a range of fuel loads and fire intensity in order to determine the relationship between fire residence time and the response of woody vegetation.

3.3.3 Fire frequency and season of burn

Objective
Determine the impact of annual and biennial burning during the early dry and late dry season on the response of woody plants.

Methods

3.3.1 Fuel load and fire intensity and season of burn.

Experimental area and design
In 1994 a small burning trial comprising 16 plots was established at Kidman Springs (Victoria River Research Station). The site was located on a grey cracking clay dominated by the woody plant rosewood (*Terminalia volucris*). The pasture layer comprised *Chrysopogon fallax, Dichanthium fecundum,* and *Aristida latifolia.* Each plot was 15 x 15m in size. Eight plots were allocated to either early dry season (EDS; June) or late dry season (LDS; October) burning treatments.

A range of fuel loads were created in plots prior to burning at each season. Fuel loads ranged between 1000-6000 kg DM/ha and were manipulated by the addition or removal of native pasture. In each plot up to 50 rosewood plants were individually identified and tagged. A total of 600 plants were tagged across all plots.

Fuel and fire measurements
The fuel load in each plot prior to burning was measured by harvesting and weighing all dry matter within 5 randomly placed 1m^2 quadrats. Moisture content was calculated from wet weights and dry weights following drying of sub-samples from several plots at 80°C.

Burning was carried out during the mid-afternoon on all occasions. The time, ambient temperature, relative humidity, wind speed and direction was measured at the site or nearby for each burn. All plots were ignited up wind of the prevailing wind, after lighting a small back burn on the down wind side to maintain safety. The rate of fire spread was calculated from the timed progress of fire across each plot, extent of back burn, and plot dimensions. Fire line intensity was calculated according to the equation of Byram (1959).

Fire line intensity

$$I = Hwv$$

where I = *fire line intensity (kJ/m/sec),*
H = *heat of combustion of native, pasture (17 000 kJ/kg) Trollope 1985*
w = *dry weight of fuel (kg/m) and,*
v = *fire line velocity (rate of spread; m/sec).*

Plot photographs were taken prior, during and immediately following treatment burns.

Measurements of woody plant response.
Plant species and initial height of tagged plants was measured during plot establishment. Fire damage was recorded following burning using a scoring system (see below). Plant height and plant response to fire (see below) was recorded following the post-burn growing season. The growth of plants in an adjacent unburnt area was also recorded each year.

Plant counts within two permanent 2 x 15m transects in each plot were recorded in 1994. These transects were recounted in 1997 to monitor plot recruitment or mortality events.

Fire damage score (after Hodgkinson)

0	unburnt
1	very slight; scorched with clusters of green leaf
2	slight; some leaves burnt but mainly scorched
3	moderate; most leaves burnt, but some scorching
4	severe; all leaves burnt off
5	very severe; all leaves and small twigs burnt off

Plant damage scores were also grouped for analysis:

1	Slight	Leaves scorched
2	Moderate	Leaves burnt
3	Severe	Leaves burnt off

Plant response score (Trollope, 1974)

0	no fire damage, unburnt
1	dead (appears dead)
2	top growth killed, coppicing from the base
3	top growth not killed, coppicing from base of stem and shooting from branches
4	top growth not killed, shooting from branches only

Plant response scores were also grouped for analysis:

1	top kill	plants resprout from base, branches killed.
2	no top kill	plants resprout from branches.

Fuel loads were grouped into the following categories:

1	Low	<2000 kg DM/ha
2	High	2000-4000 kg DM/ha
3	Very High	>4000 kg DM/ha

3.3.2 Fire residence time and fire intensity

Fire time-temperature profiles were recorded at different heights above ground level in all plots during early and late dry season burns in 1994. An array of thermocouples were suspended from an aluminium mast erected in the middle of each plot providing a recording of temperature at 0, 10, 20 , 40, 60, 120 and 200cm above ground level (Plate 9). The air temperature at the junction of chrome-alumal K-type thermocouples was recorded every 2 seconds by a data-logger (Datataker 600) protected in an insulated aluminium box. Data was down-loaded onto a laptop computer following each burn (Plate 10). The time, in seconds, that each plot was exposed to temperatures of 60, 100, 200 and 400 °C at each height class was calculated from time-temperature profiles.

Relationships between period of exposure and fuel load, fire intensity, plant damage, top kill and plant mortality were investigated using regression analysis.

3.3.3 Fire frequency and season of burn

The fuel manipulation trial described in 2.1 was established in 1994 to measure the effect of fires supported by a range of fuel loads within a small uniform area.

It was decided to continue and modify the fuel manipulation trial and utilise the existing area to continue a program of burning on either an annual or biennial basis during the original season of burning allocated to each plot. This would identify any weakness that rosewood may have with season or frequency of burning that may be exploited by practical burning management strategies. It will also continue to provide fuel load, fire intensity and plant response data for a further two years.

The original 16 plots, allocated to a range of fuel loads in both the EDS and LDS in 3.3.1 were stratified according to fuel load (low and high) and allocated randomly to either annual or biennial burning frequency treatments. The manipulation of fuel, implementation of fires and collection of fuel, fire and woody plant measurements remained the same as for 3.3.1. The number of plots allocated to season, frequency and fuel load treatments in shown in Table 3.11.

Table 3.11: The description and allocation of plots to fuel manipulation burning treatment between 1994 and 1996

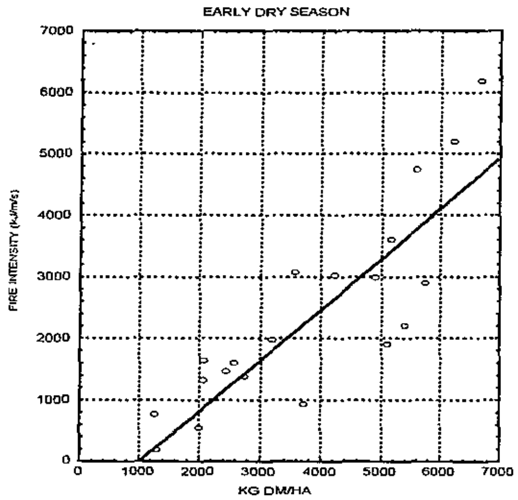
Fire season	Fire Frequency	Fuel load	1994	1995	1996
8 x Early Dry	4 x Annual	2 x High 2 x Low	Burn Burn	Burn Burn	Burn Burn
	4 x Biennial	2 x High 2 x Low	Burn Burn		Burn Burn
8 x Late Dry	4 x Annual	2 x High 2 x Low	Burn Burn	Burn Burn	Burn Burn
	4 x Biennial	2 x High 2 x Low	Burn Burn		Burn Burn

Results

3.3.1 Fuel load, fire intensity and season of burn

a) Fire behaviour

Fire intensity increases with higher fuel loads. This is expected, given that the dry weight of fuel is a function of fire intensity. This relationship for early and late dry season fires is shown in Figure 3.9.



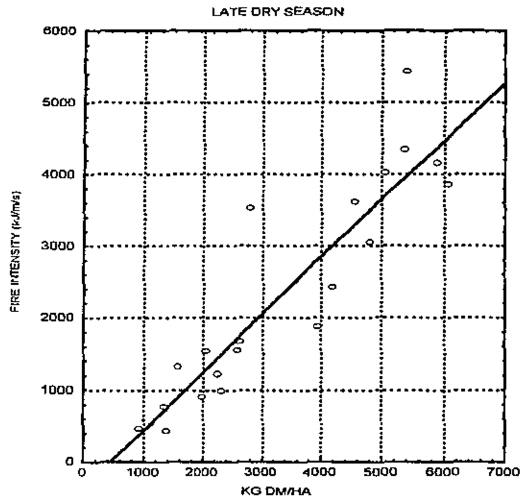


Figure 3.9 Relationship between fuel load and fire intensity (kJ/m/s) for early and late dry season fires.
Early dry season: Fire intensity = 0.840 * fuel load - 832.5;r^2=0.070; P<0.001.
Late dry season: Fire intensity = 0.911 * fuel load - 359.4; r^2=0.83; P<0.001.

Early dry season (June) fires have lower and more variable levels of intensity compared to late dry season fires at the same fuel load. This is probably due to prevailing weather and fuel conditions during the LDS promoting increased rate of fire spread.

Summary data for treatment fires is shown in Tables 3.12 and 3.13.

b) Plant Response

Burning resulted in no mortality of any tagged Rosewood plants over a three year period regardless of fuel load, fire intensity, season of burn or burning frequency. Fuel loads ranged from 900-6670 kg DM/ha during this period. Fire intensity was measured between 192.7-6187 kJ/m/s, a range of fires described as very cool to extremely hot (Trollope *et al* 1985). Plant fire damage ranged from slight scorching of leaves to complete defoliation and consumption of small twigs (Plate 11).

The main effect to individual plants following fire was death of aerial branches or top kill. Following top kill, plants would resprout from the base, near or below ground level during the following wet season (Plate 12). The proportion of plants that suffered top kill increased with higher fuel loads and fire intensity.

Table 3.12 a) Fire data from early and late dry season burns - 1994

Year	Season	Date	Plot	Fuel Load (kg/ha)	Fuel Dry Matter (DM%)	Dry Fuel Load (kgDM/ha)	Rate of Spread (m/s)	Fire Intensity (kJ/m/s)	Temperature (oC)	Rel Humidity (%)	Wind Speed (km/hr)	Wind Dir.
1994	EDS	8/6/94	D	1660.0	0.76	1262	0.27	769.6	31.0	38.0	5.7	SE/NE
		8/6/94	F	6700.0	0.76	5092	0.17	1898.3	31.0	37.0	4.3	E
		8/6/94	G	1700.0	0.76	1292	0.07	192.7	31.0	37.5	3.9	E/NE
		9/6/94	B	4700.0	0.76	3572	0.38	3073.1	29.5	43.0	10.3	NE
		9/6/94	I	3380.0	0.76	2569	0.28	1596.1	30.0	40.0	10.5	E/NE
		9/6/94	J	4200.0	0.76	3192	0.28	1983.3	31.0	37.0	7.8	E/NE
		9/6/94	L	3200.0	0.76	2432	0.27	1464.6	31.0	36.0	7.8	NE
		9/6/94	N	6450.0	0.76	4902	0.27	2990.5	31.0	36.0	6.7	NE
1994	LDS	12/10/94	A	6310.0	0.96	6058	0.36	3861.7	38.0	6.0	4.5	S-SE
		12/10/94	C	4340.0	0.96	4166	0.33	2434.7	38.0	6.0	4.5	SE
		12/10/94	E	2730.0	0.96	2621	0.36	1670.8	38.0	6.0	4.5	SE
		12/10/94	H	1390.0	0.96	1334	0.33	779.8	38.0	6.0	4.5	SE
		12/10/94	O	6120.0	0.96	5875	0.40	4161.6	38.0	6.0	4.5	SE-NE
		12/10/94	P	4100.0	0.96	3936	0.27	1881.9	38.0	6.0	4.5	E-NE
		13/10/94	K	2330.0	0.96	2237	0.31	1227.9	37.0	6.0	4.5	NE
		13/10/94	M	2690.0	0.96	2582	0.34	1554.8	37.0	6.0	4.5	NE

Table 3.13 b) Fire data from early and late dry season burns – 1995 and 1996

Year	Season	Date	Plot	Fuel Load (kg/ha)	Fuel Dry Matter (DM%)	Dry Fuel Load (kgDM/ha)	Rate of Spread (m/s)	Fire Intensity (kJ/m/s)	Temperature (oC)	Rel Humidity (%)	Wind Speed (km/hr)	Wind Dir.
1995	**EDS**	7/6/95	B	6340.9	0.88	5580	0.44	4743.0	26.9	28.4	7	S-SE
		7/6/95	G	2350.0	0.88	2068	0.33	1318.4	26.9	28.4	7	S-SE
		7/6/95	L	2336.4	0.88	2056	0.41	1628.4	26.9	28.4	7	S-SE
		7/6/95	N	7579.5	0.88	6670	0.48	6184.9	26.9	28.4	7	S-SE
1995	**LDS**	26/10/95	C	5256.0	0.96	5046	0.45	4020.8	36.0	19.0	5	SE
		26/10/95	K	2654.0	0.87	2309	0.22	992.6	35.0	13.0	5	SE-SW
		26/10/95	M	2446.0	0.83	2030	0.37	1538.5	35.5	14.0	9	ESE
		26/10/95	O	4996.0	0.96	4796	0.36	3057.6	35.5	16.0	8	E-SE
1996	**EDS**	18/6/96	B	6170.0	0.875	5399	0.21	2202.7	32.0	23.0	0	SE-S
		18/6/96	D	4820.0	0.875	4218	0.37	3031.8	32.0	23.0	1	E-SE
		18/6/96	F	7120.0	0.875	6230	0.43	5204.7	32.0	23.0	1	E-SE
		18/6/96	G	3130.0	0.875	2739	0.26	1383.5	32.0	23.0	1	SE
		18/6/96	I	4240.0	0.875	3710	0.13	937.0	31.5	23.0	1	E-SE
		18/6/96	J	5890.0	0.875	5154	0.36	3604.7	31.5	23.0	1	SE
		18/6/96	L	2290.0	0.875	2004	0.14	545.0	31.5	23.0	1	SE
		18/6/96	N	6560.0	0.875	5740	0.26	2899.5	31.5	23.0	1	SE
1996	**LDS**	23/10/96	A	5705.0	0.94	5363	0.56	5431.2	36.0	20.0	12.5	E
		23/10/96	C	5682.0	0.94	5341	0.45	4346.7	36.5	20.0	12.5	E
		23/10/96	E	4841.0	0.94	4551	0.44	3621.1	37.0	20.0	12.5	E-SE
		23/10/96	H	1620.0	0.957	1550	0.48	1321.9	39.0	16.0	12.5	E
		23/10/96	K	940.0	0.957	900	0.29	463.4	39.5	16.0	12.5	E
		23/10/96	M	1429.0	0.957	1368	0.18	437.3	39.0	22.0	14	S
		23/10/96	O	2064.0	0.957	1975	0.26	912.3	39.5	16.0	14	E-SE
		23/10/96	P	2973.0	0.94	2795	0.70	3537.9	39.9	16.0	12.5	E-SE

(i) Fuel load

The severity of plant damage increases with higher fuel loads. Although this does not result in increase plant mortality, higher fuel loads are responsible for increased proportions of plant top kill. The effect of increasing fuel load on plant fire damage and plant response is shown in Figure 3.10 and 3.11, respectively. Taller plants suffer less plant fire damage and lower proportions of top kill. Low fuel loads (< 2000 kg DM/ha) are able to inflict over 80% top kill on plants less than a meter in height, however, **fuel loads greater than 2000 kg DM/ha are required for effective top kill of at least 60% of plants greater than 1m in height.**

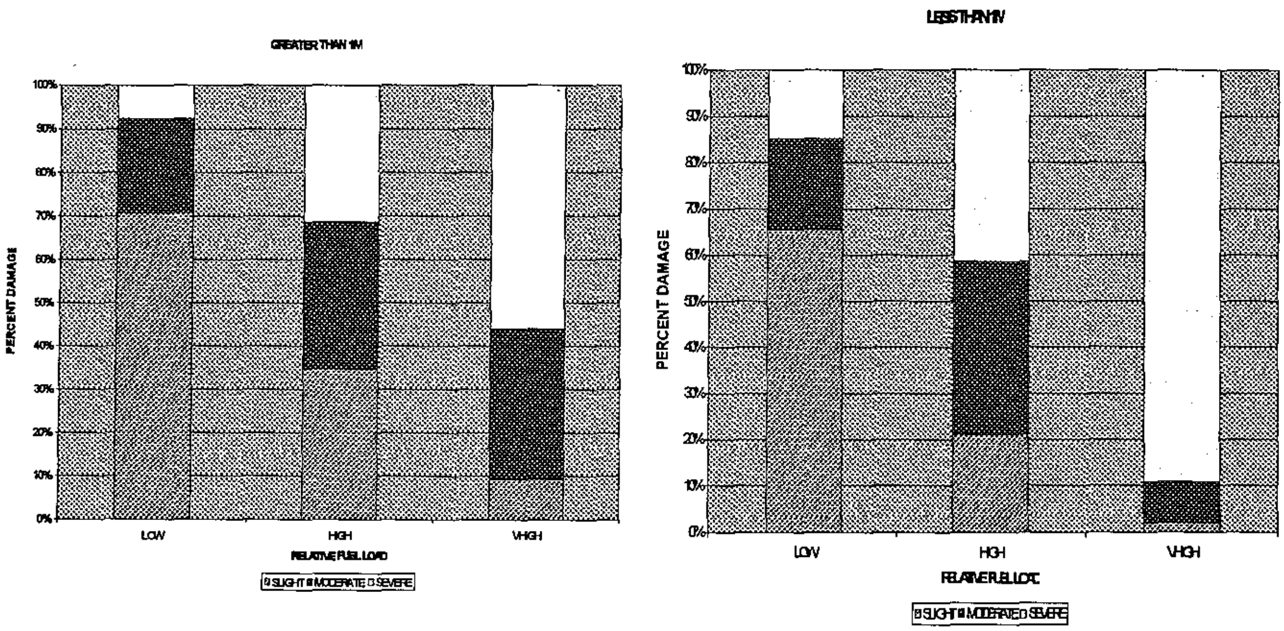


Figure 3.10 The effect of increasing fuel load on the relative levels of plant fire damage imposed on (a) plants less than 1 metre in height, and,(b) those greater than 1 metre in height.

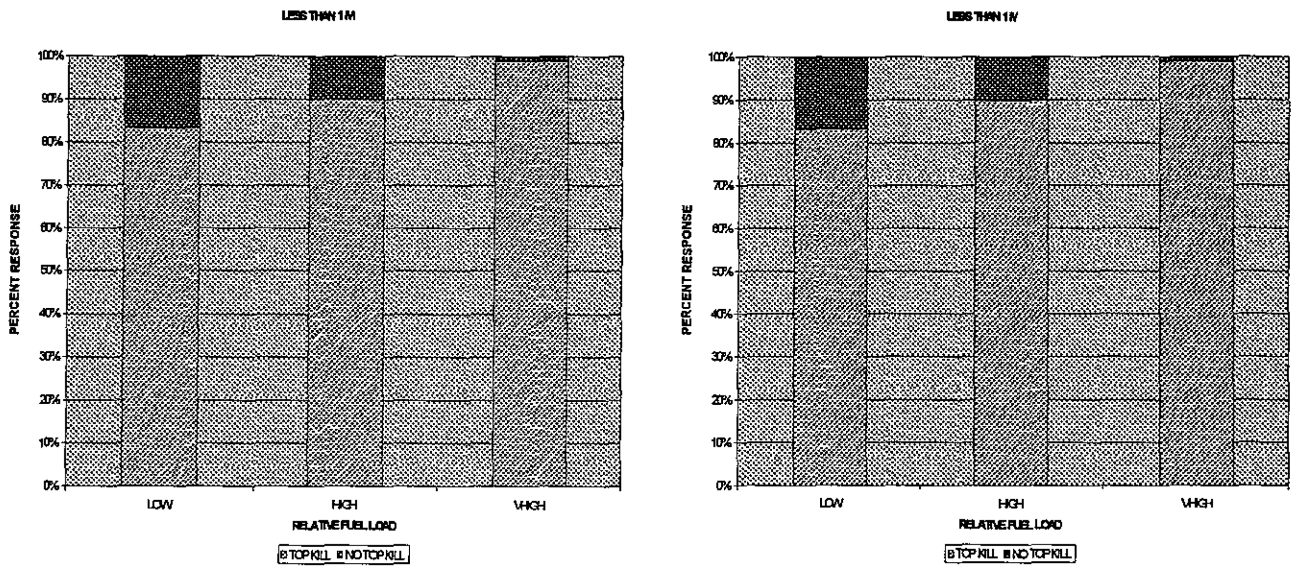


Figure 3.11 The effect of increasing fuel load on the plant response following burning from (a) plants less than 1 metre in height, and,(b) those greater than 1 metre in height.

(ii) Fire intensity

Fire intensity is a measure of the rate of heat release per length of fire-line. This is considered a standard variable when measuring and describing fire behaviour. **From results in this trial, fire intensity is well correlated with plant response.**

The relationship between fuel load, plant fire damage and plant response is similar for increasing fire intensity. Fire intensity was grouped into meaningful categories according to Trollope *et al* (1985).

Fire intensity

1	Cool Fire	< 1000 kJ/m/s
2	Moderate	1000-2000 kJ/m/s
3	Hot fire	2000-3000 kJ/m/s
4	Extremely hot fire	> 3000 kJ/m/s

As expected, **increasing fire intensity caused more severe plant damage resulting in higher proportions of plant top kill** (Figures 3.13 and 3.14). Cool fires caused significant damage and levels of top kill to greater than 80% of plants less than 1 metre in height, however were not as effective on taller plants. Cool fires could only be expected to achieve around 30% top kill in plants greater than 1 metre. **For effective control of top growth, moderate to hot intensity fires are necessary.** There is little additional response, however, from extremely hot fires over the range of height classes measured.

(iii) Plant growth and height

Without fire, the growth of normally suppressed plants will continue, gradually increasing woody plant biomass (Figure 3.12). Measurement of plant height of 35 tagged unburnt rosewood plants between 1994 and 1996 indicated a significant shift in the height class.

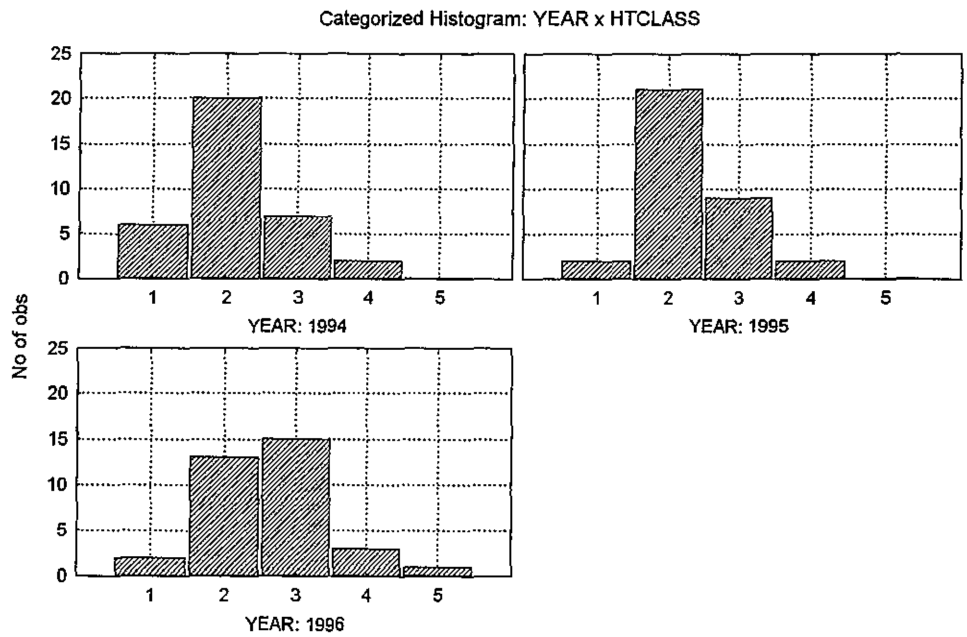


Figure 3.12 The change in height distribution of unburnt plants between 1994 and 1996.

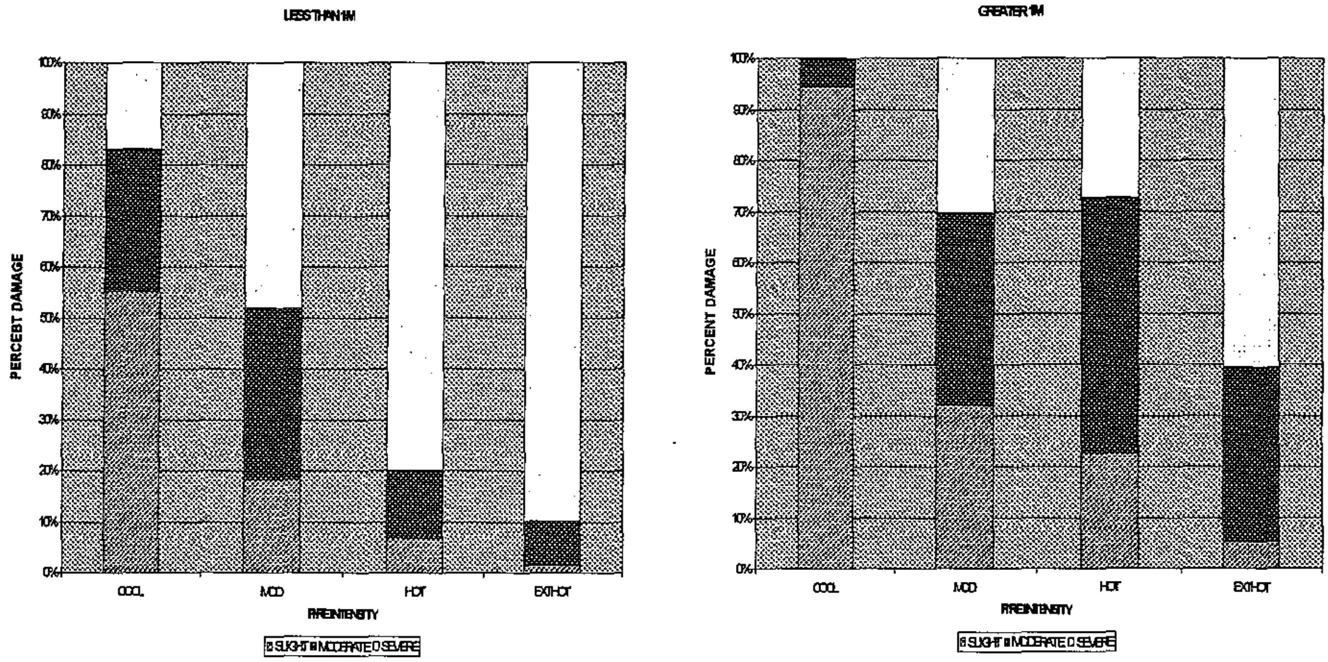


Figure 3.13 The effect of increasing fire intensity on the relative levels of plant fire damage imposed on (a) plants less than 1metre in height and (b) those greater than 1 metre in height.

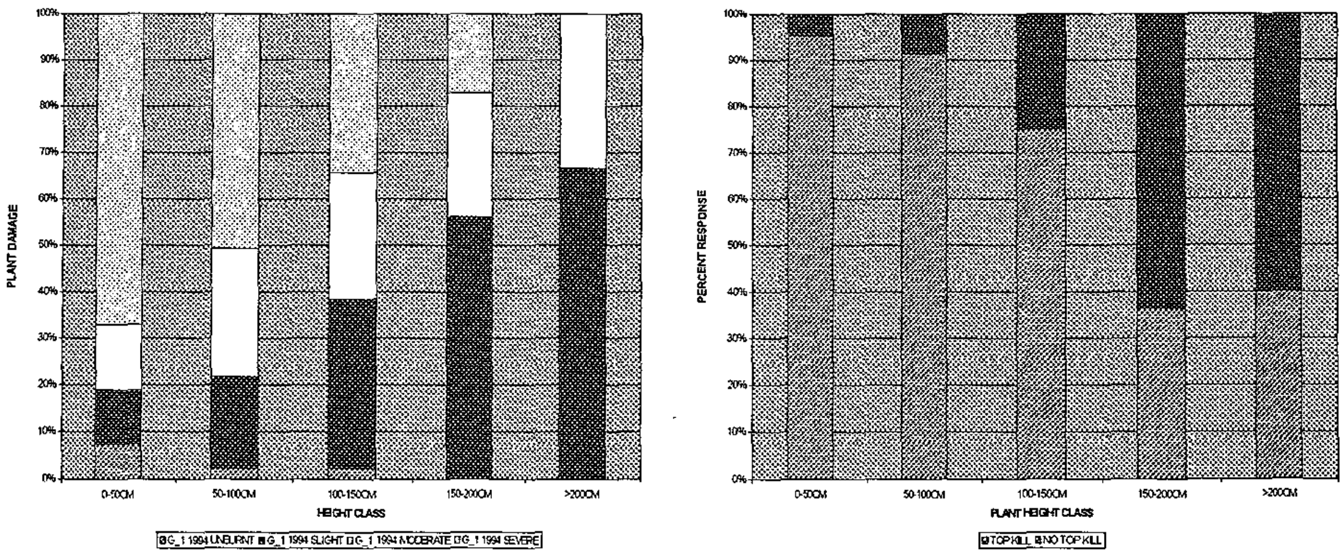


Figure 3.14 The effect of increasing fire intensity on the plant response following burning from (a) plants less than 1 metre in height and (b) plants greater than 1 metre in height.

Burning resulted in a shift from higher to lower plant height classes (Figure 3.15). The change in distribution of plants in height classes following burning demonstrated the suppressive effect of fire on plant growth. Annual burning maintained this response, however plants in biennial burn plots recovered into taller height classes following an initial decrease in height after the first burn. This indicates that regular fire is required to maintain woody vegetation at a certain level. The frequency of burning should be timed so that plant height is maintained to levels that are relatively easy to control, and therefore, will be determined by the rate of plant growth following burning.

a. Single burn

b. Two successive burns

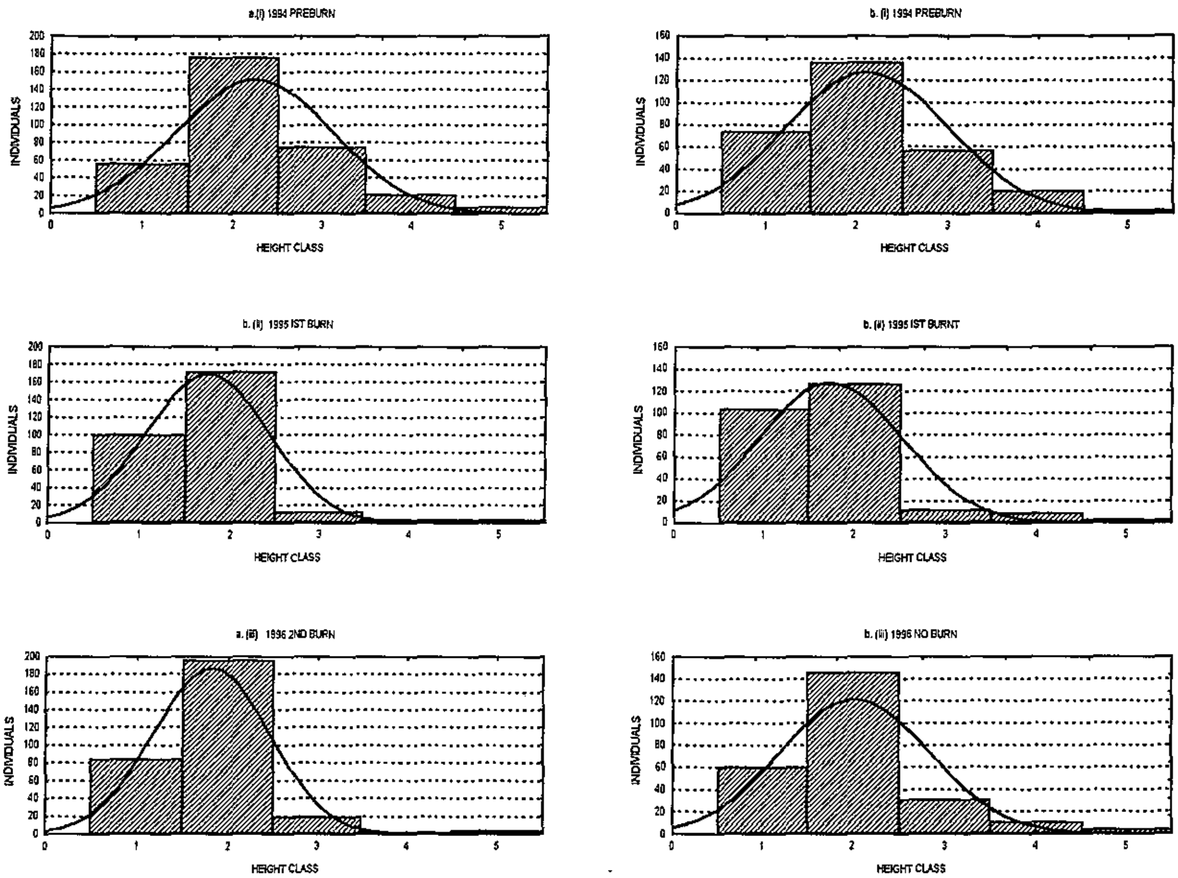


Figure 3.15 The distribution of tagged plants in height classes prior to and following (a) single and (b) successive burning treatments.

Effective top kill requires moderate to severe fire damage to aerial growing points of woody plants. **As woody plants grow and become taller they are less exposed to the direct influences of flames and therefore are generally more resistant to fire damage and control by fire.** The influence of plant fire damage and plant response of a range of height classes is shown in Figure 3.16. **Effective management of taller plants, particularly over 1.5 - 2.0 meters, requires high – very high levels of fuel or hot – very hot intensity fires.** Effective top kill of plants below 1.5 metres was greater than 70%, but fell to between 30-40% for plants greater than 1.5 metres. Management should aim to maintain emerging problem areas below these heights.

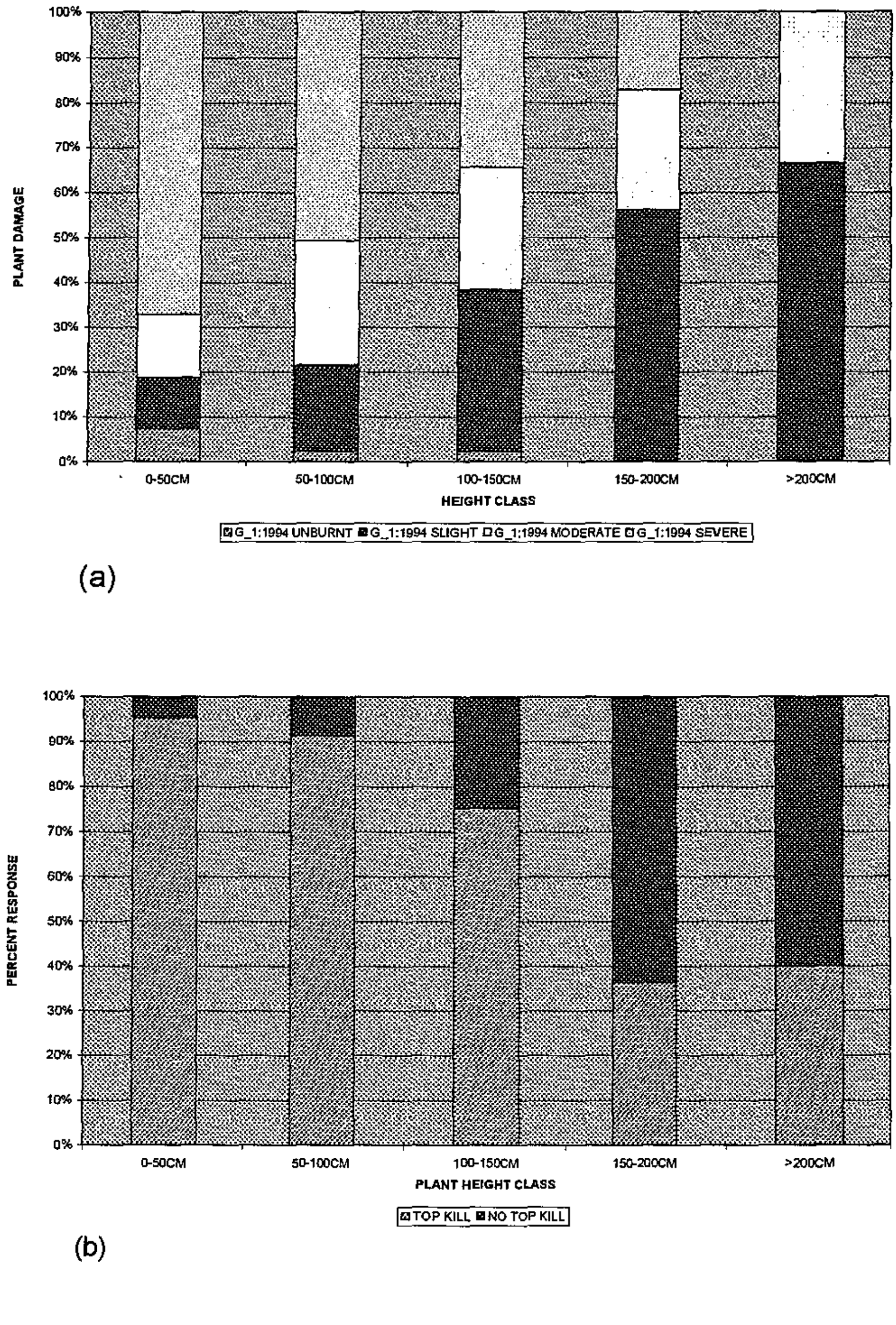


Figure 3.16 The effects of (a) plant fire damage and (b) plant response following burning for a range of plant height classes.

(iv) Plant density

Burning had no effect on plant density. Variations in fuel load, fire intensity, season and frequency caused no significant increase or decrease in plant numbers in plots measured between 1994 and 1997. There has been concern that high intensity fires may stimulate germination of seedlings or suckering of adults, which would increase current densities and exacerbate woody plant problems. Counts of plants along fixed transects in this trial seemed to indicate that this was not the case for rosewood.

3.3.2 Fire intensity and temperature residence time

The period of exposure at specified temperatures, or residence time, may be related to fire intensity or plant response.

Time-temperature profiles were measured from 16 plots in 1994. Visually there appeared to be considerable differences in fire temperatures between plots with different fuel load and fire intensities.

The time-temperature profiles for different heights above ground level measured from two very different fires are shown in Figures 3.17 and 3.18. Plot G (Plate 7) was burnt in the EDS with low fuel load (1292 kg DM/ha) which produced a very low intensity fire (192.7 kJ/m/s). In comparison Plot A (Plate 8), is a LDS fire with a high fuel load (6057 kg /DM/ha) producing a fire of very high intensity (3861 kJ/m/s). Visually the time-temperature profiles are very different. The high intensity fire reached greater maximum temperatures at all heights above ground level (Figure 3.18)

Maximum temperature was generally concentrated at 10cm above ground level and decreased with increasing height.

Residence time was calculated as the period, in seconds, above which the fire (or measured temperature) remained at or above a specified temperature. Time-temperature profiles were measured at 0, 10, 20, 40, 60, 120 and 200cm above ground level and residence times calculated for 60, 100, 200 and 400 ^{0}C at these heights. The relationship between fire intensity and residence time, and residence time and plant response at 10, 60 and 200cmabove ground level and 100^{o}C is shown in Figures 3.19 and 3.20.

Initial results suggest that time-temperature profiles and residence time do not correlate well with fire intensity and plant responses. There appeared to be no strong relationship between residence time and fire intensity at any of the heights measured above ground level (Figure 3.19). This is most likely due to the tremendous variability in fire behaviour and difficulty associated with the measurement and interpretation of time-temperature profiles. From these summary results there seems little value in relating plant response to various regimes of heat duration, however, detailed analysis in following consultation with M Gill, CSIRO, Plant Industry will be carried out.

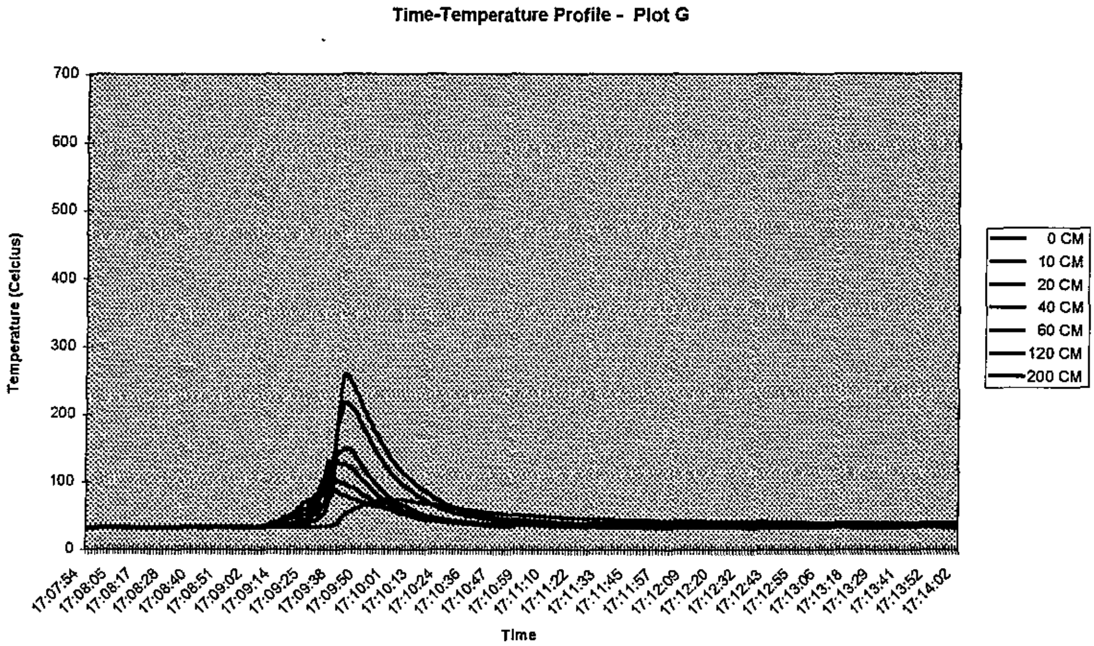


Figure 3.17 Fire time-temperature profile measured from early dry season fire of low intensity.

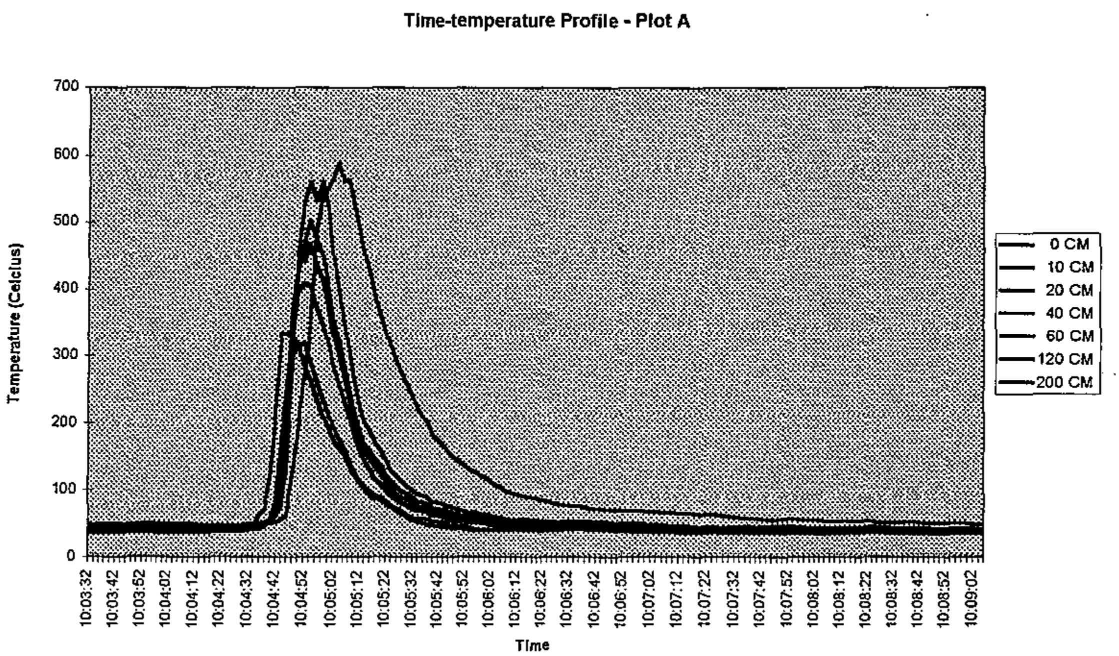


Figure 3.18 Fire time-temperature profile measured from a late dry season fire of high intensity.

p96 - 98 colour plates

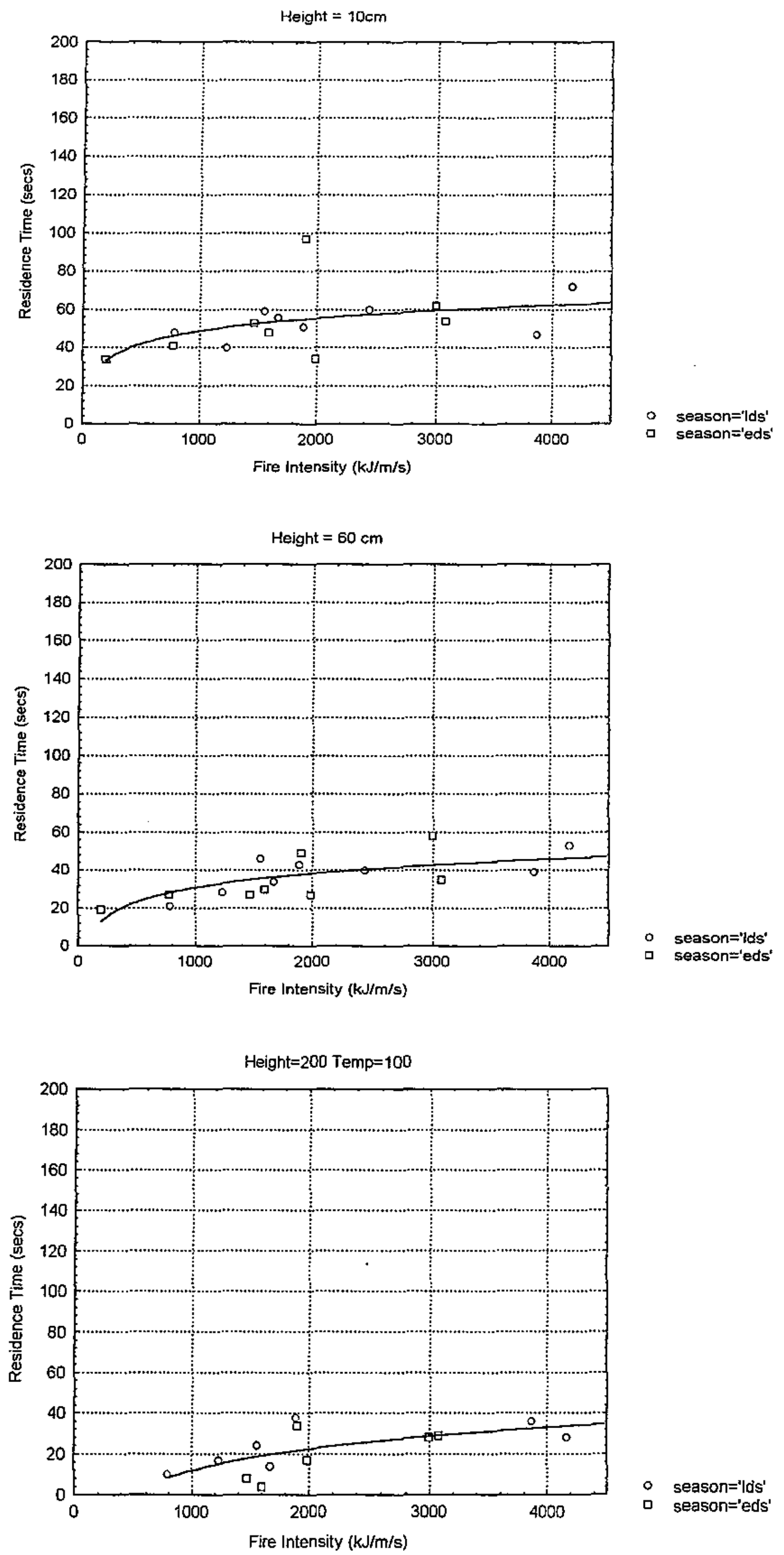
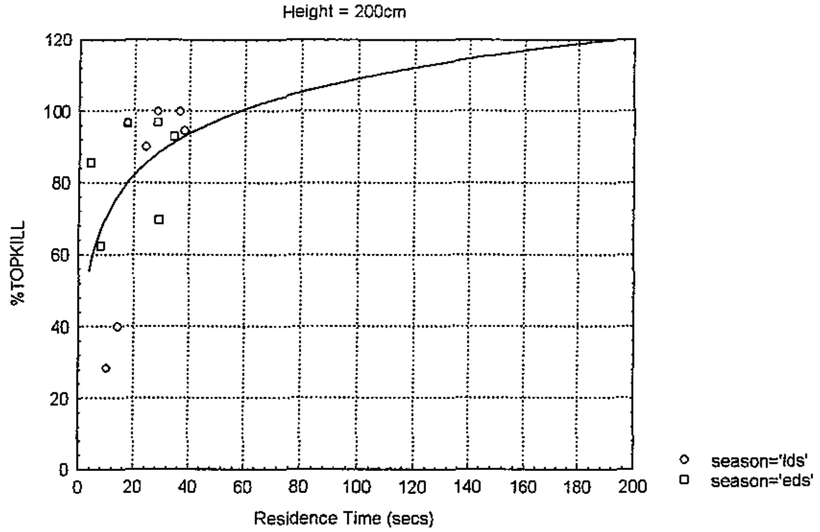
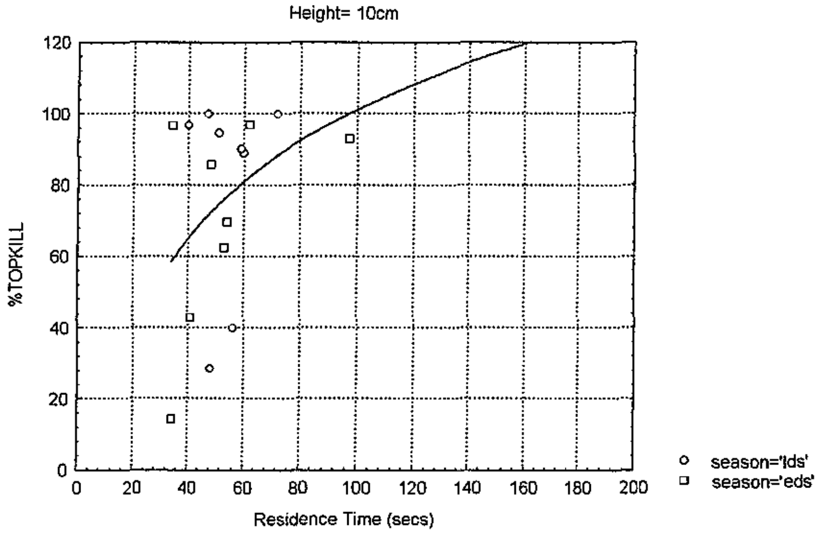


Figure 3.19 The relationship between fire intensity and fire residence time at 100°C





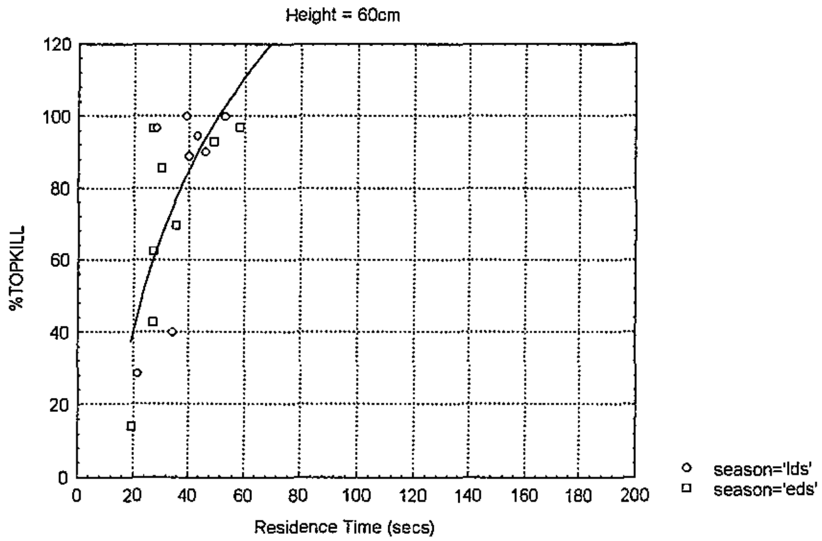


Figure 3.20 The relationship between fire residence time at 100°C and percentage plant top kill.

3.3.3 Fire season and frequency

Neither single burns, two burns on a biennial basis nor annual burning for three successive years, during either the early dry season or late dry season, weakened plant response or increased plant mortality.

Any woody plant response associated with season of burn is attributed to the higher intensity characteristic of late dry season burns and not associated with any physiological stage during that period. Therefore, there is no seasonal effect from fires of the same intensity.

Zero mortality rates from rosewood plants following annual and biennial burning over a three year period indicate that this species is well adapted to fire. The high fire frequencies during early and late dry seasons tested do not seem to weaken plant response, nor provide any advantage in control.

Sub-project 4

Local Best Practice for sustainable land management in the VRD

The Local Best Practice (LBP) process (Clark 1996) was used for three groups formed in the VRD and Sturt Plateau to document best practice land and cattle management as practiced by managers in 1995/6.

The process involved group meetings involving husbands and wives from stations on related land systems documenting the following :

- Land type descriptions including soils and vegetation.
- Opportunities and constraints for the sustainable use of the particular land types.
- Best practice management for each of the land types
- Best practice cattle management and grazing management
- Major issues for the district
- Actions required for learning and improving management of particular aspects or for removing constraints identified.

The groups were located in the NW VRD straddling the WA border, Central and Southern VRD and on the Sturt Plateau.

The groups were initially facilitated by Richard Clark, with assistance from Tom Stockwell, Blue Lewis, Tony Moran, Greg Scott and Bruno Hogan. Steve Petty and Sarah Strutt from AgWA participated in the NW VRD group.

The process effectively energised the group members, it being the first opportunity many of them had met in diverse groups to discuss management issues. The process in all instances developed a list of issues to be addressed through group activity, development of demonstration sites, organisation of seminars and field days etc.

In the Sturt Plateau instance, the group has remained very active, evolving into a "district association" and pushing for district developing while maintaining a focus on action learning. The other two groups have not persisted in the same form but many of the issues raised have been addressed through projects involving all or some of the group. The process has undoubtedly kick started an enthusiasm for learning and willingness to be involved in learning and group activities. The level of local district activities on a range of subjects has increased significantly since the commencement of the process and activities have been focused on stated group needs, held in the local environment and pitched at the appropriate level.

In all cases valuable information on land type descriptions, perceptions and experiences with land and cattle management as well as many social issues were expressed well in appropriate language.

The documents as such represent the first ever benchmark of practices at the district level and provide a good basis for ongoing learning and comparison at that level. They have also provided the government agencies with valuable resource material on which to better focus RD&E activities and programs to meet the needs of producers.
Copies of the three reports are attached.

Intellectual property

Not applicable

Data and information storage

All data, analyses and reports etc relating to this report are stored on a local area network at the NTDPIF, Katherine Research Station. Daily and weekly back-up copies are made of this network to ensure data safety. Hard copies of all information is also located at the same address.

References

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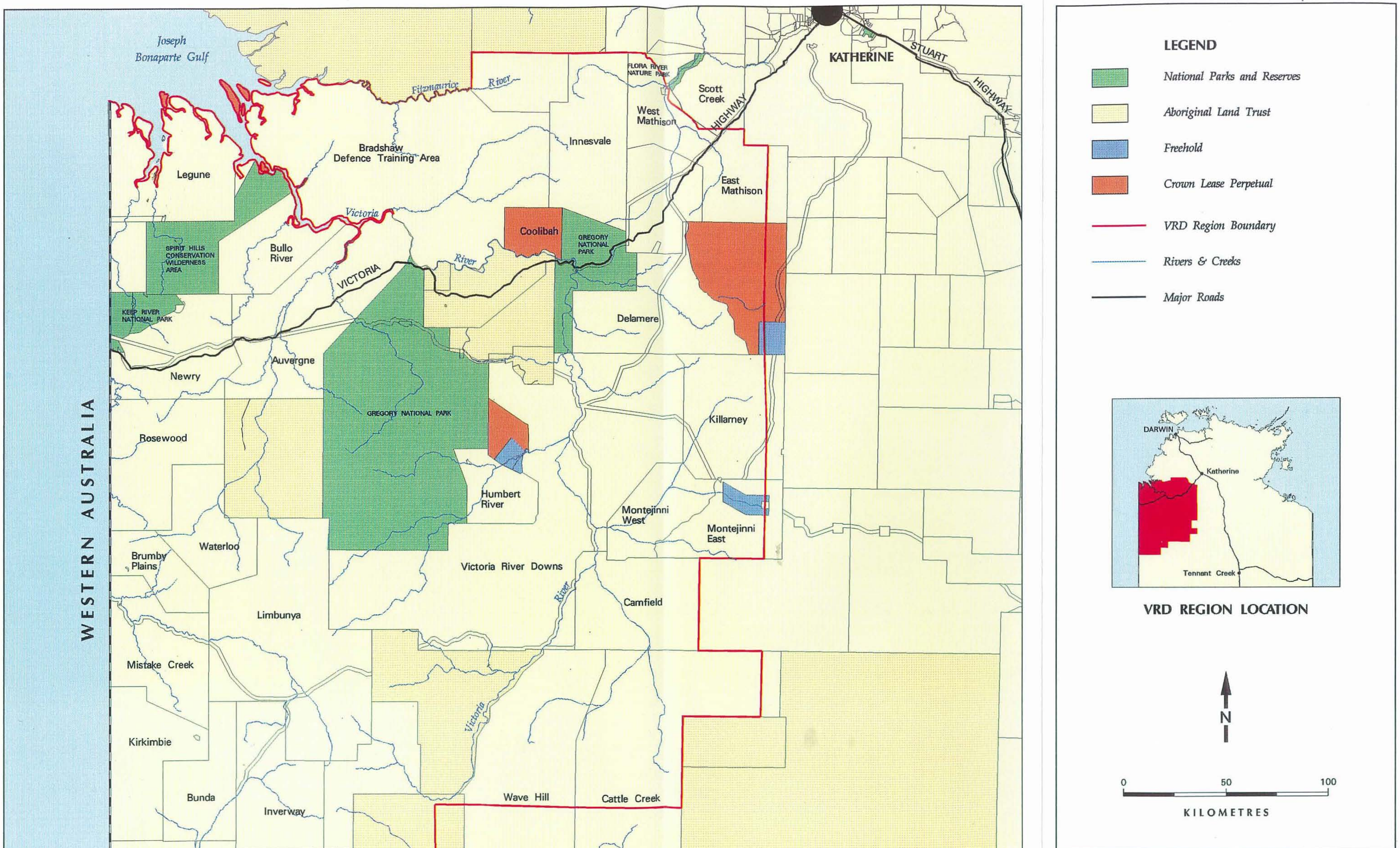
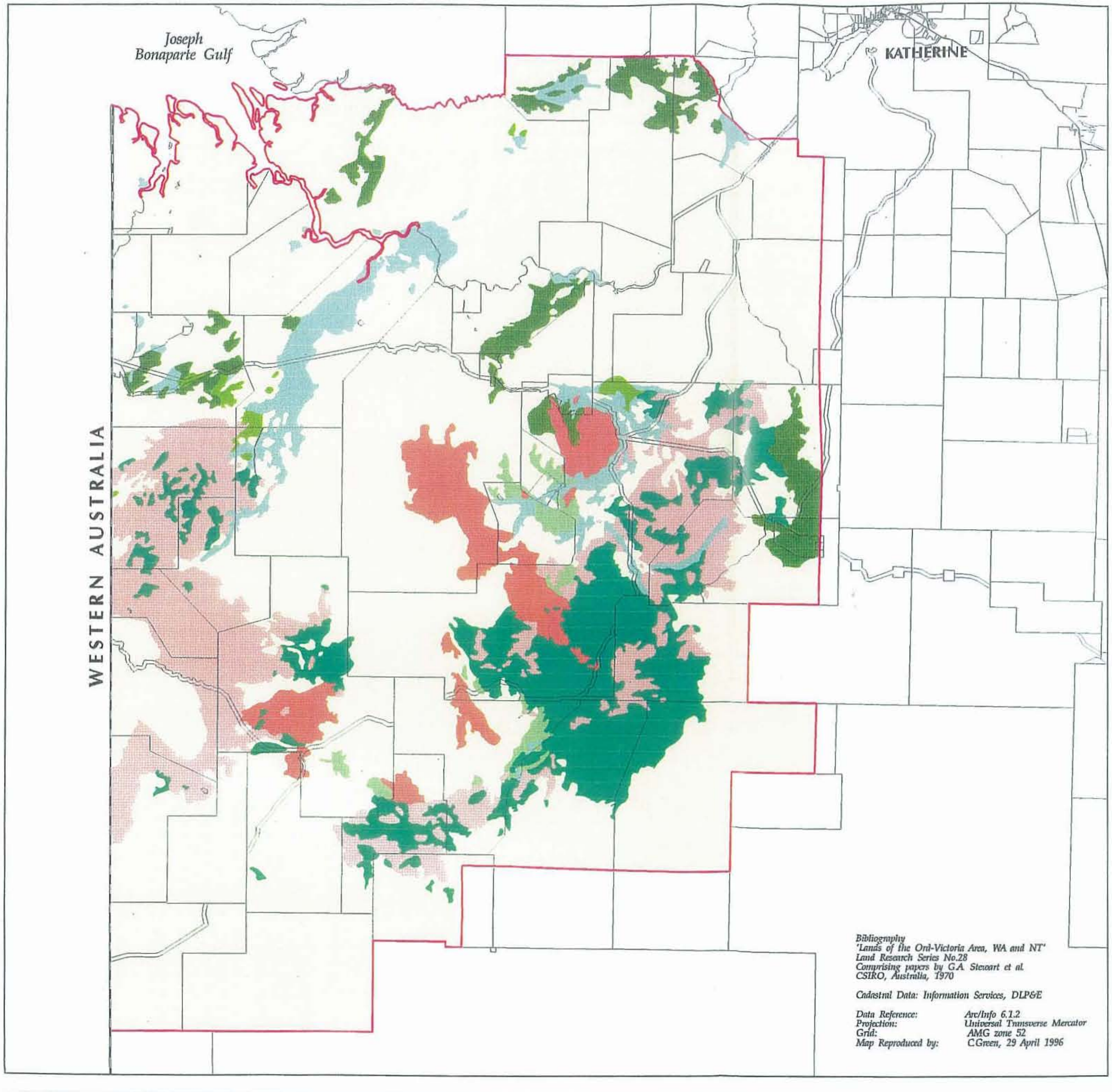


DEPARTMENT PRIMARY INDUSTRIES & FISHERIES

VICTORIA RIVER DISTRICT REGION

PROPERTY LOCATION PLAN

Map 1



LAND SYSTEM DESCRIPTION

Tippera tall grass plains

D Dinnabung (3964.7 km2)
Gently undulating plains on dolomites and shale; leached loamy soils with moderate limestone outcrop; northern box-bloodwood woodland over Tippera tall grass or upland tall grass. Rainfall 61-127cm

Arid short grass plains

Go Gordon (978.9 km2)
Undulating country on limestone & shale; shallow calcareous soils; bloodwood-southern box sparse low woodland over arid short grass. Rainfall 43-61cm

Mitchell & other grass plains

A Argyle (453.3 km2)
Undulating country on limestone & shale; cracking clays; Mitchell & other grasses. Rainfall 61-63.5cm

Wv Wave Hill (10485.3 km2)
Undulating basalt country; cracking clays; Mitchell and other grasses. Rainfall 40.6-63.5cm

Blue grass plains

Iv Ivanhoe (4212.0 km2)
Alluvial flood-plains; cracking clays with blue grass - tall grass. Rainfall 55.8-88.9cm

Hilly country with useful lowlands

An Antrim (11811.0 km2)
Mesas, buttes, rounded hills on basalt or dolerite; rock outcrops & boulders; northern box-bloodwood woodland over upland tall grass. Rainfall 40.6-68.5cm

Hu Humbert (4338.8 km2)
Ridges, hogbacks, cuestas, & structural plateaux on dolerite; rock outcrops & boulders; deciduous sparse low woodland over upland tall grass. Rainfall 43-68.5cm

all other land systems within the VRD Region

VRD Region Boundary

N

0 50 100

KILOMETRES

DEPARTMENT PRIMARY INDUSTRIES & FISHERIES

VICTORIA RIVER DISTRICT REGION

LAND SYSTEMS

Map 2