



Effects of Trees on Native Pasture Production

on the Southern Tablelands

**A report for the RIRDC/LWRRDC/FWPRDC
Joint Venture Agroforestry Program**

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Foreword

The Joint Venture Agroforestry Program is interested in promoting a broad range of agroforestry practices, including those that produce a single tree product and those that have multiple purposes involving a wider production and/or environmental benefit. These include the alleviation of salinity effects, shelter for stock, pasture and crops, and the provision of wildlife habitat and biodiversity conservation.

This project aimed to examine whether patches of remnant eucalypt woodland affect the quantity and quality of native pasture growth. The project was sited on the Southern Tablelands of NSW since they have extensive areas of native pastures, which are increasingly being seen as important, and there are large areas that are only partially cleared of tree cover. These landscapes lend themselves to the study of agricultural systems which are, in places, largely based on native species and have had limited pasture improvement. These systems may provide a model for sustainability, given the suggestion that sustainable agriculture may be achieved by mimicking natural ecosystems.

This study is one of the first to consider the effects of remnant tree patches on native pasture production. It examines their effects on pasture growth rates, pasture quality, soil properties and microclimate. The focus was on perennial native pasture growing underneath remnant eucalypts, in contrast to the RIRDC/LWRRDC National Windbreaks Program, which focussed on crops and planted windbreaks. Remnant tree cover is often more abundant than windbreaks, and so is possibly more important in terms of the effects of trees on farm productivity.

The results from this study are potentially relevant to many holdings on the Southern Tablelands and elsewhere by enabling landholders to better evaluate one of the trade-offs between tree clearance and retention. The report recommends a series of strategies for improving our understanding and management of these ecosystems.

RIRDC's involvement in this project and in the Joint Venture Agroforestry Program, is part of the Corporation's Agroforestry and Farm Trees R&D Program which aims to foster integration of sustainable and productive agroforestry within Australian farming systems.

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Peter Core

Managing Director

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About the authors

Dr David Williams is Senior Lecturer in Vegetation Ecology at the University of Canberra in the Applied Ecology Research Group. He has worked in a variety of locations on the regeneration ecology of shrubs and trees and more recently on the ACT's native grasslands. He is currently studying riparian and aquatic plant productivity and carbon transfers in lowland rivers as a member of the CRC for Freshwater Ecology. On this project he has been responsible for project management, data analysis and report preparation.

Paul Wallace has background training in agriculture and viticulture and a Bachelor's degree in resource and environmental science from the University of Canberra. On this project he has been primarily responsible for database development and custodianship, development of the survey plot component and data analysis. He is currently enrolled for the degree of Master of Applied Science (Resource Management) at the University of Canberra.

Mutjinde Katjiua worked on the initial phase of the project (fixed plots) for the degree of Master of Applied Science (Resource Management) at the University of Canberra. He had previously completed a Graduate Diploma in Environmental Management and Development (ANU) and is now a Lecturer in the Faculty of Agriculture and Natural Resources at the University of Namibia.

Dr Greg McKeon is Principal Research Scientist at the Queensland Department of Primary Industries. He is leading a team to develop a national drought alert based on modelling grass growth and consumption (GRASP). He has been responsible along with Wayne Hall for the GRASP modelling and critical review of the project as it developed.

Dr Nick Abel is a Principal Research Scientist at the CSIRO Division of Wildlife and Ecology. He has worked in Africa on modelling grass growth and consumption, livestock productivity, and studies of vegetation change induced by browsing and grazing. He is currently working on rangeland economic evaluation. He has been responsible for the initiation and earlier phases of the project.

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Executive summary

Background

The Rural Industries Research and Development Corporation (RIRDC) funded this project, under the Joint Venture Agroforestry Program. The Corporation contracted the Applied Ecology Research Group (University of Canberra) through David Williams, Nick Abel and Greg McKeon (Queensland DNR), to examine whether eucalypt open woodlands affect the quantity and quality of native pasture growth with possible consequences for stock. The project focussed on the Southern Tablelands of NSW as they have extensive native pastures, which are increasingly seen as important for production, and there are large areas that are partially cleared of tree cover.

The project complements the RIRDC/LWRRDC National Windbreaks Program, but was concerned with perennial native pasture growing underneath remnant eucalypt cover. The latter vegetation is more abundant than windbreaks, and therefore possibly more important in terms of the effects of trees on farm productivity. Results are potentially relevant to many holdings on the Southern Tablelands and elsewhere by enabling farmers to better evaluate the trade-offs between tree clearance and retention.

Aims

The specific aims of this two-year study were: -

- i) to quantify and model the effects of native trees on native pasture production, consumption, digestibility and nitrogen content;
- ii) to measure the microclimatic differences between stands of trees and adjacent more open sites so as to assess the likely effects of trees on pasture production; and
- iii) to infer the effects of trees on soil condition from current soil properties under trees and at adjacent open sites.

Key results and recommendations

The key and unexpected findings were that native pastures growing under a moderate tree cover: -

- i) had higher pasture productivity and hence produced more aboveground biomass than adjacent relatively open sites;
- ii) that the forage produced was at least comparable in quality; and
- iii) that this additional production was utilised by stock.

It appears from this study that a number of different processes contributed to the increased growth under tree cover. Factors such as microclimate, pasture composition, organic matter decomposition rates and soil moisture availability were all implicated to some degree. However, there may be others, such as nutrient accumulation, tree litter quality, precipitation interception and pasture history.

Given the desirability of achieving temperate pasture sustainability, particularly by planting deep-rooted perennial components, these findings imply that in some places at least, a diffuse tree cover will provide wider environmental benefits (groundwater interception, carbon

fixation, soil stability etc.) without compromising current levels of pasture production. With the knowledge that production need not necessarily be reduced, and even enhanced where tree cover is presently low, we might expect improved planning of properties and catchments to result.

Recommendation 1: RIRDC should support ecological research that determines the relative importance of the ecological processes that influence pasture production under moderate tree cover.

The specific environmental conditions on the Southern Tablelands for which these findings have been demonstrated were: -

- location on mid-slope positions on south-east to south-west aspects with a minimum soil depth of 0.7 m; and
- presence of an open tree canopy with a basal area of 9-14 m² ha⁻¹ for *Eucalyptus dives* — *E. mannifera* remnant woodlands and of ~20 m² ha⁻¹ in *E. pauciflora* woodlands at higher altitudes.

The extrapolation of the results to other locations will depend on a better understanding of the processes controlling pasture growth under trees and improved pasture growth models to cover climatic and spatial variation. The relative importance of the key ecological processes controlling pasture production is likely to change in different environments, but these results should be more widely applicable on the Southern Tablelands, at least to different slope positions and aspects within the tree cover parameters. They may also be applicable on the Northern Tablelands, on the Slopes and in some tropical environments.

The modelling of pasture growth in the open was highly successful, the model easily accounting for 78% of the variation in measured pasture production at these sites. However, preliminary modelling to include the trees as competitors for water and nitrogen was not as successful. The increased complexity involved in modelling treed pasture growth warrants a more detailed analysis than has been possible so far. Together with a better understanding of tree-pasture interactions (Recommendation 1), an improved capability to model grass quantity and quality in relation to tree density is highly desirable. Improved models would enable graziers to predict the effects of trees on production under a range of bioclimatic conditions and at paddock and farm scales. This will improve estimates of the net benefits to graziers of trees in the landscape.

Recommendation 2: RIRDC should support modelling research that fully incorporates tree-pasture interactions into native pasture growth models, so as to be able to better predict the effects of trees on production in a wide range of environments.

Since the open sites measured in this study were within several tree heights of tree-covered areas, they would be expected to have had a lower wind exposure and consequent yield advantage compared with fully exposed situations nearby. This underlines the importance of the present finding, for not only can windbreaks lead to increased growth, but here we have shown that a general tree cover may provide additional pasture production. However, there is a need for increased understanding and prediction of the broad-scale patterns of microclimate, especially ground conditions (grass and soil temperature, light regime, soil moisture) and precipitation interception, occurring in spatially dispersed tree cover. This is not equivalent to a system of multiple windbreaks, but is better considered as regional shelter combined with localised tree effects on pasture growth potential.

Recommendation 3: RIRDC should facilitate research that will provide tools for analysing and predicting the ground-level microclimate associated with diffuse widespread tree cover in various density and continuity patterns.

There was shown to be considerable small-scale variation in pasture composition, some of which was related to the presence of trees. Very little is known about how pasture growth and composition responds to the patchiness of an open tree canopy, but this is clearly important in understanding the tree-pasture dynamic. The manipulation of pasture composition in the presence of trees is also poorly understood, and management techniques need to be established for increasing the abundance of more nutritious, shade-tolerant native grass species such as *Microlaena*, and for decreasing the less palatable, large tussock species.

Recommendation 4: RIRDC should support research that determines the influence of tree cover on native pasture composition, and the means by which a desirable species mix under trees can be managed.

Once these tree-pasture interactions are better understood, there is an enhanced need for tree management to be integrated into normal farm planning and management operations. This will be required for the maintenance of an optimal density and spacing of trees of various sizes, as well as for managing the pasture composition.

Recommendation 5: RIRDC should support technology transfer that assists landholders to integrate the specific management of tree cover into farm operations.

Technical summary of methods and results

Methods

Two related field experimental designs were used. The first was based on comparisons between permanent paired plots at four sites near Bungendore NSW. One plot in each pair was under tree cover and the other was nearby in relatively, but not completely open conditions at several tree-heights distance from the edge of the treed area. The second experimental design used the same four sites, but had ten plots per site. These were chosen each time to represent the range of tree cover in these same paddocks, rather than a paired comparison of treed to open.

The precise measurement of pasture production, especially in mixed composition pastures under grazing, is notoriously difficult because of pasture variability. Comparing production between different environments, such as under trees and in the open, adds to the difficulty. To overcome this, we used 0.09 ha paired comparison plots inside, and next to, existing stands of trees. These stands had resulted partly from historical clearing patterns and any subsequent regeneration. From pasture mass measurements we estimated pasture productivity net of pasture decay, as is usual, and ensured good precision for pasture mass estimates on each plot. The number of sites we could measure was limited to four and, in order to make the study results more widely applicable, the four sites were at different locations, which inevitably meant they would have had differing history and management.

In each of these grazed plots we measured the pasture mass ($\equiv$ yield¹) on repeated occasions. Within each permanent plot we also measured pasture mass in short-term stock enclosure

¹ See glossary p. 83

cages so as to estimate the pasture production and consumption occurring in the grazed plots. We measured pasture quality and soil fertility properties at various intervals, and also recorded the ambient weather in half the plots with automatic weather stations. We applied the native pasture growth model GRASP, which is under active development by the Queensland DNR, to the data for pasture production and also used the model's options to explore some of the effects of trees on pasture growth.

Results

Overall the most important result concerning the pasture's growth characteristics was that pasture productivity under trees at the sites studied was significantly higher than adjacent in the open. Across five seasons it was on average 26% higher per unit land area. Pasture productivity was higher under trees when soil moisture was favourable in any season, but was the same as in the open in drier periods.

All of the increase in productivity occurred in the first three of the five seasons measured. There were approximately equal contributions to the increase from each of those three seasons, despite the mean productivity varying by a factor of three between these seasons. Maximum productivity was achieved in spring but the maximum differential effect (treed/open) was in winter. In short, tree cover increased productivity in any non-drought season and had the largest relative effect in winter.

The rate of pasture consumption was also significantly higher (26%) in treed compared with open plots. This indicated that the increased productivity under trees was being consumed (eaten and/or trampled) by grazing animals. Relative consumption levels, between treed and open, were less consistent than was shown by the production estimates, with the largest differences being in the first spring and winter of the study.

The herbage mass in these grazed pastures did not show an overall statistical difference between treed and open plots. This probably arose from the similar increase in both productivity and consumption under the trees. Pasture mass reached a peak in summer and was at a minimum in late winter. However, little can be concluded from the level of pasture mass present in perennial grazed pastures, since it represents the resultant of both production and consumption. Of necessity, these have been considered separately in order to better understand pasture growth dynamics.

The comparison of climatic features between the treed and open plots revealed that slightly higher air temperatures (minimum, maximum and mean, measured at 1.5 m) prevailed under trees. As expected, wind speeds and solar radiation were considerably lower under trees, by approximately 30% and 45% respectively in these sites, this in turn leading to much lower calculated evapotranspiration.

The surface soil horizons under trees tended to have slightly higher levels of organic matter, nitrogen and phosphorus, and in the fixed plots some of these differences were statistically significant. Soil pH was significantly lower under trees in the fixed comparison plots, but the difference was slight (0.2 units). However, when surveyed across whole paddocks, there was no relationship between soil variables (pH, organic matter, total N, available P) and the tree basal area (TBA). This apparent contradiction in results could arise simply from the greater extent of uncontrolled environmental variation in the survey plots, which were not paired. The quantity of fine leaf litter under trees ($\sim 1.5 \text{ t ha}^{-1}$) did not appear to have a large effect on soil organic matter content and acidity, but mineralisation rates could be higher under trees, thus providing more nitrogen for pasture growth. Differences in surface and deeper (15-45 cm) soil moisture under trees and in the open were small (not significant), although data were limited.

Analysis of the pasture composition in the fixed plots showed no differences in the total number of pasture species between plots under trees and in the open. Pasture composition at a fine scale was variable, but again, not consistently different between treed and open situations at these sites. These results suggested that reduced light levels under trees were not limiting the range of species that can grow in these sites. *Microlaena stipoides* in particular was not consistently preferential in this study. These and other results demonstrated that there is a suite of grass species which are well distributed in these pastures and capable of increasing their abundance wherever favourable micro-site conditions develop.

Nitrogen content of the bulk pasture, as an indicator of protein content, tended to be slightly higher where tree cover was present, and was significantly higher under trees at one site. *Microlaena stipoides* had the highest nitrogen content, followed by *Themeda australis*, *Poa sieberiana* and *Danthonia* species. Pasture quality (as digestibility) was measured in three seasons for both bulk samples of the pasture and for major species, but showed no consistent effect with variation in tree basal area.

The pasture growth model was able to explain 78% of observed variation in pasture mass for ungrazed plots in the open, using only a minimal re-calibration of pasture growth and leaf detachment rates. This is similar to the level of variation explained in other studies of this type and confirms the suitability of the model for temperate pasture growth in the open.

However, GRASP predicted about 30% less pasture production than was actually measured in the treed plots, when trees were included in the simulation as water and nitrogen resource competitors. Further modifications to the model parameters, to allow for higher potential pasture growth and lower leaf detachment rates in treed plots, did not satisfactorily explain as much variation as was achieved with the simulation in open plots. It appeared that the mechanisms of tree-pasture competition in the model, combined with the adjustments for different potential growth rates under trees, do not account for the increased production found in the field. Further work is required to examine other factors such as the extent of use of deep water by trees, pasture stimulation via increased diffuse radiation, frost protection, nutrient availability and reduced evaporation demand.

1. Introduction

1.1 Trees in native pastures

Until the late 1980s, native pastures had been largely dismissed as offering useful pasture production, and had been, as a result, widely replaced by the introduced, high-yielding grasses (Jones 1996). The increasing problem of the acidification of soils under these improved pastures, falling wool prices and drought, failure of improved pastures, among other concerns, have all contributed to a revived interest in the management and use of native pastures (Jones 1996, Lodge & Whalley 1989, Roberts 1990, Wilson & Simpson 1993).

Rural landholders are being encouraged to plant trees or promote natural regeneration in order to diversify farm income sources, increase incomes, maintain biodiversity, increase timber supply and solve other environmental problems (Prinsley 1991). The expected benefits have mainly been estimated, with direct experimental support being limited (Loane 1991). A major reason for planting is the control of dryland salinity. Planting for this has been recommended on groundwater recharge areas - hill and ridge tops, and south-facing slopes. Such areas on the Southern Tablelands are often sites where native pasture grasses prevail, and surveys in the Goulburn district have shown such pastures had a stocking rate which was, on average, 80% of the rate of improved pastures (Munnich *et al.* 1991).

The values of native grasses as summer and drought fodder are becoming better recognised. Trees at higher densities are seen to generally suppress grass growth directly under the crown (a major reason for clearance). But they may affect seasonality of pasture growth and pasture quality in a positive way, both under the canopy and at some distance out into the open via a variety of ecological interactions. Trees also provide shelter to soils, plants and livestock (Bird *et al.* 1992) and so reduce lamb mortality and promote weight gain (Bird *et al.* 1984), while increasing soil organic matter and sometimes nitrogen content.

1.2 Tree–pasture ecological interactions

Developing from numerous studies in many environments across the globe, the tenets of agroforestry investigation are just beginning to be integrated to form a central hypothesis for further refinement of the biophysical questions and to guide management (Sanchez 1995, Cannell *et al.* 1996). However there is much still to be learnt. For example, a recent review of research on tree windbreaks and shelter benefits to pasture in temperate systems (Bird 1998), found only three Australasian studies in the last 25 years worth reporting. All three studies were limited experimentally. One measured a single windbreak, another measured pasture production with just two exclosure cages, and the third attributed sheep liveweight gain to increased pasture production but did not actually measure such production.

Evidence from Queensland shows that in tropical and sub-tropical pastures trees and shrubs inhibit grass growth mainly through competition for water (Scanlan 1992). Nitrogen availability and temperature may be more important limiting factors in the temperate climate of the Southern Tablelands (Fitzpatrick and Nix 1970), so that the tropical and sub-tropical results cannot be applied directly to the Southern Tablelands without recalibration.

Trees reduce the quantity of grass produced on the Northern Tablelands, and may also affect quality and seasonality of growth by promoting a switch in species composition of grasses from C4 to C3 types (Lodge and Whalley 1989). Individual *Eucalyptus melliodora* (Yellow Box) trees were shown to affect the season of pasture growth near Bungendore on the Southern Tablelands (Rehwinkel 1994).

Trees may improve soil fertility (Ingram 1990, Young 1989). Surface return of leached nutrients by deep roots, litter fall and capture of windblown nutrients and rain can be important fluxes in this process. Eucalypt canopies shed litter and insect frass copiously, and significant quantities of nutrients are returned to the soil thereby (Lamb 1985, O'Connell 1987, Ward *et al.* 1991). Soils under a variety of tree species are often higher in nitrogen, phosphorus and other nutrients (Tiedemann & Klemmedson 1973, Everett *et al.* 1986, Belsky *et al.* 1993, Dowling *et al.* 1986). This was reflected in the relatively high quality of grasses found under large isolated Yellow Box on the Tablelands by Rehwinkel (1994).

Trees returning leached calcium (Borough 1990) can affect soil pH. However, Ryan and McGarity (1983) found that pH decreased under *Eucalyptus grandis* canopies, so the reaction may be dependent on tree species. The issue is clearly significant for production, as Munnich *et al.* (1991) found that the frequency of the nutritious and palatable native grass *Microlaena stipoides* increased with lower soil pH.

The microclimatic effects of shelterbelts have been extensively studied (see reviews in *Agriculture, Ecosystems and Environment* **22/23** 1988 and *Agroforestry Systems* **41** 1998). The effects of shelterbelts in reducing lamb mortality are well established (Bird *et al.* 1984). The effects of trees growing in other configurations, for example trees planted for salinity control on a broadacre basis, are less well known.

This project is relevant to the aims of the RIRDC/LWRRDC National Windbreaks Program (see Prinsley 1998), however, it differed in several important ways. The windbreak considered here was a general tree cover and the pasture was its understorey. Moreover both the trees and pasture were predominantly native at the site level. This general tree cover is often more abundant in the landscape than planted windbreaks, and therefore has the potential to be more important in terms of the effects of trees on farm productivity. Remnant tree cover in native pasture differs in its spatial pattern from that of windbreaks and the common agroforestry designs (see Bird 1993). Being generally more open canopied and dispersed over the landscape, there is likely to be a different net balance of the tree-pasture interactions in such a system compared with a classic windbreak-based system.

1.3 Objectives

The project aimed to estimate some of the costs and/or benefits to graziers of native pasture production in sites where there is a remnant tree cover which was not of direct value itself. This has implications for maintaining native tree cover or promoting natural revegetation on hill slopes. The aim was addressed by determining the effects of tree cover on climate, soil and pasture quality and pasture production and consumption.

Three main aims were established: -

1. to measure the microclimatic differences between stands of trees and adjacent more open sites so as to assess the likely effects of trees on production;
2. to infer the effects of trees on soil condition from current soil properties; and
3. to quantify and model the effects of native trees on annual production, seasonal growth, digestibility and nitrogen content of native pasture.

2. Methods

2.1 Experimental Design

The possible designs for appropriate experiments on catchment- and landscape-scale issues such as tree effects on pasture have inherent constraints. Three approaches were considered and a non-manipulative one (No.3, **Table 1**) was adopted for this study because of the short time span and the resources available.

Table 1 Possible experimental designs for tree-pasture interaction studies.

Approach	Advantages	Disadvantages
1. Differentially plant up a uniform area to trees and measure effects on pasture over time.	Initial site uniformity can be thoroughly checked. Some results apparent in a few years.	High setup cost. Long time to establish mature tree cover and “equilibrium” with soil conditions and pasture composition.
2. Differentially clear a uniform area and measure responses over time.	Initial site uniformity can be thoroughly checked. Some responses will be almost immediate.	High setup cost. Some responses medium to long term, such as tree root decay and pasture change.
3. Compare existing treed and historically cleared open sites chosen to be as similar as possible in other respects.	Long-term equilibrium conditions of trees, soils and pastures presumably reached. Lower cost. Data from just a few years should detect any major differences.	Lack of comparable sites because historic tree clearance may have been on better quality sites. Less than ideal control of tree layout factor.

Two inter-related survey designs were used as the basis for this study. The first design (Fixed Plots), was based on comparisons between pairs of permanent plots, one placed in the open and one under adjacent trees. This paired arrangement was repeated at four different locations or blocks and these plots were measured over two years. This design of *randomized complete blocks* is especially useful in environmental research because it helps to control for the considerable environmental heterogeneity found in field-based experiments at larger spatial scales. Ideally one has replicates within blocks, but this was not possible in this study. For statistical analysis of this design we can test for the effects of the treatment, but not of the blocks (= sites). In fact the interpretation of the block (site) effect is secondary to the main aim of testing the treatment effect (treed vs. open). In other words, we accept there will be differences between the sites, and what is of more interest is whether there are consistent effects of the treatment (tree cover) across sites. With this design we measured pasture yield, production and consumption, as well as soil conditions and microclimate. Two-way analysis of variance (ANOVA) and repeated-measures ANOVA were the main statistical methods used here.

The second design (Survey Plots) grew out of experience with the first year’s results and entailed ten subjectively selected plots being laid out in various locations within the paddock containing the fixed plot. These were selected (each time) to represent the range of tree basal area within that paddock. Using this design in the second season, we measured the pasture mass and soil properties in each of the four paddocks using the same methods as for the fixed plots. We were able to relate these directly to tree basal area using regression analyses.

The fixed plots were selected such that they were as similar as possible in soil texture, soil depth, aspect and position on the slope. One of the plots was placed under trees (*Eucalyptus* open woodland) and the other in the open, but adjacent to the trees on the more exposed aspect. The tree cover varied generally in density and extent across each paddock, but each treed plot was chosen to be as homogeneous as possible. Four sites on grazing properties were selected, two in snowgum woodlands and two in box woodlands. Field sampling was done

from August 1995 to May 1997. The rectangular fixed plots were 900 m² in area. The distance between the treed and open plot at a site was about 50 m and the distance of the open plot from trees averaged 25 m.

For the survey plots, 20 x 20 m plots were selected without replacement on each occasion to represent the range of tree basal area in the paddock. At each time, ten plots were measured across the paddock. Obvious sheep camps were avoided, as well as *Acacia* thickets.

2.2 Site Descriptions

Physiography

After assessing many possible sites in the area using augers to check soil profiles, four locations were chosen which contained a patchwork of wooded and open native pastures, were of generally southerly aspect and had at least 70 cm soil depth (see **Table 2**).

All four sites were located in the vicinity of Bungendore, approximately 50 km by road east of Canberra (**Figure 1**). This area was chosen as being sufficiently representative of much of the native pasture grazing land of the Southern Tablelands, with the exception of the basalt soil areas of the southern Monaro district.

The sites can be placed into two groups:

1. lower altitude box woodland over sedimentary rocks (M1 and M2 sites) and;
2. higher altitude snow gum woodland on granite and volcanic rock types (VE and VW sites).

Further comparisons of these sites are contained in the following sections.

Within each site paddock the fixed plot pairs were located at lower to mid-slope positions with the open plot generally to the westerly, more exposed side of the treed plot. **Table 3** shows the general features of the fixed plots. Tree basal area, based on diameter at 1.3 m, ranged from 10 to 20 m² ha⁻¹, whilst tree stem density varied much more. The M1 site had a high density of small stems (**Figure 2**), indicating a more recent regeneration event. The basal area of trees in the paddocks in which the plots were located varied from zero up to 37 m² ha⁻¹, as determined in the 20 m square survey plots.

Table 2 Physiographic features of the paddocks containing the fixed plots.

Feature	“McRoberts” (M1)	“Millpost” (M2)	“Valley” East (VE)	“Valley” West (VW)
Altitude range (m)	730-760	815-860	820 – 970	810 – 960
Relief type	Rolling	Rolling	Hills	Hills
Predominant aspects	NE, E, S	SE, S	S, SW	E, SE, S
Lithology	sedimentary, aeolian and igneous	sedimentary	granitic & volcanic colluvium	granitic & volcanic colluvium
Paddock area (ha)	~10	102	165	40
Maximum tree basal area (m ² ha ⁻¹)	17	33	32	37
Latitude S	35° 15.059'	35° 18.160'	35° 18.577'	35° 18.577'
Longitude E	149° 31.773'	149° 21.927'	149° 31.766'	149° 30.078'

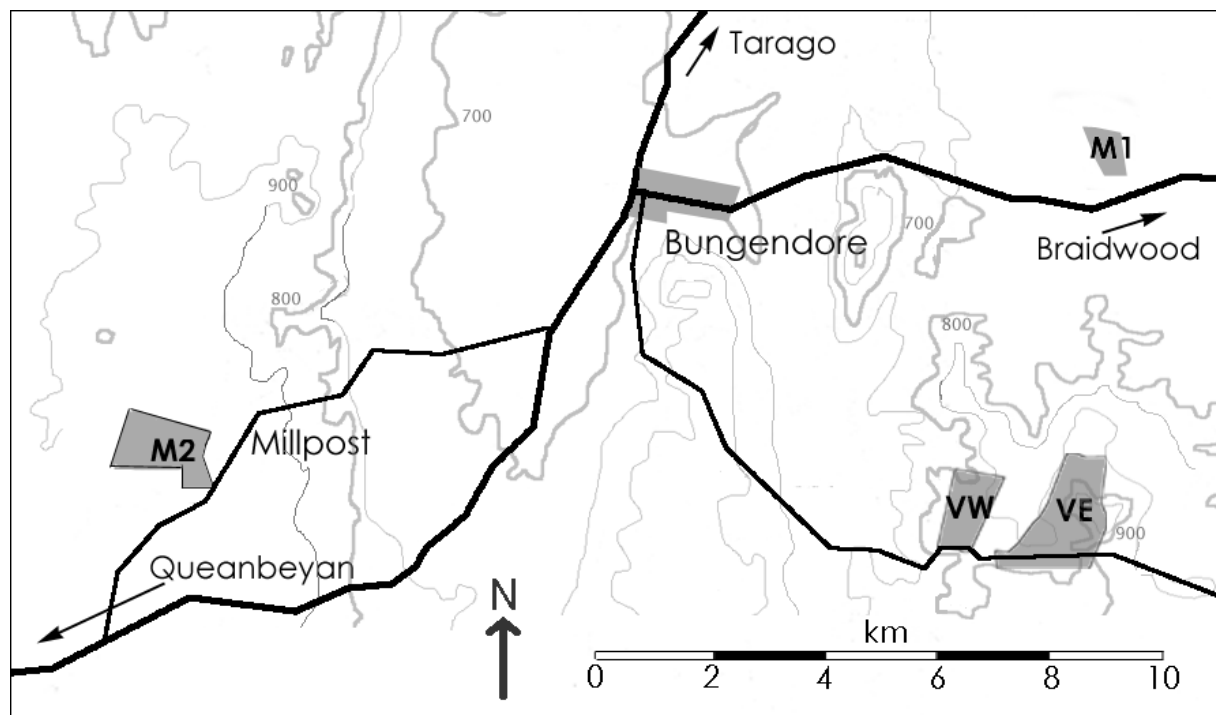


Figure 1 Site locations indicating approximate size of the sample paddocks and the site code names (refer **Table 2** for site descriptions).

Table 3 Physiographic and tree cover features at the fixed plots.

Feature	“McRoberts” (M1)	“Millpost” (M2)	“Valley” East (VE)	“Valley” West (VW)
Altitude (m ASL)	750	870	920	900
Slope (%)	10	18	26	27
Aspect	South	South-east	South-west	South-east
Tree stem density (ha ⁻¹)	1289	278	144	444
Tree basal area (m ² ha ⁻¹)	9.1	13.7	20.0	19.2
Dominant trees	<i>E. dives</i> <i>E. mannifera</i>	<i>E. mannifera</i> <i>E. dives</i> <i>E. melliodora</i> <i>E. bridgesiana</i>	<i>E. pauciflora</i>	<i>E. pauciflora</i>

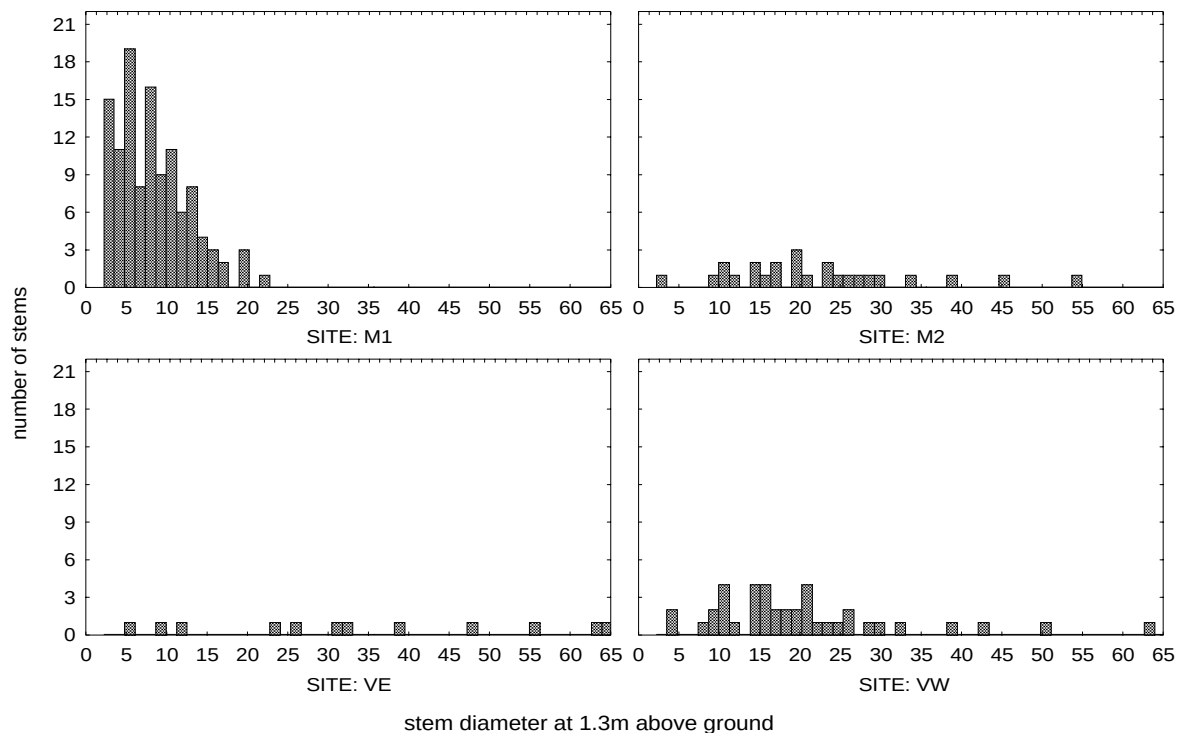


Figure 2 Frequency histograms of eucalypt stem diameter in each of the treed fixed plots.

Lithology and soils

Whilst soil depth varied considerably across the sites, the plots at each site were located such that they had a minimum soil depth of 70 cm. Augers were used to assess soil depth at 6-12 points in every plot. About 80% of all the auger tests hit rock fragments before 70 cm. The remaining 20% (range 6-27%) of tests recorded a profile deeper than 70 cm. Field observations suggested the granite soils were deeper than the sedimentary profiles.

Where the underlying geology was granitic or volcanic (VE & VW), soil depths determined with an auger were generally shallow on the upper slopes (< 50 cm) with frequent rock outcrops, and deeper (> 70 cm) on the lower slopes. Gravel and stones were common in the upper horizons indicating colluvial origins. Dolerite intrusions occur on both these sites and plots and fragments of both rock types sometimes occurred together in the same profile.

The site at M1 was on sedimentary rock and had soils derived from metamorphosed shale (phyllite) which were generally shallow (< 50 cm) with considerable areas of rock outcrops, and some quartz felspar (aplite) intrusions. Soils were derived from the sedimentary material with evidence of some aeolian deposition of sediments from nearby Lake George.

At the M2 site the underlying rock was inter-bedded shale and sandstone with the latter outcropping in many places. Soils were derived largely from the shale component of the rock (K. McQueen *pers. comm.*). Where present, the A horizon was dark and fairly high in organic matter, the underlying horizons being comprised of a grey clay tending to orange with depth. Frequently no bottom was found with a 70 cm auger, though at this depth fragments of rock were evident.

The underlying geology of the remaining two sites, VE and VW, was granitic with some dolerite intrusions around the fixed sites, in particular the open site at VW, although dolerite was present at VE as well. Soil depths determined with an auger were generally shallow on

the upper slopes (< 50 cm) with frequent rock outcrops, and deeper (> 70 cm) on the lower slopes. They had a well-defined A horizon of around 20 cm depth, with a yellow/orange B horizon of moderately high clay content tending to gravel at greater depths. Some heavy grey clay was found at around 70 cm.

Climate

The nearest long-record official weather station is located about 16 km from site M2 at the Canberra Airport in the Majura Valley. The airport is situated at an altitude of 580 m on a cold-air drainage natural grassland plain, whilst the study sites are 170 to 340 m higher in altitude. However, comparisons based on monthly means suggest broadly similar weather patterns (**Figure 3** to **Figure 5**). The total monthly rainfall was above average in January, May, October and November of 1995 and the total monthly rainfall in January 1995 (prior to this study) was the highest (218.4 mm) monthly rainfall ever recorded in Canberra. Climatic data collected during 1996 at two of the study sites are summarised in **Table 4** along with corresponding values for Canberra Airport.

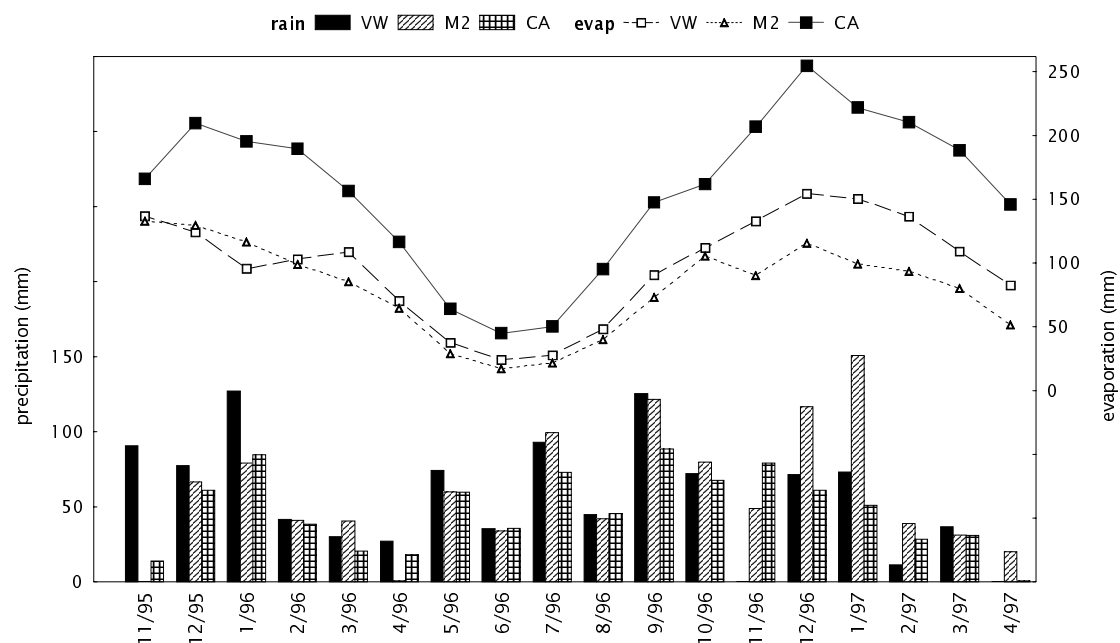


Figure 3 Monthly total rainfall and mean monthly potential evaporation for the study period at M2, VW and Canberra Airport (Source: Bureau of Meteorology).

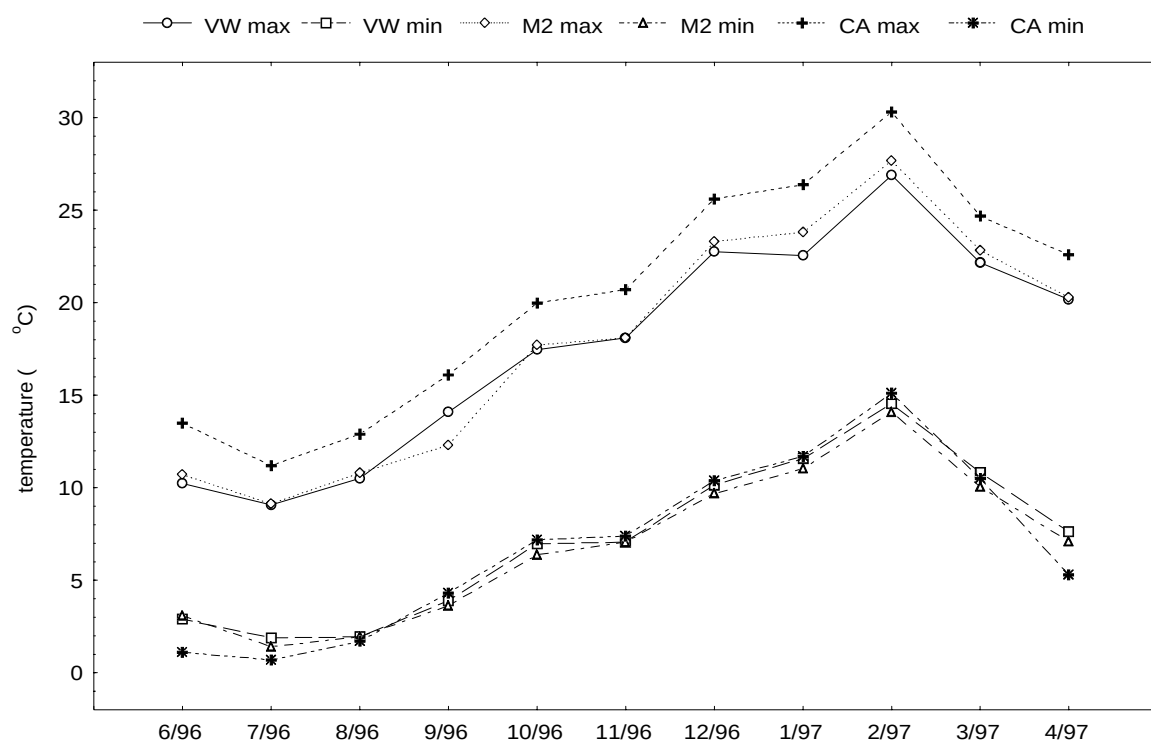


Figure 4 Average monthly maximum and minimum temperature for M2 and VW and at Canberra Airport (Source: Bureau of Meteorology).

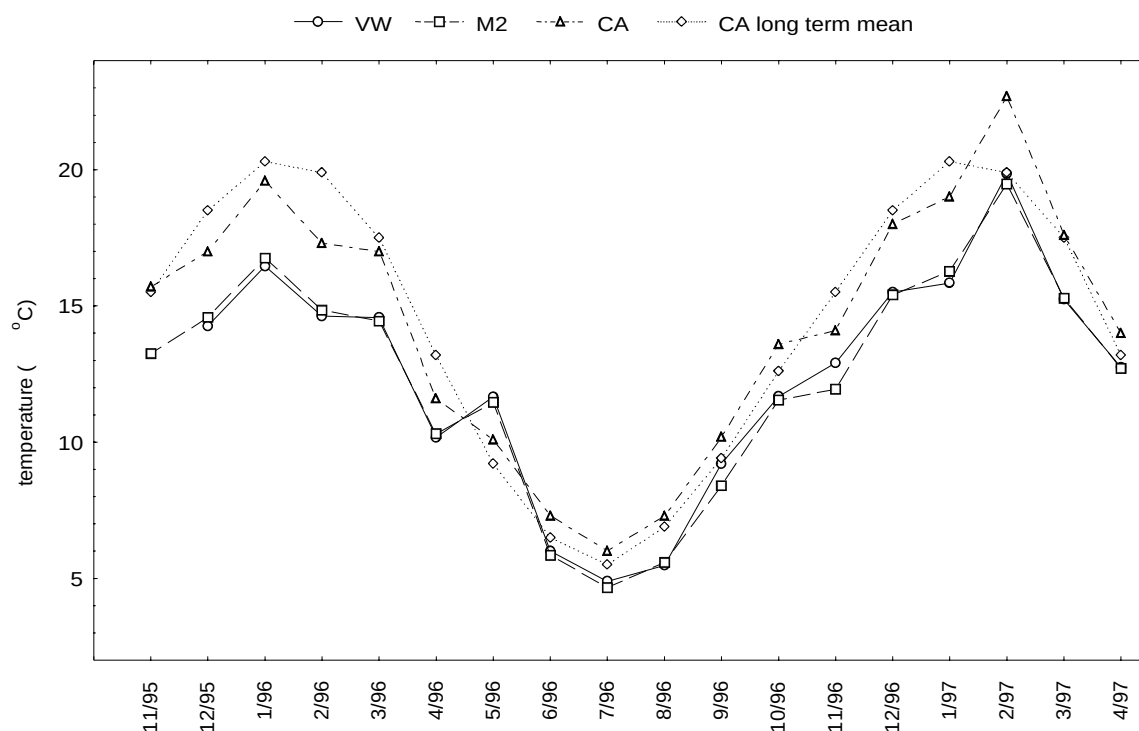


Figure 5 Mean temperature for M2, VW and Canberra Airport during the study period compared with the Canberra Airport long-term mean.

Table 4 Annual weather summary for M2 and VW sites in 1996 compared with Canberra Airport long-term average (Source Bureau of Meteorology).

Climate variable	M2	VW	Canberra Airport
Precipitation (mm)	764	745	631
Penman evaporation (mm)	782	980	1686 (pan evap'n.)
Wind run (km day ⁻¹)	129	217	203
Solar radiation (MJ day ⁻¹)	12	14	n.a.

Pasture composition

In general the pastures were similar at all sites in that they all had the major native sward species present, but they varied in the relative amounts of these species as well as the size of the annual component. The M1 and M2 sites were predominantly *Themeda* and *Danthonia* whilst the VE and VW sites were dominated by *Microlaena*, *Themeda* and *Poa* spp. More detailed descriptions of each site follow.

M1 pasture

Themeda australis and *Microlaena stipoides* were the most abundant grass species with *Danthonia* and *Poa* spp. making up the bulk of the remaining pasture mass. Forbs contributed < 2% of the pasture mass, and although it was a very minor constituent, lichens were frequently evident on bare patches between grass plants.

M2 pasture

Open areas were dominated by *Themeda australis*, which forms a monoculture, but under trees *Chionochloa pallida*, *Poa* spp., *Danthonia* spp., *Microlaena stipoides* and *Elymus scaber* were the most common grasses observed. The observed C3 to C4 ratio was 1:2, with forbs comprising less than 2% of the pasture mass.

VE pasture

Native grass species occurring on this site were mainly cool-season C3 species such as *Microlaena stipoides*, *Poa sieberiana*, *P. labillardieri* and *Danthonia* spp., comprising about 55% of the herbage mass. The C4 species *Themeda australis* and *Bothriochloa macra*, contributing about 20% of the biomass, occurred in the more open parts of the paddock.

Exotic annual and perennial grasses (mostly *Vulpia* spp., *Holcus lanatus*, *Bromus* spp. and *Lolium* spp.) were common, making up some 17% of the herbage mass during the early summer, decreasing later in the season following the death of the annual component. The remainder comprised forbs, with *Trifolium subterraneum*, *T. repens*, *Glycine tabacina*, *Acaena* sp. and *Hypochoeris radicata* being the most abundant.

VW pasture

The pasture here contained more *Poa* spp. and less *Themeda*, with the ratio of C3 to C4 grasses consequently being of the order of 7:1. Again the low-lying ground was dominated by *Poa labillardieri* and the high ground was used as a sheep camp. *Stipa* spp. dominated in small areas, usually on exposed stony areas and made up about 7% of the biomass sampled. Forbs were mainly *Glycine tabacina*, *Dichondra* sp. and *Trifolium* spp. and constituted about the same percentage of the pasture as in VE. *Microlaena stipoides* was very abundant over large sections of the paddock.

Table 5 General species composition of the pasture at the sites.

Species group	“McRoberts” (M1)	“Millpost” (M2)	“Valley” East (VE)	“Valley” West (VW)
Dominant spp.	<i>Themeda</i> , <i>Microlaena</i>	Open areas dominated by <i>Themeda</i> . Under trees are <i>Chionochloa pallida</i> , <i>Poa</i> spp., <i>Danthonia</i> spp., <i>Microlaena</i> and <i>Elymus scaber</i> .	<i>Microlaena stipoides</i> , <i>Poa sieberiana</i> , <i>P. labillardieri</i> and <i>Danthonia</i> spp. More open parts with <i>Themeda</i> & <i>Bothriochloa</i> .	<i>Microlaena</i> , <i>Poa</i> spp. <i>Themeda</i> , <i>Bothriochloa</i> Low-lying ground dominated by <i>Poa labillardieri</i> .
Minor spp.	<i>Danthonia</i> <i>Poa</i> spp. <i>Nassella</i> Forbs contribute < 2% of the herbage mass	Forbs contribute < 2% of the herbage mass	<i>Trifolium subterraneum</i> , <i>T. repens</i> , <i>Glycine tabacina</i> , <i>Acaena</i> sp. and <i>Hypochoeris radicata</i> .	<i>Stipa</i> spp. dominate in small areas. Forbs are mainly <i>Glycine tabacina</i> , <i>Dichondra</i> sp. and <i>Trifolium</i> spp.
C3/C4 species (mass ratio)	2:1	1:2	4:1	7:1

Management history

“McRoberts” (M1)

This paddock is subject to heavy grazing pressure from sheep, cattle and horses and consequently herbage mass is frequently low. Woodland has been allowed to regenerate over a few hectares on a southern slope of the area (**Figure 6**), which is otherwise almost clear of trees. The fertiliser history of the paddock is uncertain, although it is believed that several small (i.e. < 100 kg ha⁻¹) applications of superphosphate have been made to some sections.

An infestation of *Nassella trichotoma* covers about 10% of the paddock, and disturbance caused by efforts to control it is considerable. This species was not considered when calculating herbage mass and species distributions as it is considered a management effect rather than a result of tree cover. Therefore infested sections of the site were avoided as much as possible during sampling.



Figure 6 View of open part of paddock at site M1. Groups of young trees showing in the middle distance are mostly *E. dives* and *E. mannifera*.

“Millpost” (M2)

Situated about 12 km to the west of VW, the paddock has been almost totally cleared in the early part of this century (probably 1915). It was re-cleared in the 1930s with only a few trees left. Since then, regrowth of woodland tree species has not been inhibited, resulting in a heterogeneous distribution of blocks of regrowth and open grassland (**Figure 7, Figure 8**). Sheep and kangaroos graze the paddock, the former being removed for most of the winter. It has apparently had little fertiliser applied, only about 100 kg ha⁻¹ of superphosphate having been applied to a small area that was not sampled during this project.

Diversity of tree species was higher than that of any of the other sites and included *Eucalyptus mannifera*, *E. dives*, *E. melliodora*, *E. macrorhyncha*, *E. blakelyi*, and *E. bridgesiana*. *Acacia dealbata* and *Lissanthe strigosa* were common shrubs. *Juncus* spp. and *Drosera auriculata* occurred frequently on the poorly drained lower slopes.

“The Valley” (VE and VW)

These two sites are subject to similar management strategies of stocking by sheep and cattle at rotational intervals of about 30 days (B. Crozier *pers. comm.*). Their carrying capacity is estimated by the owner to be about 5 dry sheep equivalents (DSE) per hectare. Both sites have received additions of superphosphate. These were of the order of 1 t ha⁻¹ and were applied at the rate of 100 kg ha⁻¹ yr⁻¹ during the 1970s. The VW site received a further 100 kg ha⁻¹ in 1989. No pasture improvement has been carried out. Both sites were substantially cleared in the 1930s, the current woodland blocks are predominantly regrowth that has occurred over about the past thirty years (**Figure 9, Figure 10**). The remainder comprises large remnant trees, often around granite tors.



Figure 7 View of edge of treed area at site M2. Trees are mostly *E. melliodora*, *E. dives* and *E. mannifera*.



Figure 8 General view of site M2 from above the fixed plots. Remnants of earlier clearing visible in the foreground and typical regrowth in the middle distance.



Figure 9 General view of site VE, looking across valley to the fixed plot location (open plot on the left obscured by trees this side of valley, treed plot on right). Trees are mostly *E. pauciflora*.



Figure 10 View of the open plot location at site VW looking north east with the automatic weather station in the centre of the plot. Treed plot out of view to the left. Trees are *E. pauciflora*.



Figure 11 View of the open plot location and weather station at site VW looking south west, showing the exposed nature of the location.



Figure 12 View of site VW treed plot location, showing fallen wood from mature snow gums and open condition of the canopy.

2.3 Pasture Quality and Quantity

Pasture quality was measured as: -

- the floristic richness and composition in spring;
- the relative contributions to herbage mass by the dominant species, and
- the pasture digestibility and protein content both, in bulk, and for dominant species.

Pasture quantity was measured as: -

- the pasture mass each season;
- the seasonal production, and
- the seasonal consumption.

Methods for each aspect of pasture assessment are described here.

Pasture quality

Sampling for the full species composition and abundance was possible only during the peak growing season (November) when individuals were able to be readily identified to species. Twenty quadrats (0.25 m²) were located using restricted random sampling within each of the fixed plots and the species present were recorded. Contributions to biomass were recorded at the same time using the Dry-Weight-Rank method. Maxine Osborne checked plant identifications. Nomenclature follows Harden (1993).

The Jackknife method was used to estimate the total number of species on each plot. This estimate is based on the observed frequency distribution of rare species in the community. It is non-parametric and uses the species present in each quadrat (Krebs 1989). Richness is given by

$$S = s + \left(\frac{n-1}{n} \right) k$$

where S = Jackknife estimate of species richness; s = observed total number of species present in n quadrats; n = total number of quadrats sampled and k = number of species that occur in only one quadrat.

A paired t -test was used to compare the mean species richness in the open and under trees and the number of species on each quadrat was also compared between the plots at each site using a two-factor ANOVA (procedure GLM, SAS) with quadrats as replicates. In addition, a two-factor ANOVA was used to test whether the species richness of particular lifeforms such as native grasses, exotic grasses, native forbs and exotic forbs, differed between plots under trees and in the open. All results were considered significant if the probability of obtaining the observed values by chance alone was equal to or less than 0.05. The Tukey-Kramer multiple comparisons of means were performed as a follow-up analysis of significant main effects to determine where the differences lay.

Numerical classification of this set of quadrats on the basis of their pasture composition was also used to examine patterns of species association at the quadrat level between sites and treatments. The Czekanowski dissimilarity measure was used to calculate associations

between quadrats and then UPGMA fusion to provide an agglomerative hierarchical classification (see Belbin 1994).

The Dry-Weight-Rank method (DWR of t'Mannetje and Haydock 1963) for pasture composition was used simultaneously with the comparative yield method of Haydock and Shaw (1975) for herbage mass (yield) estimation. The combination of these methods has been successfully used in many studies (Friedel *et al.* 1988; Scanlan and Burrows 1990; Tothill *et al.* 1992; Brown 1993; and Hobbs 1993). These calibrated visual estimation techniques allowed for rapid non-destructive sampling for herbage composition and biomass in the plots and paddocks.

The multipliers (weights) derived by t'Mannetje and Haydock (1963) from the empirical relation between the actual dry weight and ranked dry weight composition of herbage were used to convert the rank scores to percentage herbage composition. Herbage components ranked 1 were given a value of 0.70, rank 2, 0.21, and rank 3, 0.09 as the multipliers (t'Mannetje and Haydock 1963). The multipliers for each component were summed over the quadrats within each plot and expressed as a percentage of the total yield scores of all the components. These percentages were converted to actual weight by multiplying them with the total dry weight estimate for each plot (Tothill *et al.* 1992). For the survey plots, with a wider range of yields, the multipliers were applied to individual quadrats to obtain a quadrat level biomass for each of the ranked species. This takes into account the differing yields of the quadrats. The quadrat scores were then averaged to get the plot means (Jones and Hargreaves 1979).

Several attempts were made to develop specific multipliers for the study area, based on the relationship between actual dry weight of species and ranked quadrat yield. However, difficulties were found with estimation bias for the different plant life forms and with reliable and efficient separation of the species from clipped quadrats. Jones and Hargreaves (1979) used data from a wide range of tropical and temperate pastures to create new DWR multipliers, but found that it was inadvisable to create new multipliers since the overall benefits from new multipliers would only be slight.

In the fixed plots samples taken for protein content consisted of those grass species which occurred under trees and in the open and contributed highly to pasture mass at the time of the spring 1995 sampling. Where possible, three species were sampled on each plot. Each species was replicated three times for each fixed plot using a systematic sampling procedure. Only fresh green material (leaves and non-flowering tillers) was collected. Samples were harvested with stainless steel scissors at about 20 mm above the ground to avoid soil particles. Latex gloves were used to avoid contamination while handling the samples. The samples were put in paper bags and placed immediately in a field refrigerator.

In the laboratory samples were surface washed with de-ionised water and then placed in an oven at 60°C for 48 hours. After this, total Kjeldahl nitrogen in the foliage was determined by an automated spectrophotometric method. Heffernan (1985) describes the method (PS11) in detail. The nitrogen in the foliage was converted to ammonium salts by destructive digestion of the foliage. The ammonium in the digest was reacted with alkaline phenol and sodium hypochlorite to form the indophenol blue complex.

In the survey plots, samples of the aboveground herbage were taken in September and December 1996 and April 1997 from each of the 16 quadrats in each plot for nitrogen content and digestibility. For each quadrat approximately 10% of the herbage mass was cut, the samples for the plot were then bulked and a subsample was dried at 70°C until no further weight loss occurred. Once dry, samples were stored at room temperature.

In the December sample, three perennial native grasses were also sampled separately. The grasses were *Themeda australis*, *Microlaena stipoides* and *Danthonia* spp. These were chosen because they are present in substantial quantities in the four paddocks surveyed and are agronomically significant species (Archer and Robinson, 1988; Robinson and Archer, 1988; Whalley, 1991 Simpson, 1994 and Jones, 1996). *Poa* spp. were not sampled as they are not generally considered to be particularly palatable (Simpson, 1994), although they do provide some useful forage during winter (Archer and Robinson, 1988).

When these grass species were sampled, actively growing leaves were taken from plants growing within the quadrats. Thus these samples were not a random selection as were the bulk samples previously mentioned. The two samples are therefore not directly comparable.

The technique used for dry matter digestibility (DMD) was the second stage (acid pepsin) of the *in vitro* digestion method described by Tilley and Terry (1963). The full two-stage process was not used due to lack of availability of the necessary facilities and sheep rumen liquor, as well as animal ethics considerations associated with the obtainment of the latter.

Tilley and Terry (1969) compared the results of a number of analyses of the soluble constituents of herbage. The data they presented shows a strong correlation between the results of *in vivo*, *in vitro* and acid pepsin analyses. **Table 6** presents the means and standard deviations of the differences between the *in vivo* and acid pepsin DMD and between *in vitro* and acid pepsin DMD. It indicates that the acid pepsin process provides a result that is fairly consistently 29% lower than that obtained from either of the other two processes.

Table 6 Means and standard deviations of the differences between acid pepsin and *in vivo* and *in vitro* determinations of DMD (after Tilley and Terry 1969).

Determination method	n	Mean	Standard Deviation.
<i>in vivo</i> - acid pepsin	25	28.4	3.28
<i>in vitro</i> - acid pepsin	25	29.5	4.50

The analysis method used was that outlined by Larter (1992), involving the digestion of a 200 mg sample in 20 mL of solution at 37°C for 48 h. The solution was made up of 2 g pepsin (1:10,000) dissolved in 1 L of 0.1M HCL. After digestion the undigested residue was filtered off, dried and weighed, with the percent digestibility given by $(1 - 5w) \times 100$.

Nitrogen content of the plant samples from the survey plots was analysed using a Leco 2000 CNS analyser on samples of approximately 100 mg. This determination method was calibrated against total Kjeldahl nitrogen.

A three factor mixed model ANOVA (procedure, SAS) with SITE (random effect), TREE and SPECIES as treatment effects, was used to compare the nutritional values of pasture species sampled under trees and in the open at the four experimental sites. The Tukey-Kramer multiple comparison of means was then used following a significant result of the main treatment effects where the degrees of freedom exceeded one.

Pasture quantity

Yield

The comparative yield method (CYM) of Haydock and Shaw (1975) was tested and used to estimate plot yield on a seasonal basis (**Table 7**). For measurements taken after the three initial sampling dates (refer **Table 7**), the coefficient of variation in quadrat yield in any plot

at one time was on average 60% for an average yield of 80 g m⁻². This corresponded to an average absolute error in quadrat yield of about 20 g m⁻² (range 5-60). Using an approximate equation for the variance of plot yield (Haydock & Shaw 1975 after Cochran 1963), the average plot yield had a standard deviation and also precision of ~20 g m⁻² (n = 4, p < 0.05) i.e. 200 kg ha⁻¹. Given that the quadrats are actually sub-samples in the CYM (plot yields were calculated as the mean of the 30 quadrat yields), we regarded the precision of the plot yield estimates as very acceptable for native pasture assessment (see Campbell & Arnold 1973, Haydock & Shaw 1975).

Table 7 Seasons and dates of sampling for pasture yield in fixed and survey plots.

Sampling dates	Season	Time from start (days)	Fixed plots sampled	Survey plots sampled
15-21 Aug 1995	Late winter	0	✓	
11-14 Sep 1995	Early spring	26	✓	
9-12 Oct 1995	Mid spring	53	✓	
28-30 Nov 1995	Late spring	103	✓	
3-9 Apr 1996	Early autumn	231	✓	
13-15 May 1996	Mid autumn	271	✓	
12 Sep 1996	Early spring	365	✓	✓
03 Dec 1996	Early summer	474	✓	✓
08 Feb 1997	Mid summer	542		✓
18 Apr 1897	Mid autumn	610	✓	✓

The standard field procedures for CYM included the establishment of five reference quadrats, the yield rating (to the nearest 0.25 on a scale from 1 to 5) of 30 frequency quadrats, setting up and rating exclosures and calibrating yield estimates with 12 clipped quadrats. These procedures were carried out on and adjacent to each plot on each sampling occasion. The reference and calibration quadrats were placed within 15 m but outside each plot.

The harvesting of calibration quadrats would have had minimal effects on the growth conditions in the plots because only 0.27% of the area within 15 m around each plot was harvested on each sampling occasion. All quadrats were 0.25 m² and where required were clipped with electric grass shears (Makita 100 mm, model UM1000D) to a height of about 15 mm except where *Poa* tussocks were involved. In this case the tussock was clipped only for standing green material.

Each harvested quadrat sample was put in a plastic bag and placed in shade while in the field to minimise weight loss by respiration. The samples were transported to the laboratory and stored at 5°C. Tree litter, uprooted grass tufts and scats were removed, and then samples were dried at 80°C in a forced draft oven for 48 hours. The dry weight was measured to ± 0.05 g.

A pilot study was done in spring 1995 on Reservoir Hill to the north of the University of Canberra campus in Bruce (ACT). This area had similar remnant vegetation, slopes and aspects to those of the experimental sites. The most abundant grass species were *Danthonia* spp., *Stipa* spp., and *Bothriochloa macra*. This site was used to train assessors. Either M. Katjiua or P. Wallace, usually assessing jointly with a field assistant did all pasture assessments for the study in the field. The sward was handled often and the reference quadrats revisited frequently as recommended by Haydock and Shaw (1975), to achieve accurate and precise ratings. Photographic references were not found to be useful. Reference quadrats were rated first, then frequency then calibration quadrats. In each plot six frequency quadrats were selected randomly from each of five subsections of the plot arranged along the contour.

The calibration quadrats were selected subjectively to represent the frequency distribution of herbage mass on the reference quadrats. A calibration equation was derived by regression of the dry weight of the quadrats on their yield scores. The scores of the 30 frequency quadrats and 10 exclosures were then converted to pasture mass using this equation. The calibration was carried out independently at nearly every plot and harvest to enable more precise pasture yield estimation.

Wire mesh cages were used to determine pasture mass in the absence of grazing vertebrates. The ten exclosures on each plot used in the first year had a circumference of 2.5 m and a height of 1.2 m, being open at the top. These were made from welded wire mesh to prevent grazing from rabbits, kangaroos, sheep and cattle and were secured with steel pickets. The number of exclosures allocated to a particular rank of the reference quadrats approximately followed the frequency distribution of ranked yields so as to represent better the pasture yield on the plot. At random positions we selected the nearest quadrat with pasture mass required for a particular rank. Before exclosures were placed, the quadrats (areas of 0.25 m²) were rated against the reference quadrats. Thereafter, at the end of the period an area of 0.25 m² within each cage was rated again to estimate herbage yield protected from grazing. In this way the initial dry weight and the final dry weight for each exclosure was determined. Cages were not placed where there had been one in the previous two sampling periods nor within one metre of large rocks, tree trunks or fallen timber with a diameter exceeding 150 mm. In this manner the effects of exclosures on the microenvironment were minimised.

In the second year the exclosure design was improved by remaking the cages slightly smaller and closed at the top, by increasing them to 15 in each plot and also fully randomising their positions. This avoided an intermediate analysis step in estimating plot yields in the absence of grazing which was introducing avoidable error variance.

Calculation of pasture measures

Herbage mass

The pasture yield at any harvest was calculated by converting the frequency quadrat yield scores to dry weight using the calibration equation for that particular harvest and plot. This was expressed as grams per square meter and is here referred to as herbage mass, yield or biomass interchangeably. These plot yields are referred to here as the open yields (OY) and the yield estimates for the exclosure cages at the end of a period as closed yields (CY).

Table 8 Units and formulae used to express pasture quantities (after t'Mannetje 1978).

Quantity	Units	Calculation formula
Herbage mass, Yield or Standing Dry Matter (SDM)	g m ⁻²	OY _t where t is the time of sampling
Production (in a stated time period) or Net Pasture Growth	g m ⁻² time ⁻¹	(CY ₂ - OY ₁) / time
Productivity	g m ⁻² day ⁻¹	(CY ₂ - OY ₁) / t ₂ - t ₁ or (CY ₂ - CY ₁) / t ₂ - t ₁ for cages
Consumption	g m ⁻² day ⁻¹	(CY ₂ - OY ₂) / t ₂ - t ₁

Pasture production

Pasture production or growth is usually calculated from the difference between the pasture yield inside exclosures at the end of a period and the yield inside the exclosures at the commencement of a period (Cayley and Bird 1996; t'Mannetje 1978; Milner and Hughes 1968). However, this method, being based on changes in standing dry matter, actually measures pasture growth net of leaf detachment and decay of standing dead matter. Methods for measuring the true pasture production (i.e. the aboveground net primary production) are extremely laborious in mixed composition pastures (Cayley and Bird 1996) since they additionally require the application of shoot demographic techniques. In this study we have used the simpler approach of measuring pasture growth net of decay (net pasture growth or production).

For the first year's sampling, the exclosures were not a random sample of the plot, hence for these data it was first necessary to estimate the amount of growth occurring during a time period on each frequency quadrat, as if it had been protected from grazing.

To do this, the yields of the exclosures at the beginning of a period and at the end were used to calculate each exclosure's productivity (dCY/dt). Within plots, the cage productivity was found, not unexpectedly, to be a function of the starting biomass, with an overall significant linear regression ($dCY/dt = 0.86 - 0.006CY_1$), for all plots and times combined. A similar equation was derived for all eight plots combined at each sample time. There were insufficient differences between plots at the same time to warrant deriving a separate relationship for each plot. These equations were integrated to enable estimation of growth on the plots in the absence of grazing (hence providing a CY_2 estimate) and enabling calculation of production and consumption for the plots.

For summing production and consumption data over sample periods, Defosse and Bertiller (1991) recommended summation of positive increments of total biomass between harvests because it requires less effort than methods which take into account concomitant increases in dry, old dead material and litter. In common with Defosse and Bertiller (1991), Biondini *et al.* (1991) argued that production is not just the difference between biomass at the end of a period and biomass at the beginning, but only the positive values of this difference. This leads to over-estimation because the distribution of positive values is a truncated normal distribution rather than a normal one (Sala *et al.* 1988). This overestimation can be as high as 700% (Singh *et al.* 1984). For the present analysis we have not set small negative values for productivity and consumption to zero.

Data Analysis

As the same plots were repeatedly estimated for pasture yield the appropriate statistical analysis in many cases was repeated-measures analysis of variance (von Ende 1993). We applied a hierarchical ANOVA model using GENSTAT 5 (Digby *et al.* 1989) to accomplish this analysis and so to determine the effects of time and trees on production and consumption of pasture.

2.4 Soil Conditions

Plots for this study have been under their present vegetation cover for several decades at least. Pairs of contrast plots are adjacent, and geomorphology and soils are reasonably similar. Differences in soil conditions would hopefully be related more to differences in vegetation cover.

Soil moisture

A Time Domain Reflectometer (Soilmoisture Equipment Corp. USA, TDR, Model 6050X1) was used to measure soil moisture. TDR allows for rapid measurements of volumetric soil water without calibrating for specific soils or knowing soil bulk density and water content by depth (Reeves and Smith 1992). Probes were placed permanently for the last 16 months of the study, one pair in each third of each plot down the slope. Each pair measured the average volumetric soil moisture over the range 0-15 cm and 0-45 cm depth. The probes were located at least a metre from large tussocks, surface rocks and trees because these affect accuracy. The probes were measured at each sampling period but unfortunately the instrument frequently malfunctioned and was not able to be used for extended periods.

Soil fertility

Surface soil samples for chemical analysis were taken in April 1996 at the fixed plots. Four replicates were taken on each plot, arranged in four strata down slope similarly to the TDR probes. Each replicate was a composite of four sub-samples within each stratum. The subsample locations were placed by restricted random sampling and for each subsample the A_0 horizon was removed. Soil cores (0-10 cm) were then sampled with a clean auger to minimise contamination.

The sample replicates were put into plastic bags and kept cool between sampling and receipt at the laboratory, to minimise biological transformations (Rayment and Higginson 1992). In the laboratory the samples were stored in a cold room at 4°C for a night and then dried at 40°C in a forced draft oven in foil containers for 48 hours. When the soil was thoroughly dried it was ground and sieved using a 2 mm sieve, then stored in airtight plastic bags at room temperature prior to chemical analysis.

Soil samples were taken from the survey plots for analysis in September and December 1996 and April 1997. A core of 2 cm diameter by 15 cm deep was taken at each of the sixteen quadrats in each plot. The A_0 horizon was removed before the sample was taken if it was present. The sixteen sub-samples were bulked, dried at 40°C and stored at room temperature until analysed.

Tree litter (leaves, buds, fruits and twigs up to 6 mm diameter) was collected in the treed plots in November 1995 on the calibration quadrats. Sampling for tree litter was not carried out in the open plots, because it was negligible in amount.

Total nitrogen and total phosphorus analysis

Total Kjeldahl N and P in the fixed plot soils (in April 1996) were determined by the automated spectrophotometric method (method no. PS13) as described by Heffernan (1985) for the CSIRO Forest Division.

Soil nitrogen in the survey plots was determined using a Leco CNS 2000 analyser at CSIRO Wildlife and Ecology, Lyneham, ACT. The results obtained from this analysis closely approximate Kjeldahl nitrogen (D. Tongway, *pers. comm.*).

Available phosphorus analysis

Phosphorus available for plant growth was determined for samples from the survey plots taken in December 1996 and April 1997, but not for those taken in September 1996 due to inadequate sample size. The automated bicarbonate extraction method described by Rayment and Higginson (1992, pp. 66-68) was used.

Organic carbon analysis

The organic matter in the soil was determined by combustion for the fixed plot comparison. Five gram samples of soil were weighed into crucibles and held at 550°C for 45 minutes in a muffle furnace and then cooled in a desiccator for 90 minutes.

Soil carbon for the survey plots was determined using the Leco CNS 2000 at the same time as the nitrogen analysis. This analysis can be compared to ashing the soil, but is considered to be more accurate and repeatable (D. Tongway, *pers. comm.*).

pH

The soil pH for the earlier fixed plot samples was determined by placing 5 g of soil into 100 ml de-ionised water, shaking by hand and then let stand for 2 hours. These were shaken again and left for 10 minutes before readings were taken with a pH meter.

The pH for the survey plots was measured using 1M potassium chloride solution as described by Rayment and Higginson (1992, p. 20). This method is particularly suitable for the weathered acid soils found in the study sites. It provides a result that is approximately one unit lower than that which would be obtained using water as the suspension agent but is more repeatable.

2.5 Microclimatic Effects

Automatic weather stations were installed near the centre of each plot at sites M2 and VW. Instruments for temperature were housed in a ventilated screen at 1.5 m high, whilst cup anemometers and radiation sensors were at 2 m. Envirodata instruments and loggers (Envirodata Australia Pty. Ltd., Easidata Mk-3) were used. Stations recorded air temperature, relative humidity (unaspirated wet/dry bulb) and wind run as 60 minute averages. Rainfall (tipping bucket) and global solar radiation were also measured in the open plots.

Penman evaporation was calculated by the loggers from other sensor inputs using the approach presented by Doorenbos & Pruitt (1984) and their formula given below.

$$E_{t0} = c \left[\frac{\Delta}{\Delta + \gamma} (R_n) + \frac{\gamma}{\Delta + \gamma} \cdot f(u) \cdot (ea - ed) \right]$$

where: E_{t0} = evapotranspiration

c = crop coefficient

Δ = slope of saturation vapour pressure to temperature relationship

γ = psychrometer constant

R_n = net radiation in equivalent depth of water evaporation

$f(u)$ = wind function = $0.27[1 + (U/100)]$ where U = daily wind run

$(ea - ed)$ = vapour pressure difference.

Photosynthetically active radiation

Measurement of photosynthetically active radiation (PAR) at grass level was done at the winter solstice and the spring equinox in 1997. A linear PAR ceptometer with a probe length of 80 cm was used within an hour of solar noon under cloud-free conditions.

The fixed plots were measured along with a number of other plots of various basal areas using the Bitterlich technique to estimate tree basal area at a point. Sixteen randomly selected points were measured within each plot; each PAR measurement being the mean of twenty individual readings made over a period of about 30 seconds. PAR in the open was measured before and after each plot was sampled and taken as 100%.

2.6 Modelling the Effects of Trees on Pastures

We used the site data to calibrate the QDNR GRASP model (McKeon *et al.* 1990) for the Southern Tablelands. We examined the capability of GRASP, developed for tropical native pasture, to simulate growth of temperate pastures and to include the effects of trees on pasture growth in a temperate environment. The GRASP model was designed to simulate key aspects of grass growth and to predict soil water, pasture production and animal intake. GRASP uses daily climate inputs to simulate the water balance (runoff, infiltration, soil evaporation, transpiration and drainage), pasture growth (green growth, death and detachment of parts) and animal intake (diet selection, utilisation and live weight gain). The only effects of trees on pasture production that are explicitly included operate through competition for water and nitrogen in the soil. Other effects can be included indirectly to a limited extent.

3. Results

The results and their specific discussion are here presented under three main headings. These sections cover firstly the studies done at fixed plots to make paired comparisons and secondly those done in the survey plots to examine the extent of variation in pasture and soil properties with tree basal area at the paddock scale. The third examines simulation modelling of the pasture growth and the effects of trees on it. A discussion and synopsis follows.

3.1 Comparisons between Paired Open and Treed Plots

Microclimate

The two sites with weather records at the fixed plots, M2 and VW, were used to compare treed and open plots for the period February 1996 to August 1997, as we had the most complete records for that time. Differences between treatments were tested using ANOVA on monthly means for 12 months and for the daily means for both sites combined. Variances did not differ between treatments.

Significant differences in daily comparisons for mean temperature, maximum temperature, minimum temperature, relative humidity, evaporation and wind run were found between treed and open stations for the whole period (**Table 9**). Temperatures and relative humidity were slightly higher, whilst wind run and potential evaporation were markedly lower in treed plots.

Analysis of monthly means, including month as a factor, showed significant differences between treed and open plots at the two sites in their relative humidity, evaporation and wind run but not for temperatures (**Table 10**, **Figure 13** to **Figure 19**). Although temperatures in treed plots still tended to be slightly higher, as found with the comparison of daily means. The difference in the significance of daily vs. monthly mean temperatures was probably related to the reduced sample size available for months and the small temperature difference.

Table 9 Mean daily weather (2/96-8/97) in treed and open plots at the M2 and VW sites, with standard errors. Probability that they are different is < 0.001 for all variables.

Climate variable	Treed plot mean	Open plot mean
Minimum air temperature (°C)	7.3 ± 0.2	6.2 ± 0.2
Maximum air temperature (°C)	17.8 ± 0.3	16.6 ± 0.2
Mean air temperature (°C)	12.6 ± 0.2	11.3 ± 0.2
Relative humidity (%)	77 ± 0.4	80 ± 0.3
Penman evaporation (mm day ⁻¹)	1.8 ± 0.1	2.6 ± 0.1
Wind run (km day ⁻¹)	108 ± 2	160 ± 3

Solar radiation was reduced under the tree canopy by an average of 45%, but this figure can be taken as indicative only, because of the use of just a single sensor in each plot (for this reason radiation was not included in the daily analysis). Rainfall differences were not tested, as single gauges were used in each plot and they would not accurately represent the fall under trees. For evaporation and radiation, the interaction with month was also significant; indicating the relative difference between treed and open plots differed during the year. This may be a response to seasonal changes in leaf area of the eucalypts, and requires further investigation.

Photosynthetically active radiation (PAR) measured under clear skies at the spring equinox at the fixed plots showed percentage transmissions through the tree canopy averaged for the treed plots were M1 65%, M2 89%, VE 65% and VW 51%. When these data were combined

with further random plots across the paddocks, there was a moderate negative correlation ($r = 0.81$) of PAR transmission with TBA (**Figure 20**). The average 35% reduction in PAR at the fixed plots in spring is comparable with the reduction in global solar radiation of 45%.

Table 10 Mean monthly weather (7/96-6/97) in treed and open plots at the M2 and VW sites showing results of ANOVA.

Climate variable	Treed plot mean	Open plot mean	F value for main effect of TREE, Pr > F	F value for interaction of TREE*MONTH, Pr > F
Minimum air temperature (°C)	8.0	6.9	NS	NS
Maximum air temperature (°C)	18.7	17.6	NS	NS
Mean air temperature (°C)	12.3	11.4	NS	NS
Relative humidity (%)	75.5	78.5	29.8, <0.0001	0.64, 0.79
Penman evaporation (mm day ⁻¹)	1.6	2.8	311.8, <0.0001	4.03, <0.0001
Wind run (km day ⁻¹)	106	163	120.6, <0.0001	1.04, 0.41
Solar radiation (kWm ⁻²)	7.1	12.9	423.9, <0.0001	2.78, 0.001

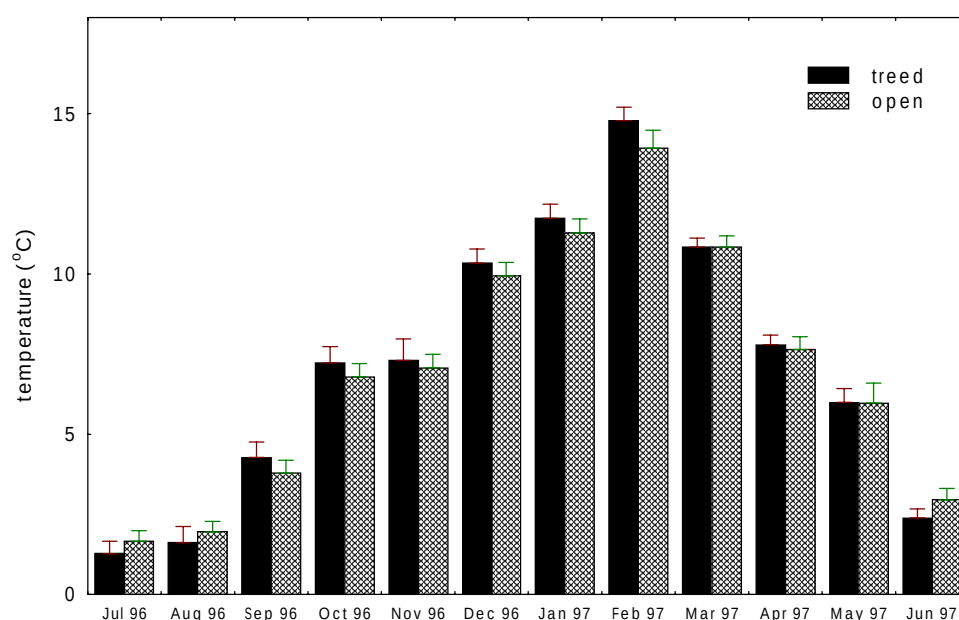


Figure 13 Minimum daily temperature in treed and open plots averaged across M2 and VW sites for the period 7/96 to 6/97. Error bars are one standard error.

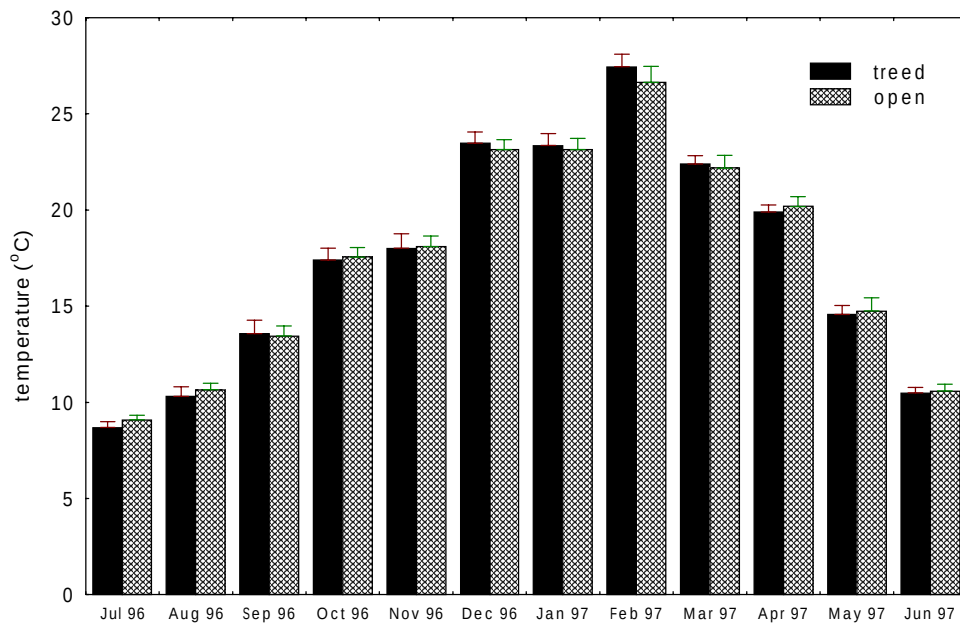


Figure 14 Maximum daily temperature in treed and open plots averaged across M2 and VW sites for the period 7/96 to 6/97. Error bars are one SE.

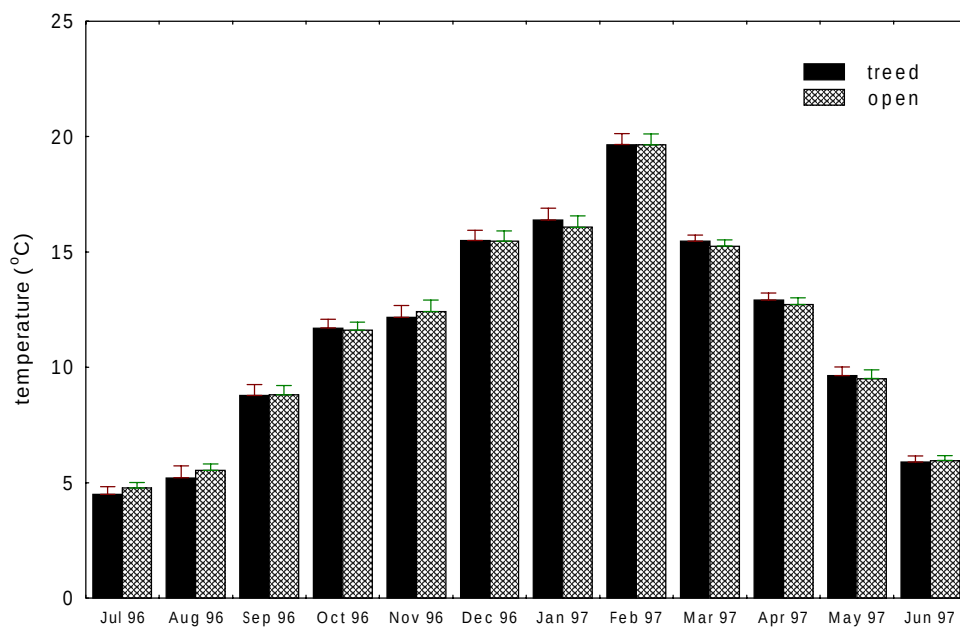


Figure 15 Mean daily temperature in treed and open plots averaged across M2 and VW sites for the period 7/96 to 6/97. Error bars are one SE.

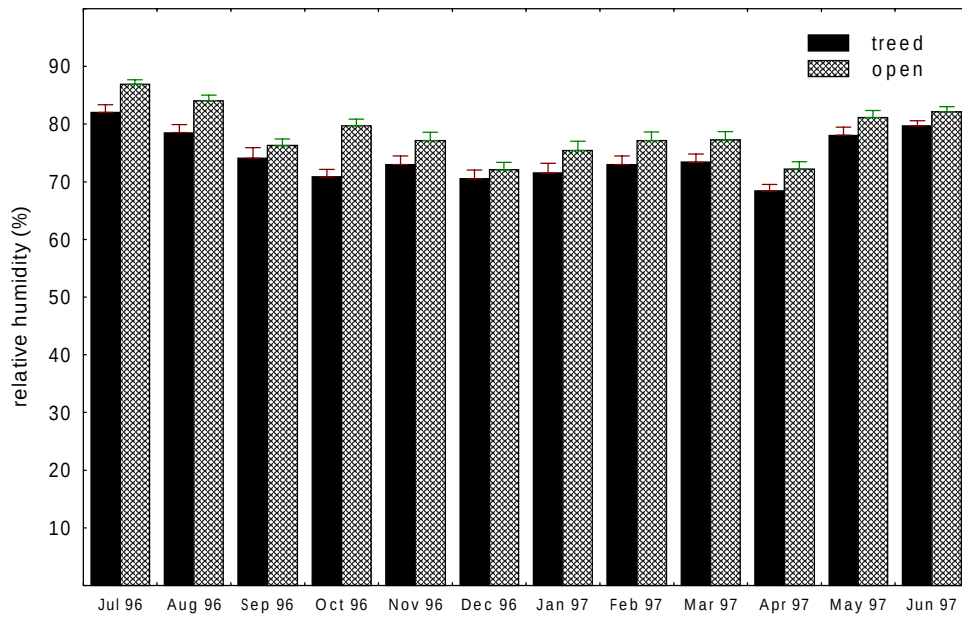


Figure 16 Mean daily relative humidity in treed and open plots averaged across M2 and VW sites for the period 7/96 to 6/97. Error bars are one SE.

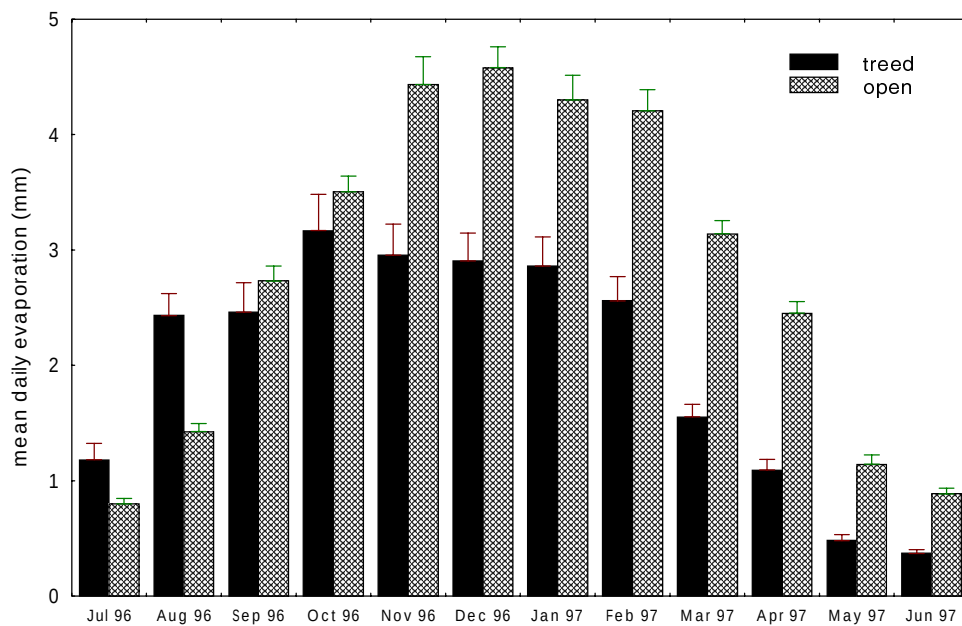


Figure 17 Mean daily Penman evaporation in treed and open plots averaged across M2 and VW sites for the period 7/96 to 6/97. Error bars are one SE.

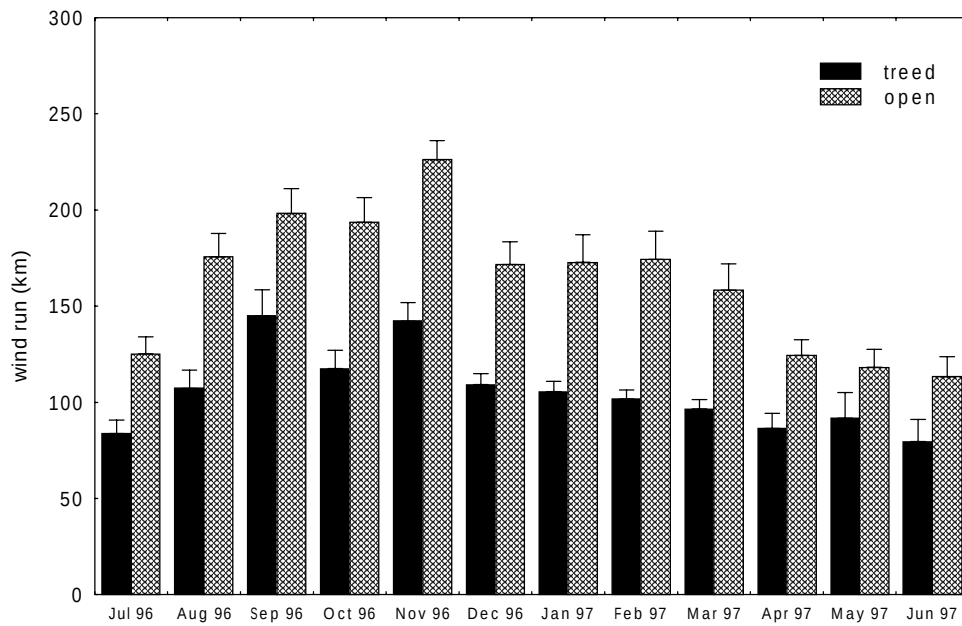


Figure 18 Mean daily wind run in treed and open plots averaged across M2 and VW sites for the period 7/96 to 6/97. Error bars are one SE.

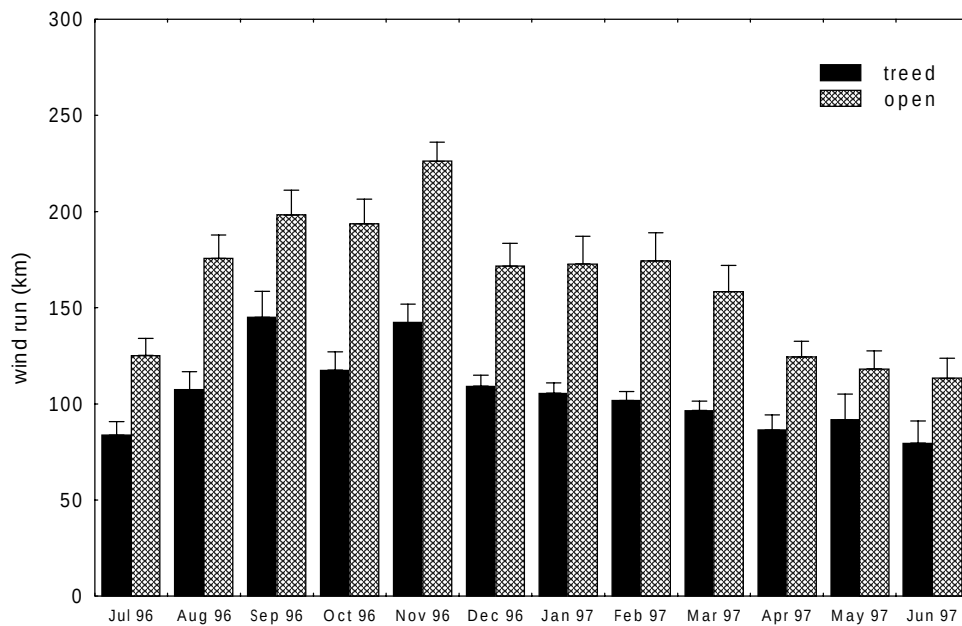


Figure 19 Mean daily solar radiation in treed and open plots averaged across M2 and VW sites for the period 7/96 to 6/97. Error bars are one SE. Note that radiation levels in treed plots are indicative only.

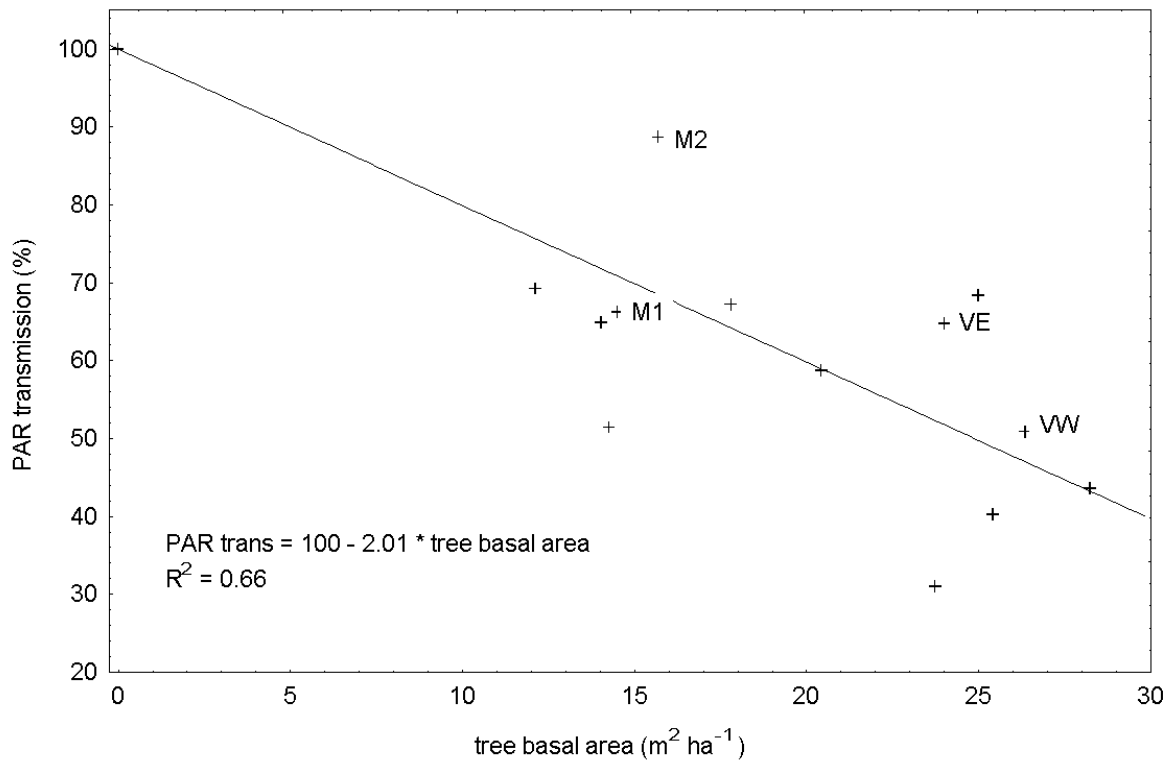


Figure 20 Percent transmission of photosynthetically active radiation through the tree canopy in plots measured at the winter solstice and spring equinox 1997 in relation to tree basal area. Labelled points refer to the fixed plots measured in spring and the other points represent randomly selected plots at both times.

Soil properties

Soil moisture

Soil moisture at two depth intervals was measured eight times in 1995/6 in the fixed plots. The difference in soil moisture between plots under trees and in the open was non-significant (**Table 11**, **Table 12**). The overall surface soil moisture in the treed and open plots was $18\% \pm 1$ (mean $\pm$ SE) and for the deeper soil layer it was $22\% \pm 1$ in treed plots and $24\% \pm 1$ in the open ones.

Table 11 Results of ANOVA for soil moisture (0-15 cm depth) in the fixed plots.

Effects	df Effect	MS Effect	df Error	MS Error	F	p-level
TREE	1	143.47	5	36.087	3.98	0.103
TIME	7	505.78	35	15.349	32.96	0.0000
TREE*TIME	7	41.86	35	15.349	2.73	0.023

Table 12 Results of ANOVA for soil moisture (15-45 cm depth) in the fixed plots.

Effects	df Effect	MS Effect	df Error	MS Error	F	p-level
TREE	1	246.28	17	255.52	0.964	0.340
TIME	5	968.22	85	26.586	36.42	0.0000
TREE*TIME	5	14.65	85	26.586	0.551	0.737

Soil nutrients

Surface soil total N and P, soil organic matter and pH were compared between the fixed plots based on sampling in April 1996. The amount of tree litter was compared between the treed plots, the amount of litter in open plots being negligible.

Tree litter

Tree litter differed slightly between some of the sites. Site VW had the highest dry weight of litter (211 g m^{-2}), then M2 (160 g m^{-2}), VE (156 g m^{-2}) and M1 (83 g m^{-2}) (**Figure 21**). The difference in tree litter between VW and M1 was significant ($p < 0.05$), but all other comparisons were non-significant. Tree litter was linearly related to the plot tree basal area ($y = 8.48x + 21.0$, $R^2 = 0.68$, $\text{RMS} = 36$).

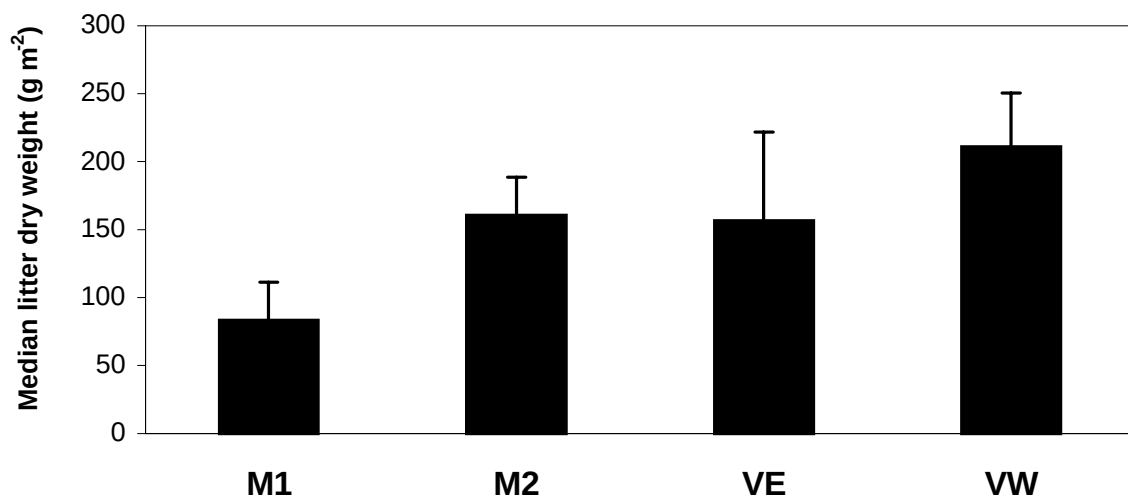


Figure 21 Mean and SE for tree litter on the treed plots in November 1995 at the four experimental sites.

Soil pH

Soil pH was moderately acidic at all sites. It differed slightly but significantly between plots under trees and in the open ($F = 11.69$; $df = 1,24$; $p < 0.005$) and among the four sites ($F = 16.03$; $df = 3,24$; $p < 0.0001$). The interaction effect (TREE $\times$ SITE) was non-significant ($p = 0.59$). The mean soil pH in the open was 5.7 ± 0.2 SD and 5.5 ± 0.2 SD under trees.

Soil organic matter

Soil organic matter (SOM, measured as loss on ignition) did not differ significantly between plots under trees and in the open ($p = 0.055$) but was different between sites ($df = 3,24$; $F = 29.11$; $p < 0.001$). The interaction between TREE and SITE was non-significant ($p = 0.39$). The SOM under trees was 7.8 ± 2.1 SD and 6.9 ± 1.7 SD in the open.

Total nitrogen and total phosphorus

Total soil N and P did not differ significantly between plots under trees and in the open ($p = 0.47$ and $p = 0.32$ respectively, **Figure 22**). There was a trend for TN and TP to be higher under trees. Soil total N differed significantly between sites ($F = 5.93$; $df = 3,24$; $p < 0.01$).

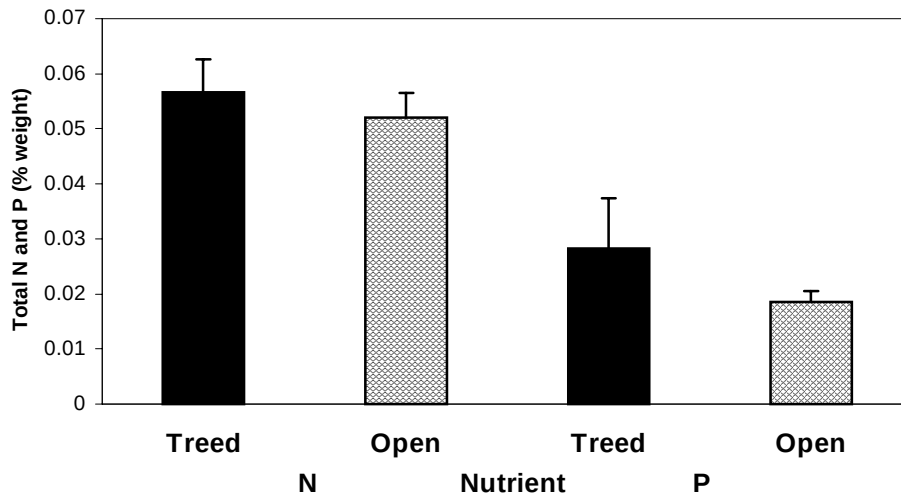


Figure 22 Mean total N and P on plots under trees and in the open. The differences between the treed and open plots were non-significant. The error bars show the 95% confidence intervals.

Pasture composition

This section examines the composition and quality of the pasture under trees and in the open. We have compared the species richness, i.e. the number of species, the floristic composition and the percentage dry weight contributions of herbs to the pasture. Seasonal variations in species composition could not be tested because it was logistically impossible to identify all pasture species, except during the spring flowering period.

Species richness

At the plot level (area = 0.09 ha), Jackknife estimates showed no difference ($p = 0.69$) in the number of species between the plots under trees and in the open. Species richness appeared lower under trees at M1 but higher under trees at VW suggesting an interaction effect and precluding testing for differences between sites (**Table 13**). The mean species richness in plots was estimated to be 48.

When the actual number of species occurring on each quadrat (area = 0.25 m²) was compared, there were small significant differences among sites ($F = 6.67$; $df = 3,156$; $p < 0.001$, **Table 13**). However, as with the richness estimates for plots, the TREE treatment had no significant effect on the number of species on the quadrats ($p = 0.26$). The interaction of TREE and SITE was also non-significant ($p = 0.095$).

Table 13 Pasture species richness for the fixed plots (Jackknife estimate) and quadrats (measured) in the fixed plots at four sites.

Site	Estimated plot species richness	Mean quadrat species richness $\pm$ SD
M1	44	10 $\pm$ 2
M2	56	13 $\pm$ 3
VE	48	12 $\pm$ 2
VW	44	12 $\pm$ 3
Mean	48 $\pm$ 6	11 $\pm$ 3

Species of native and exotic herbs occurred on all plots, but there were more native species of both grasses and other herbs (**Table 14**). There were no effects of trees and sites on the number of species of herbs of these kinds.

Table 14 The mean number ($\pm$ SD) of species of native and exotic herbs recorded on quadrats at the fixed plots in December 1995.

Grasses		Forbs	
Native	Exotic	Native	Exotic
7.9 $\pm$ 1.9	5.0 $\pm$ 1.3	15.9 $\pm$ 5.5	9.6 $\pm$ 2.4

Floristic groups at the quadrat level

The classification of quadrats produced five floristic groups defined at a dissimilarity distance of 1.175. Group 1 was the largest and consisted of 80 quadrats. The group consisted predominantly of quadrats from sites M1 and VE (**Table 15**). Ninety-five per cent and 85% of the quadrats on the plot in the open and under trees at VE were in this group respectively. Furthermore, the group contained 100% of the quadrats of the plot in the open and 85% of the plot under trees at M1 (**Table 15**). This group had no indicator species as no particular species isolated this floristic group from the rest of the groups (**Table 16**). There was no clear separation of quadrats into their respective plots in the open and under trees at the two sites dominated by this floristic group. Together the quadrats on these two sites made up 93% of the total group membership. The most frequent perennial grass species were *Microlaena stipoides* and *Danthonia racemosa* (**Table 16**).

Floristic group 2 had 41 members dominated by quadrats in the plots at M2 (**Table 15**). Together they made up 85% of the total group membership. As with group 1, there was no clear separation of the quadrats belonging to the plot in the open and that under trees, although quadrats from the same plot tended to be clustered together at lower levels in the classification. Group 2 was distinct from other groups because it had a high fidelity of *Elymus scaber* var. *scaber*, *Schoenus apogon* and *Haloragis heterophylla*, and high constancy of *Themeda australis* and *Briza minor* (**Table 16**). Group 3 was an outlier of group 2 and contained 3 quadrats that were from plots at M2 (**Table 15**). The group had a high fidelity of the forbs *Viola betonicifolia* and *Ranunculus plebeius*. As with group 2, group 3 had a high constancy of *Themeda australis* (**Table 16**).

Floristic group 4 had 23 members most of which were quadrats from the VW treed plot (**Table 15**). Eighty six per cent of the quadrats under trees were in this group and made up 81% of the group total membership. The group was distinct from other groups because of the high fidelity of *Bromus hordeaceus* and *Hydrocotyle laxiflora* (**Table 16**).

The last group, Group 5, contained 80 per cent of the quadrats of the plot in the open at VW (**Table 15**). This constituted the total membership of the group. The group had a high fidelity of the forbs *Acetosella vulgaris*, *Plantago varia* and *Dichondra* species A, and high constancy of *Trifolium glomeratum*. Although this group was clustered separately from group 4, the two groups were more similar to each other than to any other groups.

In summary, the analysis of species composition in quadrats showed similar species associations occurred between treed and open plots at all sites except VW. The latter site had *Microlaena* and *Vulpia* in the treed plot and *Danthonia* and *Trifolium glomeratum* in the open. These species differentiated the treed and open plots at that site. Quadrats from sites M1 and VE showed a high level of floristic affinity, both within and between plots.

Table 15 Percentage of quadrats in each plot belonging to each floristic group based on species presence. The most frequent (>80%) floristic groups for each plot are shaded.

Floristic Group	M1		M2		VE		VW	
	Treed	Open	Treed	Open	Treed	Open	Treed	Open
1	85	100	10		85	95	14	5
2	15		85	90	5	5		5
3			5	10				
4					10		86	10
5								80

Dry-Weight-Rank composition

Microlaena stipoides made a considerable contribution to pasture mass at VE, VW and M1 (Table 17). However, its contribution in treed and open plots was variable. At VE it contributed a similar amount to treed and open plots, while at VW it was only a significant contributor to the treed plot and at M1 the converse applied.

Themeda australis dominated the plots in the open at M2, VE and under trees at M1. *Danthonia racemosa* did not show any clear trend except that it was a major contributor only in the box woodland sites (M1, M2). *Vulpia bromoides* contributed at VW and VE, and was more dominant under trees. *Poa sieberiana* and *Poa labillardieri* dominated the plot under trees and in the open respectively at VW. Other species such as *Hypochoeris radicata*, *Lolium rigidum*, *Holcus lanatus* and *Elymus scaber* did contribute in some plots, but without clear trends.

In summary, for the fixed plots as a whole, the dominant species (*D. racemosa*, *T. australis*, *M. stipoides*, *P. sieberiana*) each made similar contributions to treed and open plots but did not necessarily show this pattern within sites. Each of the minor pasture species tended to contribute to either treed or open plots, but not both, and usually they were contributors at one site only.

Table 16 Percentage frequency of occurrence of pasture species in floristic groups for species whose frequency was more than 49% in any one group.

	Floristic group number				
	1	2	3	4	5
Group size (no. quadrats)	80	41	3	23	17
Aira sp.	89	92			
Microlaena stipoides	86			65	
Vulpia bromoides	54			83	
Hypochoeris radicata	79	75		70	71
Trifolium dubium	76	93		61	82
Danthonia racemosa	73	79			88
Trifolium glomeratum	60	75			100
Briza minor	61	100			
Themeda australis		100	100		
Schoenus apogon		83			
Trifolium arvense		59			
Haloragis heterophylla		58			
Elymus scaber		55			
Asperula conferta		75			65
Viola betonicifolia			67		
Ranunculus plebeius			67		
Lolium rigidum				91	76
Trifolium subterraneum				65	82
Hydrocotyle laxiflora				57	
Bromus hordeaceus				52	
Acetosella vulgaris					59
Plantago varia					65
Dichondra sp. A					82

Table 17 Percentage contribution of species to herbage mass for the fixed plots in December 1995. The three top-ranking species on each plot are shown. Species ordered by totals.

Site Species	M1		M2		VE		VW		All sites	
	Treed	Open	Treed	Open	Treed	Open	Treed	Open	Treed	Open
<i>Themeda australis</i>	22		45	87		35			67	121
<i>Microlaena stipoides</i>		24			36	25	23		59	50
<i>Danthonia racemosa</i>	21	36	26	2					48	38
<i>Vulpia bromoides</i>					28	23	16		44	23
<i>Poa sieberiana</i>							28	19	28	19
<i>Poa labillardieri</i>								17	0	17
<i>Lolium rigidum</i>								17	0	17
<i>Poa sp.</i>	13								13	0
<i>Holcus lanatus</i>					13				13	0
<i>Hypochoeris radicata</i>		10		2					0	12
<i>Elymus scaber</i>			8						8	0
Total percentage	56.0	70.0	79.0	91.0	77.0	83.0	67.0	53.0		
Plot herbage mass (g m ⁻²)	116	139	121	112	88	104	103	109		

Pasture species quality

We compared the total N and total P content for foliage of the major pasture species sampled in the fixed plots in December 1995. Most species at that time were at or near peak seasonal biomass but not drying off. As it was not possible to obtain all the species for comparison across all sites (see **Table 18**) a more limited set of comparisons, but all involving comparison of treed and open plots (TREE effect), were made using separate ANOVAs. A summary of the results is provided in **Table 19**.

Table 18 Fixed plots where particular species were collected in December 1995 for foliar nitrogen and phosphorus analysis.

Site Species	M1		M2		VE		VW	
	Treed	Open	Treed	Open	Treed	Open	Treed	Open
<i>Poa sieberiana</i>							✓	✓
<i>Danthonia racemosa</i>	✓	✓						
<i>Themeda australis</i>	✓	✓	✓	✓				
<i>Microlaena stipoides</i>	✓	✓			✓	✓	✓	✓

Table 19 Summary of the significant effects of TREE, SITE and SPECIES on pasture nitrogen and phosphorus in the fixed plots. Refer to previous Table for the sites and/or species used in each ANOVA, all included the TREE effect. NS signifies no significant effects.

ANOVA	Foliar nitrogen	Foliar phosphorus
Within site M1	NS	NS
Within site VW	TREE, SPECIES	TREE, SPECIES
Within <i>Themeda</i>	NS	NS
Within <i>Microlaena</i>	SITE, TREE*SITE	SITE, TREE, TREE*SITE

No significant effects on pasture N or P were found when species (*Danthonia*, *Themeda*, and *Microlaena*) were compared between treed and open plots at M1. However, at the VW site there were differences between species and between treed and open plots. A slightly higher N content was found under trees ($1.55\% \pm 0.15$ SE) compared to the open ($1.30\% \pm 0.09$ SE) ($F = 9.02$; $df = 1,8$; $p < 0.05$). *Microlaena* had a higher N content ($1.67\% \pm 0.09$ SE) than *Poa sieberiana* ($1.19\% \pm 0.06$ SE) ($F = 33.53$; $df = 1,8$; $p < 0.001$). The P content was also higher under trees ($0.16\% \pm 0.01$ SE) compared to open ($0.10\% \pm 0.01$ SE) ($F = 88.89$; $df = 1,8$; $p = 0.0001$). In summary, at VW we found higher pasture N and P under trees and *Microlaena* was higher than *Poa sieberiana*.

When *Themeda* was compared between treed and open plots at the M1 and M2 sites no significant differences were found ($p=0.396$ for N and 0.532 for P). By contrast *Microlaena* compared across M1, VE and VW showed most effects were significant, including the interaction of TREE with SITE. This shows that the effect of trees versus open is not consistent across sites. For nitrogen, *Microlaena* was higher in the snow gum sites and under trees there, but was higher in the open at M1 (**Table 20**). A similar pattern was found for P content.

Table 20 Means and standard errors (n=3) for N and P content of green *Microlaena* foliage in the fixed plots at three sites.

Site	M1		VE		VW	
	Treed	Open	Treed	Open	Treed	Open
Mean N%	1.093	1.293	1.750	1.683	1.846	1.493
SE	(0.052)	(0.038)	(0.095)	(0.171)	(0.104)	(0.050)
Mean P%	0.123	0.117	0.147	0.117	0.183	0.113
SE	(0.009)	(0.007)	(0.009)	(0.012)	(0.009)	(0.003)

Further analysis was performed using the Tukey-Kramer procedure ($\alpha = 0.05$) to determine which species differed in nitrogen content irrespective of SITE and TREE effects. This showed that *Microlaena stipoides* had the highest nitrogen content and was significantly different from *Themeda australis*, *Poa sieberiana* and *Danthonia racemosa*. The differences between the rest of the species were non-significant.

Herbage mass, productivity and consumption

This section examines the effects of trees on pasture mass, productivity and consumption rate, as measured on the fixed plots over two years (8/95-4/97). The herbage mass under continuous grazing conditions was estimated on the fixed plots nine times over the two years. Several of the earlier more frequent harvests were grouped to calculate seasonal values (**Table 21**). These values were used for all analyses reported in this section.

Table 21 Sampling periods used to derive seasonal pasture growth estimates and the mean production in the fixed plots.

Season	Sample periods	Period dates	Length of period (days)
Spring 1995	1-3	18/8/95-29/11/95	103
Summer/Autumn 1996	4-5	29/11/95-15/5/96	168
Winter 1996	6	15/5/96-12/9/96	94
Spring 1996	7	12/9/96-3/12/96	109
Summer/Autumn 1997	8	3/12/96-18/4/97	136
Total	1-8	18/8/95-18/4/97	610

Herbage mass

The herbage mass was compared for each of the seasonal harvests using hierarchical ANOVA. These values did not require transformation prior to ANOVA and the residuals were close to a normal distribution. Re-estimation of a single value with a large residual did not change the significance of effects.

The ANOVA showed trees had no significant effect on the levels of herbage mass in these pastures (**Table 22**). As expected, there was a highly significant difference in herbage mass with time. Herbage mass peaked in both summers and the lowest values were recorded in early spring (**Figure 23**). The interaction of TIME*TREE was not significant, indicating that the treed and open plots varied in herbage mass in the same way over the different times.

Table 22 Analysis of variance for pasture mass in treed and open plots measured at six times across the four sites. No test of site effects was appropriate; the plot effect is called TREES for clarity. Probability values in bold are significant at 95% or better.

Source of variation	Degrees of freedom	Sum of Squares	Mean Square	F value	Probability
SITES	3	3322	1107	1.06	
Site.plot stratum					
TREES	1	1786	1786	1.71	0.283
Residual	3	3140	1047	3.00	
Site.plot.time stratum					
TIMES	5	33392	6679	19.11	< 0.0001
TIMES*TREES	5	2949	590	1.69	0.168
Residual	30	10482	349		
Total	47	55071			

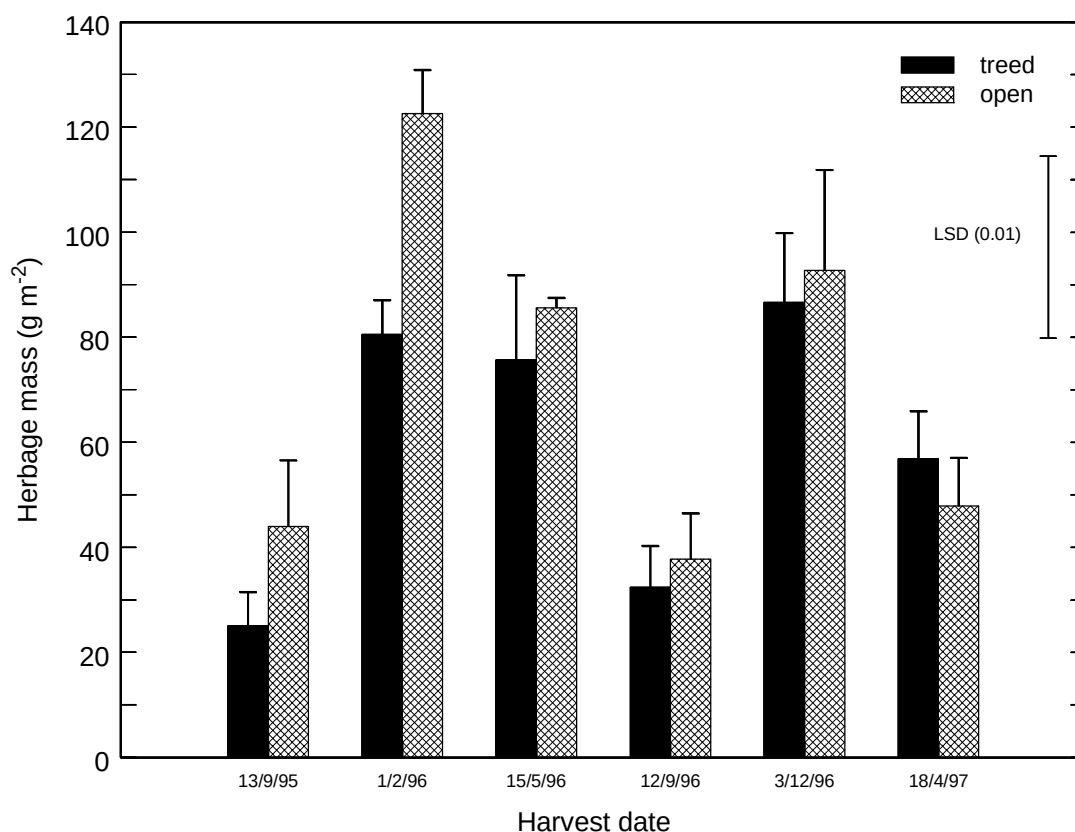


Figure 23 Mean pasture mass in treed and open plots for each harvest date. The first two dates are the mean of several harvests (see **Table 21**). Least significant difference shown is for comparisons of mean herbage mass between times within the treed plots or within open plots. Error bars show one standard error.

Pasture productivity

The daily rates of pasture production (productivity) were compared for each of the seasonal periods using hierarchical ANOVA. Pasture productivity values did not require transformation prior to ANOVA. The model residuals were close to a normal distribution and re-estimation of two values with large residuals did not change the significance of effects.

The effect of trees was significant ($p < 0.05$, **Table 23**). The overall productivity in treed plots was 27% higher with a mean of $0.74 \text{ g m}^{-2} \text{ day}^{-1}$, whilst in the open plots it was 0.59 (**Figure 24**). All of this difference was attributable to the first three seasons and each of these contributed similar amounts to the differential in productivity, despite the level of productivity differing between these three seasons by a factor of at least three. The implication is that major pasture productivity differences can arise in any season.

The interaction of TIME*TREE was not significant and this indicated that the temporal pattern of pasture productivity was broadly similar in both the treed and open locations. Time had a highly significant effect on pasture productivity, with peak productivity occurring in spring in both years of the study. Summer productivity was moderate in 1995/6 (comparable to the following winter) but close to zero in the drier summer/autumn of 1996/7.

Table 23 Hierarchical ANOVA for pasture productivity measured in treed and open plots over five periods across the four sites. No test of site effects was appropriate. Probability values in bold are significant at 95% or better.

Source of variation	Degrees of freedom	Sum of Squares	Mean Square	F value	Probability
SITES	3	0.178	0.059	6.18	
Site.plot stratum					
TREES	1	0.244	0.244	25.49	0.015
Residual	3	0.029	0.010	0.16	
Site.plot.time stratum					
TIMES	4	8.397	2.099	35.83	< 0.0001
TIMES*TREES	4	0.155	0.039	0.66	0.626
Residual	24	1.406	0.059		
Total	39	10.410			

Pasture consumption

The pasture consumption was calculated as the difference between caged quadrats and grazed quadrats, expressed as a daily rate for the sample period. Pasture consumption values did not require transformation prior to ANOVA and the residuals were close to a normal distribution.

The consumption of pasture was significantly ($p < 0.05$) higher (**Table 24**) in the treed plots, which had a mean consumption of $0.69 \text{ g m}^{-2} \text{ day}^{-1}$ compared with the open plot consumption of $0.54 \text{ g m}^{-2} \text{ day}^{-1}$. This 27% higher level in treed plots is similar to the difference found in pasture productivity, but consumption was less variable across all seasons, as may be expected.

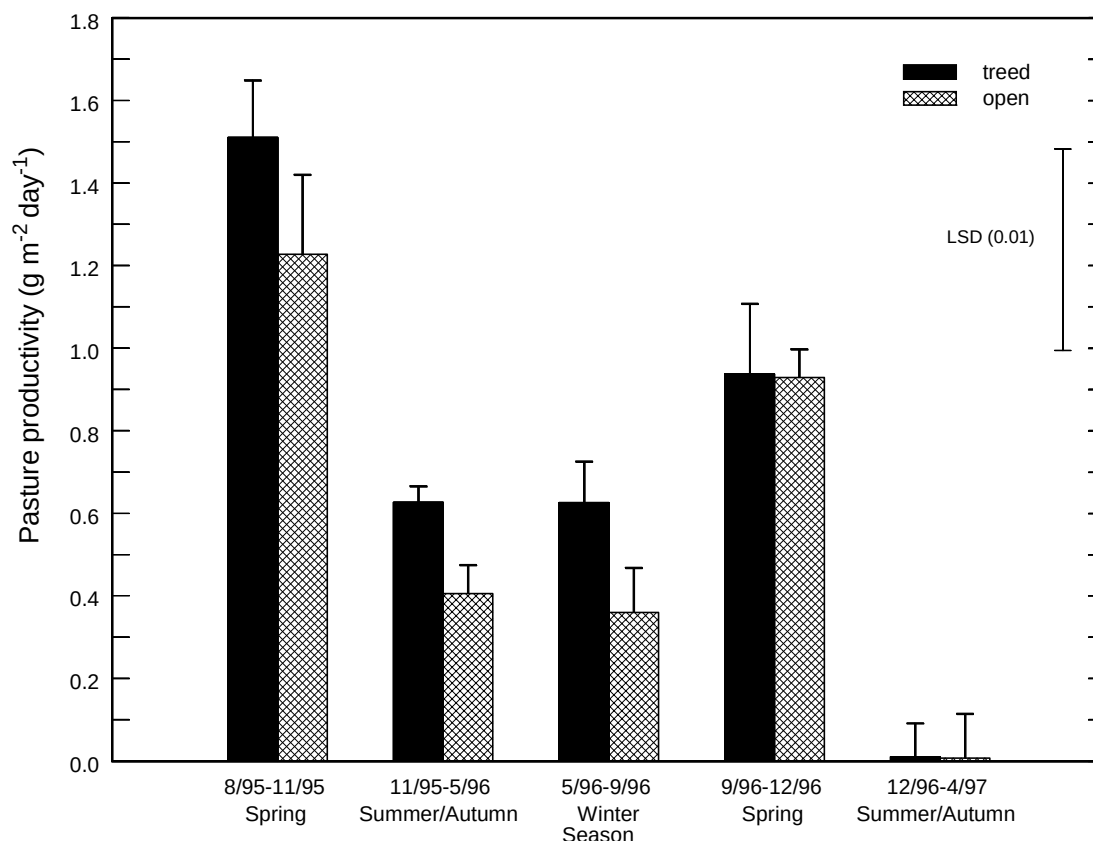


Figure 24 Mean pasture productivity in treed and open plots for consecutive seasons. Least significant difference shown is only for comparisons of mean productivity between times within the treed plots or within the open plots. Error bars show one standard error.

The interaction TIME*TREE was not significant, which indicated that the pattern of pasture consumption was similar over time in both the treed and open locations. There was a highly significant effect ($p < 0.01$) of time on consumption rates, with a major decline in consumption being seen in the drier late spring and summer of 1996/7 (**Figure 25**).

Generally, the patterns of consumption in relation to the treed/open comparison, followed the productivity ones, except that in the summer/autumn 1995/6 period, when production was higher under trees, consumption was the reverse. This period included a time when herbage mass in the open was much higher, and the stock may well have been responding to this difference.

Table 24 Hierarchical ANOVA for pasture consumption rate measured in treed and open plots over five periods across the four sites. No test of site effects was appropriate. Probability values in bold are significant at 95% or better.

Source of variation	Degrees of freedom	Sum of Squares	Mean Square	F value	Probability
SITES	3	0.306	0.102	8.01	
Site.plot stratum					
TREES	1	0.221	0.221	17.45	0.025
Residual	3	0.038	0.013	0.12	
Site.plot.time stratum					
TIMES	4	2.312	0.578	5.23	0.004
TIMES*TREES	4	0.849	0.212	1.92	0.140
Residual	24	2.653	0.111		
Total	39	6.380			

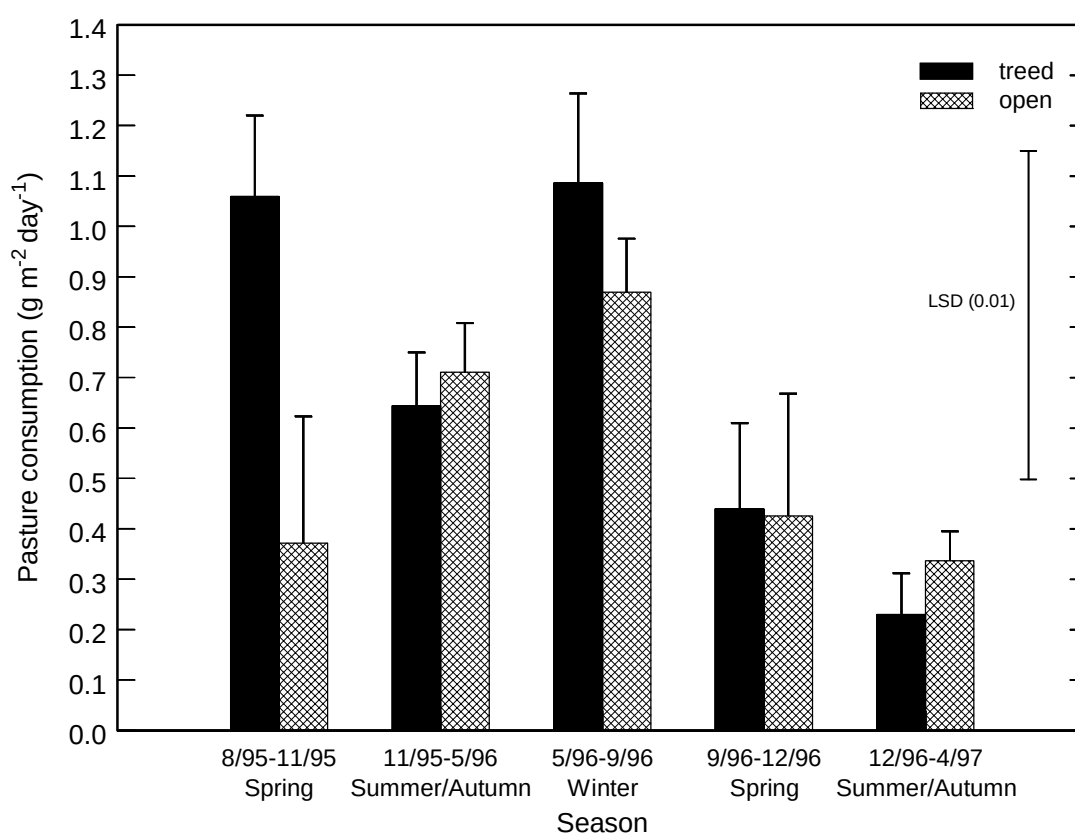


Figure 25 Mean pasture consumption rate in treed and open plots for consecutive seasons. Least significant difference shown is only for comparisons of mean consumption between times within the treed plots or within open plots. Error bars show one standard error.

Annual pasture production

Given the significant effect of trees on pasture productivity, it is also useful to examine the total amount of pasture produced on a seasonal basis. The total production under trees during the study period was 4.2 t ha⁻¹ and in the open it was 3.3 t ha⁻¹ (**Table 25**). This difference was not consistent across seasons, as the first three seasons contributed all of the increased production under trees (**Table 25**, **Figure 24**), while the last two seasons produced the same amounts of pasture in the two situations, with zero production in the last season.

Table 25 Summary of pasture produced in treed and open plots over five seasons. Values shown are means $\pm$ SE.

Season	Treed plot production (g m^{-2})	Open plot production (g m^{-2})
Spring 1995	155.6 $\pm$ 14.2	126.5 $\pm$ 19.8
Summer/Autumn 1996	105.3 $\pm$ 6.4	68.2 $\pm$ 11.6
Winter 1996	58.9 $\pm$ 9.3	33.9 $\pm$ 10.1
Spring 1996	102.2 $\pm$ 18.5	101.3 $\pm$ 7.4
Summer/Autumn 1997	1.5 $\pm$ 11.0	1.0 $\pm$ 14.5
Total	4.2 t ha ⁻¹	3.3 t ha ⁻¹

3.2 Comparisons with Tree Basal Area

This section reports the results for the survey plots, which were located so as to sample the range of basal areas within the same paddock as the fixed plots at each of the four sites. However, the sampling times cover only the 1996/7 growing season (**Table 7**). On each occasion these plots were assessed for pasture yield and tree basal area. On some occasions the pasture and soil quality were also assessed. Results in most cases have been presented by grouping the plots into basal area classes as shown in **Table 26**.

Table 26 Basal area classes used to group survey plots for ANOVA.

Class	Tree basal area class ($\text{m}^2 \text{ha}^{-1}$)	No. of plots
Open	0	47
Light	> 0 – 10	31
Moderate	> 11 – 20	53
Dense	> 20	30

Soil available P, TN, organic carbon and pH

Soil available P was determined for the top 15 cm of the profiles in December 1996 and April 1997. There was no statistically significant relationship found with TBA at any site or time. The mean available P for each site is shown in **Figure 26**.

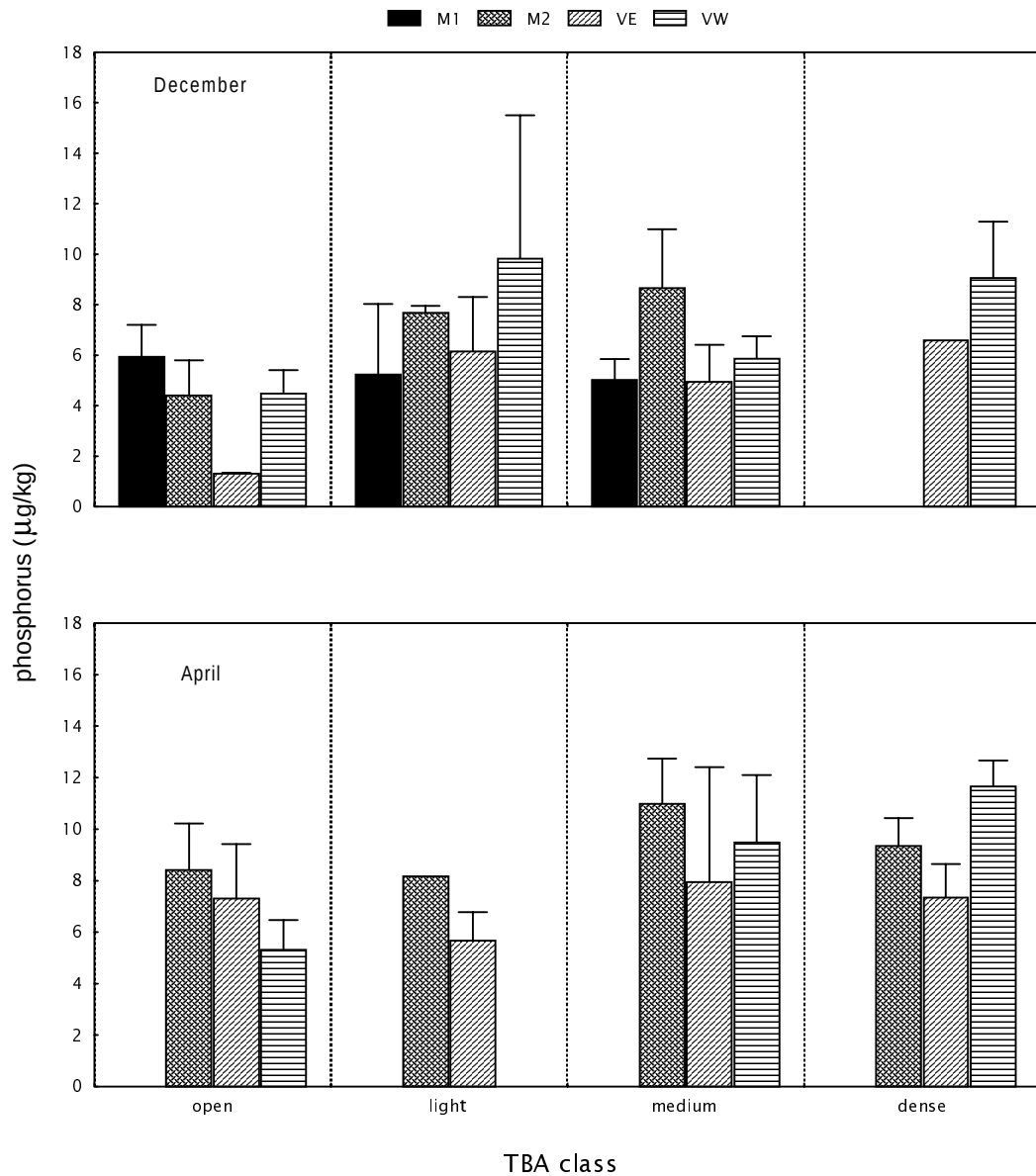


Figure 26 Mean ($\pm$ SE) soil available phosphorus in December 1996 and April 1997 at four sites in relation to tree basal area classes.

Soil total N was sampled three times over the season and only one instance showed a significant relationship with TBA. We conclude there is no overall relationship with soil TN. The means for each site are shown in (Figure 27). Soil organic carbon and pH likewise showed no relationship to tree basal area (Figure 28, Figure 29).

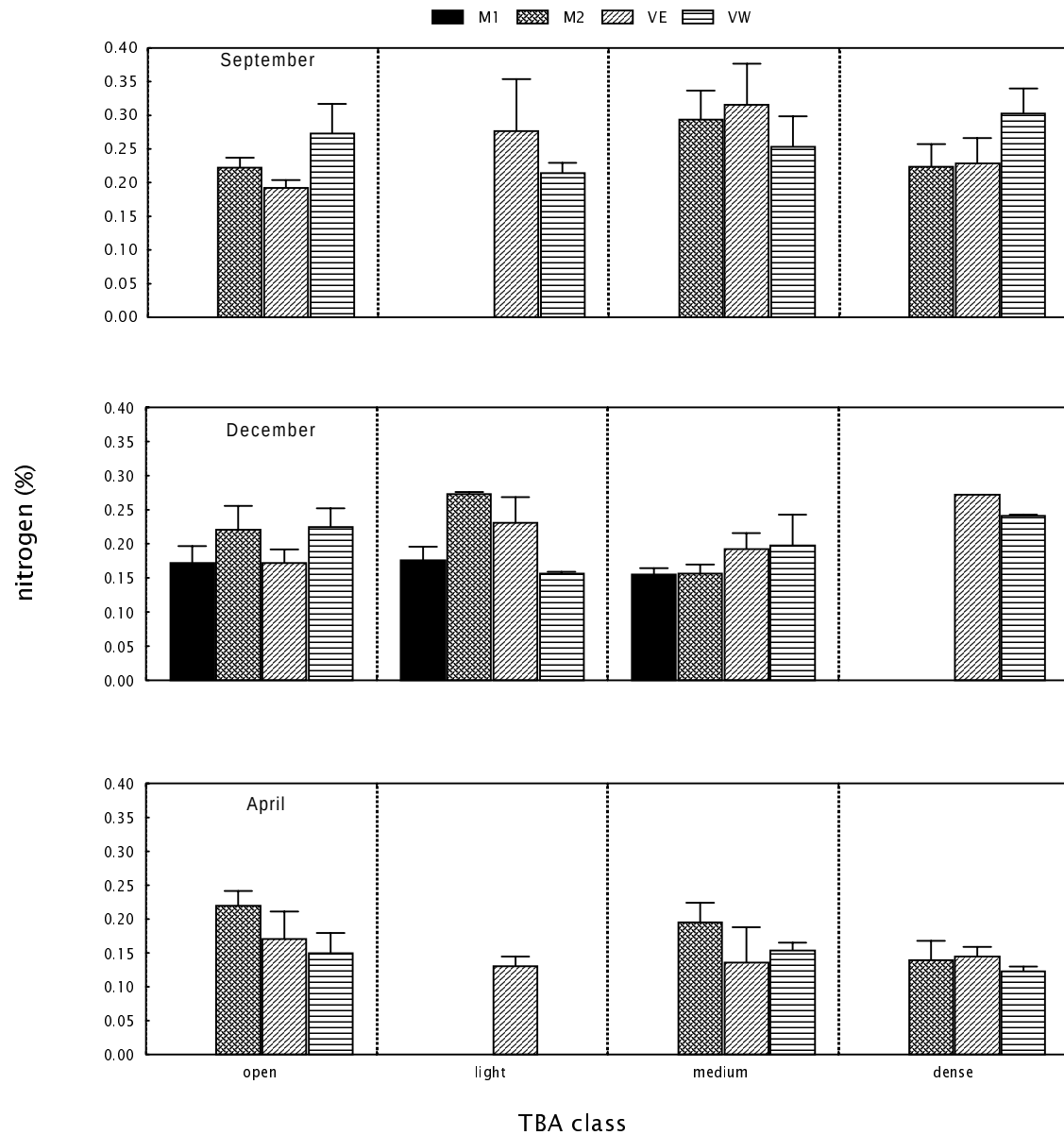


Figure 27 Mean ($\pm$ SE) soil nitrogen at three times (1996/7) at four sites in relation to tree basal area classes.

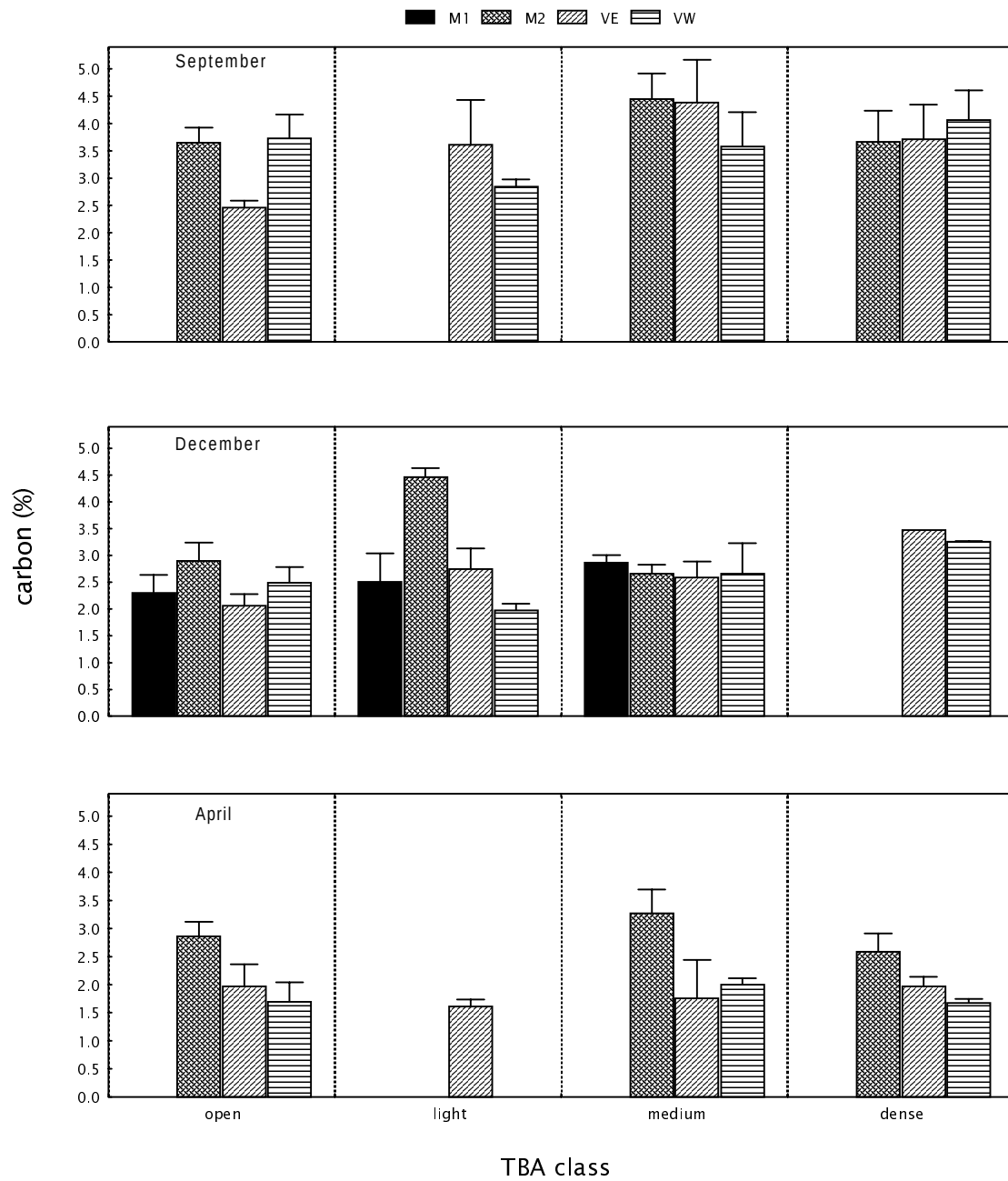


Figure 28 Mean ($\pm$ SE) soil carbon at three times (1996/7) at four sites in relation to tree basal area classes.

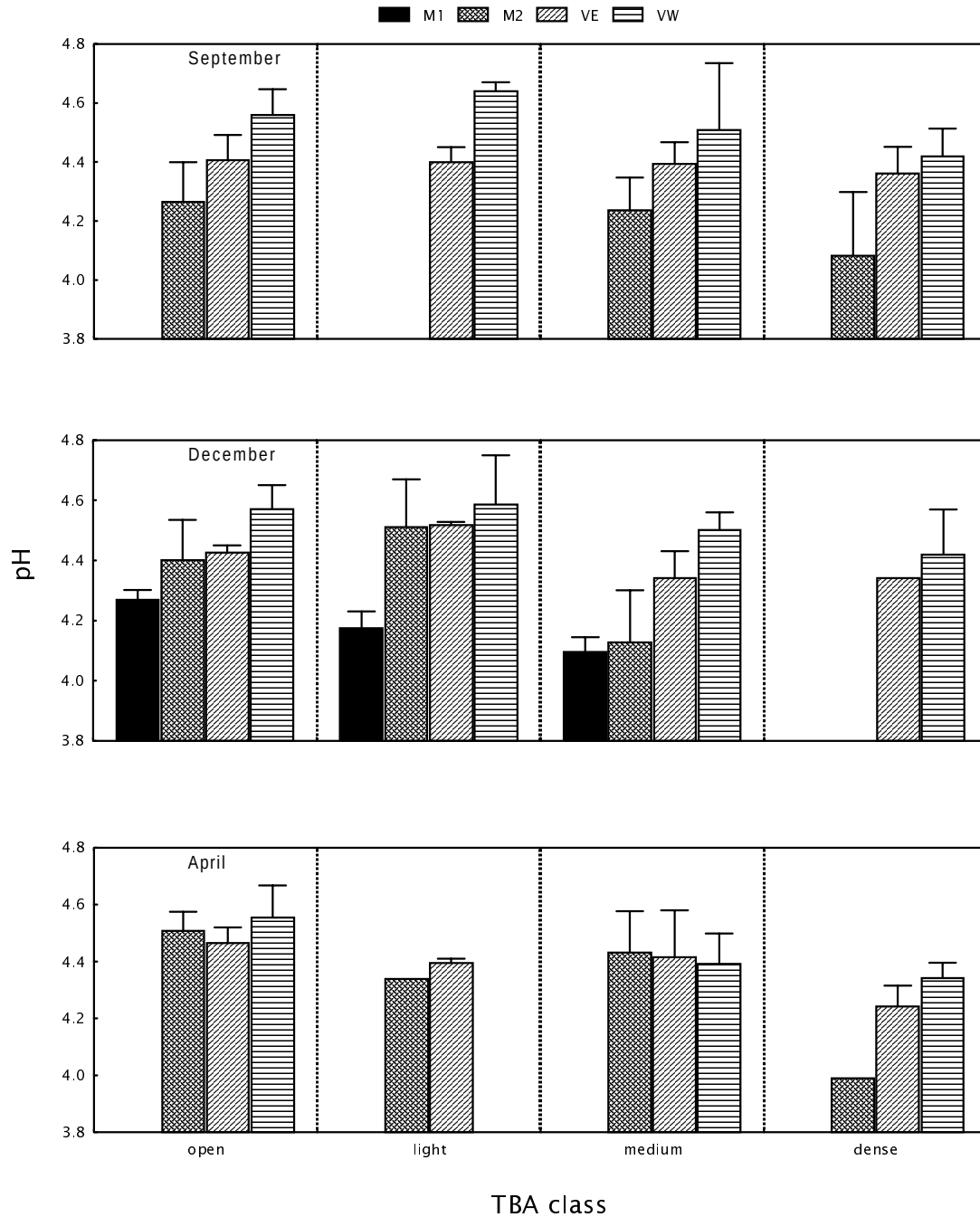


Figure 29 Mean ($\pm$ SE) soil pH at three times (1996/7) at four sites in relation to tree basal area classes.

Pasture composition

Pasture composition in relation to basal area in the paddocks was tested using the yield estimates apportioned between species on the basis of dry weight ranking (refer Methods). For the associated figures, the class “large tussocks” comprises the percentage contribution to biomass of *Poa labillardieri*, *P. sieberiana* and *Chionochloa pallida*. Because of differing pasture compositions we analysed trends in the composition of *Themeda*, *Microlaena* and large tussock species separately at each of the four sites using single-factor ANOVA.

In the box woodland sites (M1, M2) *Themeda* showed a strong and significant decline in its contribution to the pasture with increasing tree cover (**Table 27**, **Figure 30**, **Figure 31**). At

the other two sites it was not significantly related to TBA, although at VE there was a trend for increasing *Themeda* contribution with increasing TBA.

Table 27 ANOVA result and means for *Themeda* percentage contribution to herbage mass in relation to tree basal area in the survey plots in summer 1996/7. Similarly superscripted means are not significantly different using Tukey's HSD test.

Site	ANOVA summary	Tree basal area class			
		Open	Light	Moderate	Dense
M1	df=2,16; F=13.1; p<0.001	58 ^a	45 ^a	6 ^b	-
M2	df=3,16; F=3.6; p<0.05	83 ^a	68 ^a	47 ^a	21 ^a
VE	df=3,16; F=1.8; p=0.19	6.5 ^a	13 ^a	22 ^a	36 ^a
VW	df=3,16; F=0.63; p=0.60	10 ^a	3 ^a	9 ^a	8 ^a

Microlaena showed no trends in its contribution to the herbage mass in relation to TBA (Table 28, Figure 30 to Figure 33). At site VW there was an overall significant ANOVA but there were in fact no differences between TBA classes (Table 28) and no trend with increasing TBA.

Table 28 ANOVA result and means for *Microlaena* percentage contribution to herbage mass in relation to tree basal area in the survey plots in summer 1996/7. Similarly superscripted means are not significantly different using Tukey's HSD test. *Microlaena* was a very minor component in site M2.

Site	ANOVA summary	Tree basal area class			
		Open	Light	Moderate	Dense
M1	df=2,16; F=2.30; p=0.13	9 ^a	32 ^a	24 ^a	-
VE	df=3,16; F=1.38; p=0.29	50 ^a	42 ^a	30 ^a	38 ^a
VW	df=3,16; F=3.75; p<0.05	21 ^a	41 ^a	16 ^a	46 ^a

The large tussock species, although minor components of the pasture as a whole, showed significant relations with TBA at all sites (Figure 30, Figure 31, Table 29). The tussock species generally increased with TBA but there was some evidence from VE and VW that they decline at the highest levels of TBA.

Table 29 ANOVA result and means for *Poa* and *Chionochloa* percentage contribution to herbage mass in relation to tree basal area in the survey plots in summer 1996/7. Similarly superscripted means are not significantly different using Tukey's HSD test.

Site	ANOVA summary	Tree basal area class			
		Open	Light	Moderate	Dense
M1	df=2,16; F=4.94; p<0.05	4 ^a	4 ^a	3 ^b	-
M2	df=3,16; F=9.56; p<0.001	7 ^a	7 ^a	30 ^b	51 ^b
VE	df=3,16; F=4.23; p<0.05	2 ^a	2 ^a	26 ^b	4 ^a
VW	df=3,16; F=4.72; p<0.05	27 ^{ac}	21 ^{ac}	59 ^a	14 ^{bc}

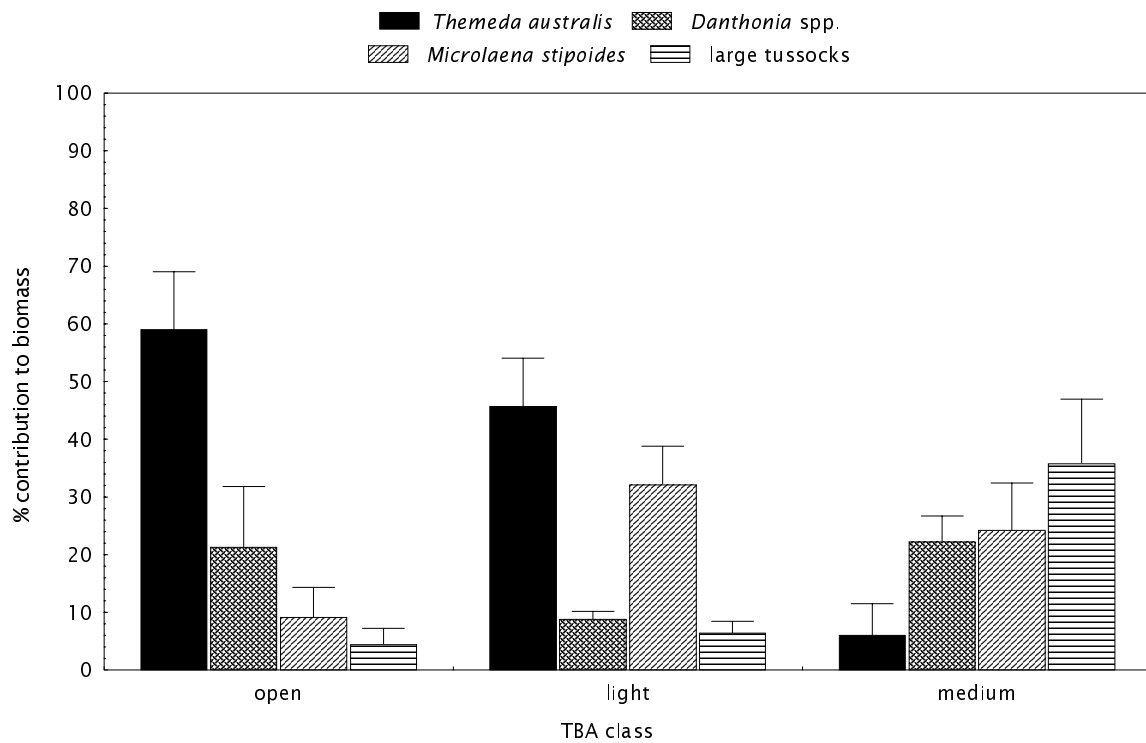


Figure 30 Change in percentage contribution to herbage mass by dominant grasses with basal area class: site M1.

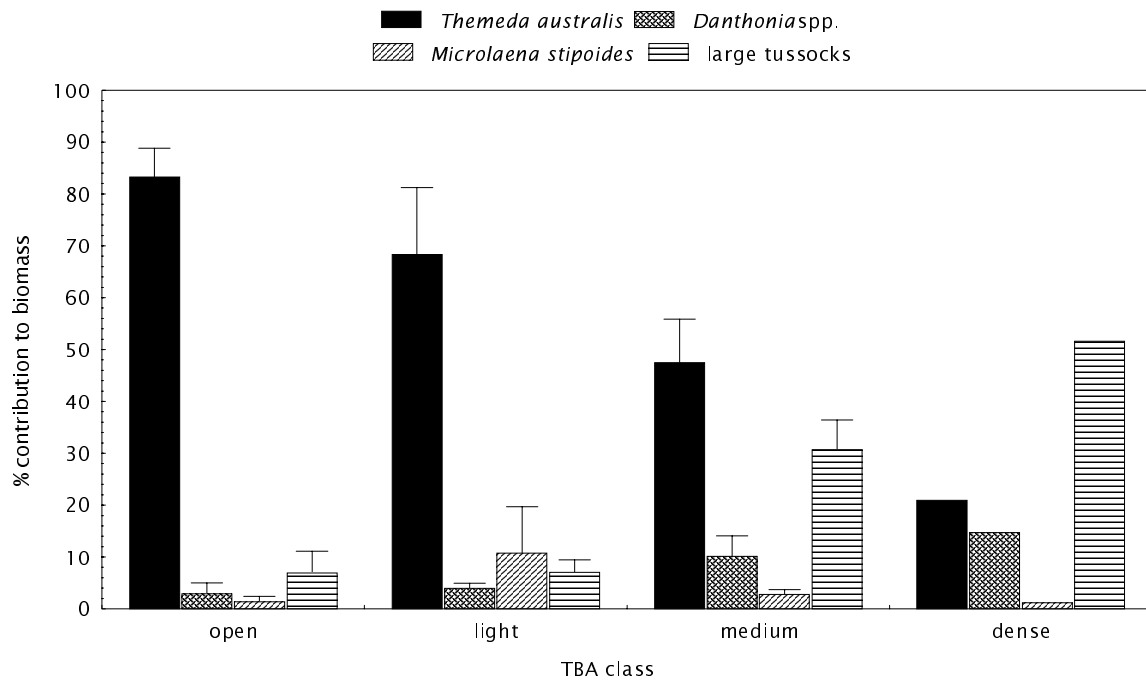


Figure 31 Change in percentage contribution to herbage mass by dominant grasses with basal area class: site M2

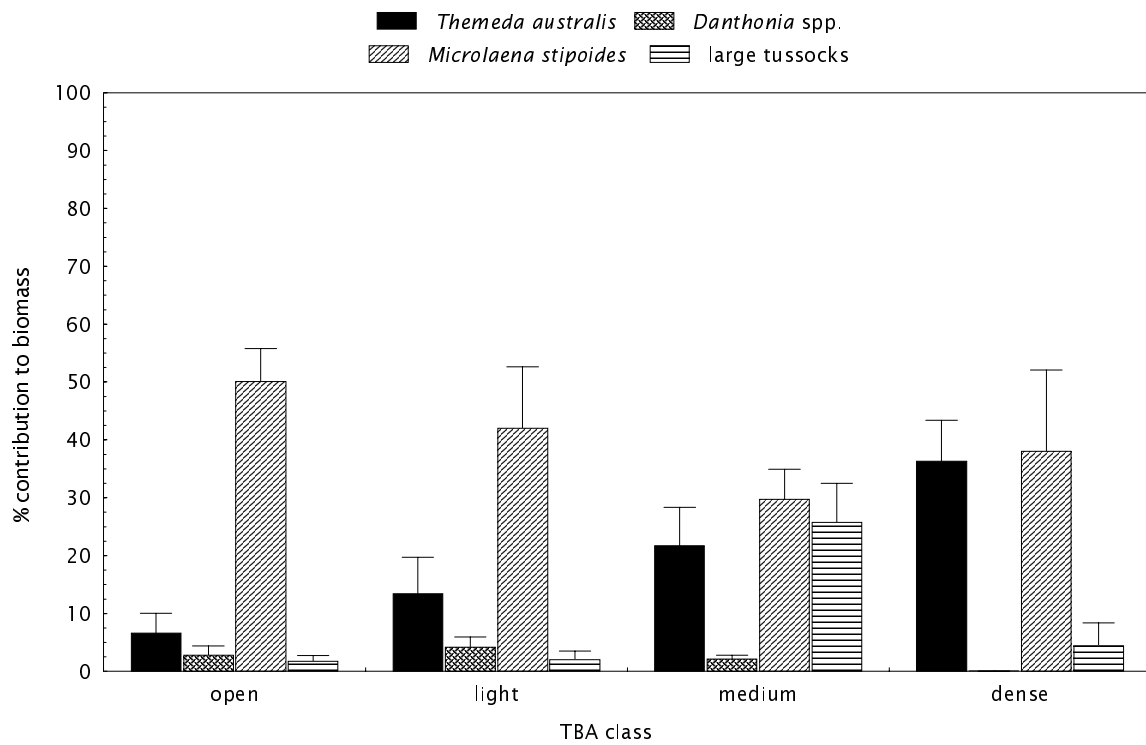


Figure 32 Change in percentage contribution to herbage mass by dominant grasses with basal area class: site VE.

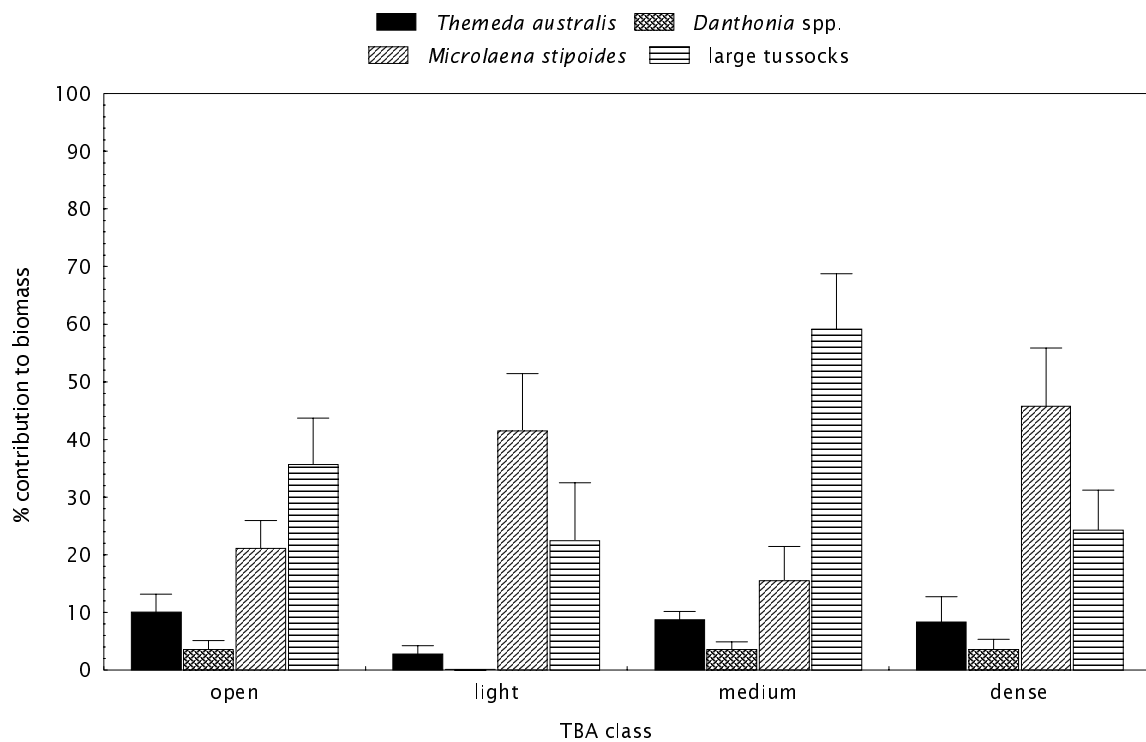


Figure 33 Change in percentage contribution to herbage mass by dominant grasses with basal area class: site VW.

Herbage mass

Herbage mass was sampled four times during the 1996/7 season in the survey plots at all sites. On occasions however, there was insufficient biomass to allow clipping of the quadrats. Results are presented for each site separately.

The relationship between herbage mass and TBA was dependent on site and harvest time. On many occasions there was no significant fit between herbage mass and TBA (**Figure 34, Table 30**). Where there was a significant relationship, the box woodland sites showed a decline in herbage mass with TBA whilst the snow gum site VE showed an increase in herbage mass with TBA. The other site (VW) showed no relationship (**Table 30**). We concluded there was no strong relationship between pasture mass and TBA in these paddocks.

Table 30 Correlation coefficient and probability for linear regression fit between herbage mass and tree basal area at each site on four occasions in the 1996/7 season.

Date	M1	M2	VE	VW
Sep 96	no data	$p < 0.05, r = -0.66$	$p < 0.05, r = 0.49$	NS
Dec 96	$p < 0.05, r = -0.65$	NS	NS	NS
Feb 97	NS	$p < 0.01, r = -0.80$	NS	NS
Apr 97	no data	$p < 0.01, r = -0.85$	$p < 0.05, r = 0.69$	NS

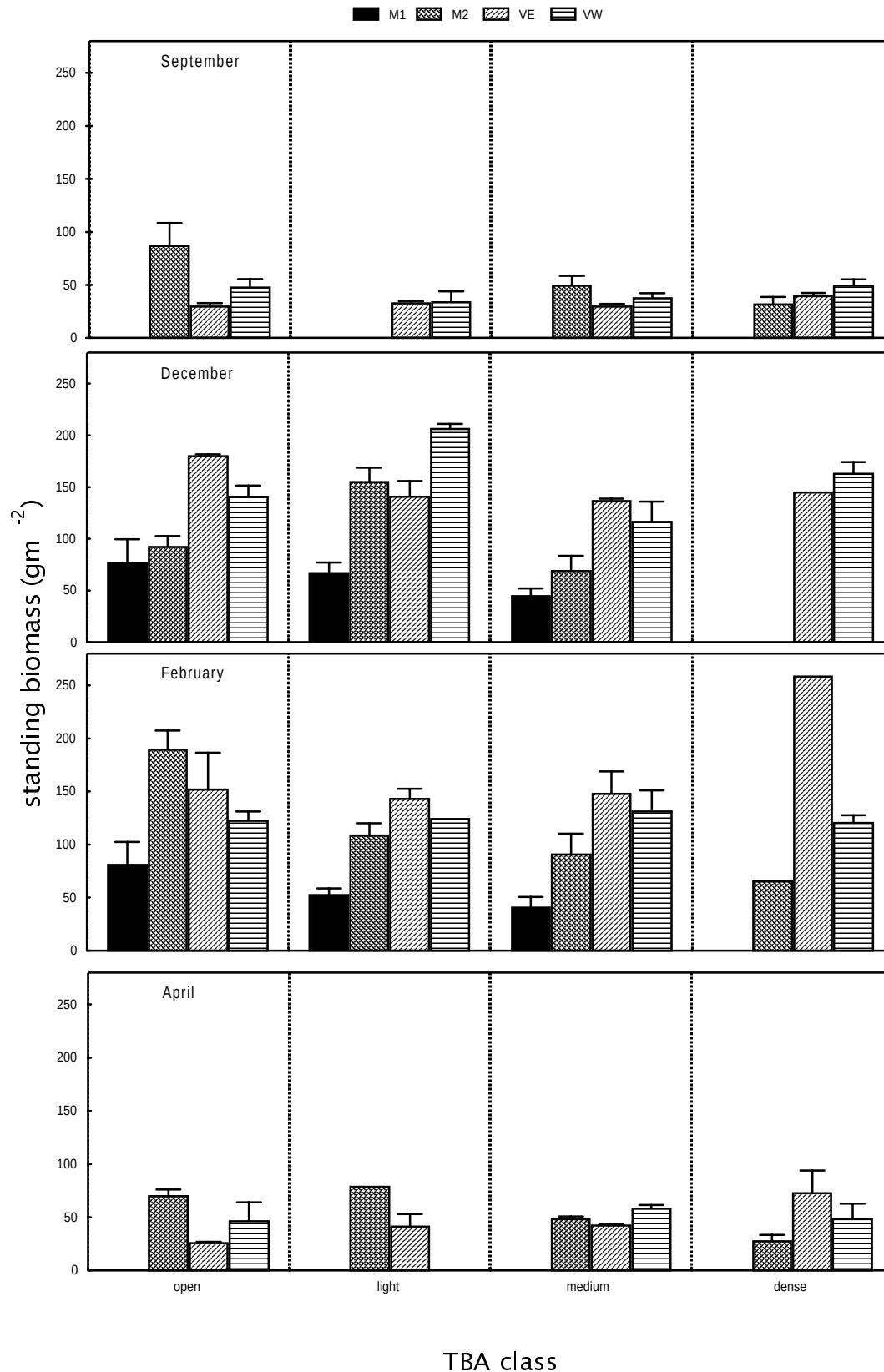


Figure 34 Mean ($\pm$ SE) herbage mass against tree basal area for the four sites at four times during the 1996/7 season. No data for M1 in September 1996 and April 1997 due to insufficient biomass to permit sampling.

Pasture quality: digestibility and nitrogen content

Pasture quality was assessed as *in vitro* digestibility by acid pepsin and as total N (a measure of protein content). Two different samples were taken. One was the bulk pasture sampled at three times in the 1996/7 season and the other was a selective sample of *Themeda*, *Danthonia* and *Microlaena* foliage taken in December 1996.

Bulk pasture

For this sample there was only one instance of a significant relationship between digestibility and TBA (M1 for December; $p < 0.05$, $r = 0.73$). We conclude that there was no overall relationship with TBA (**Figure 35**). The bulk pasture foliage TN also showed no relationship with TBA at any site or time (**Figure 36**).

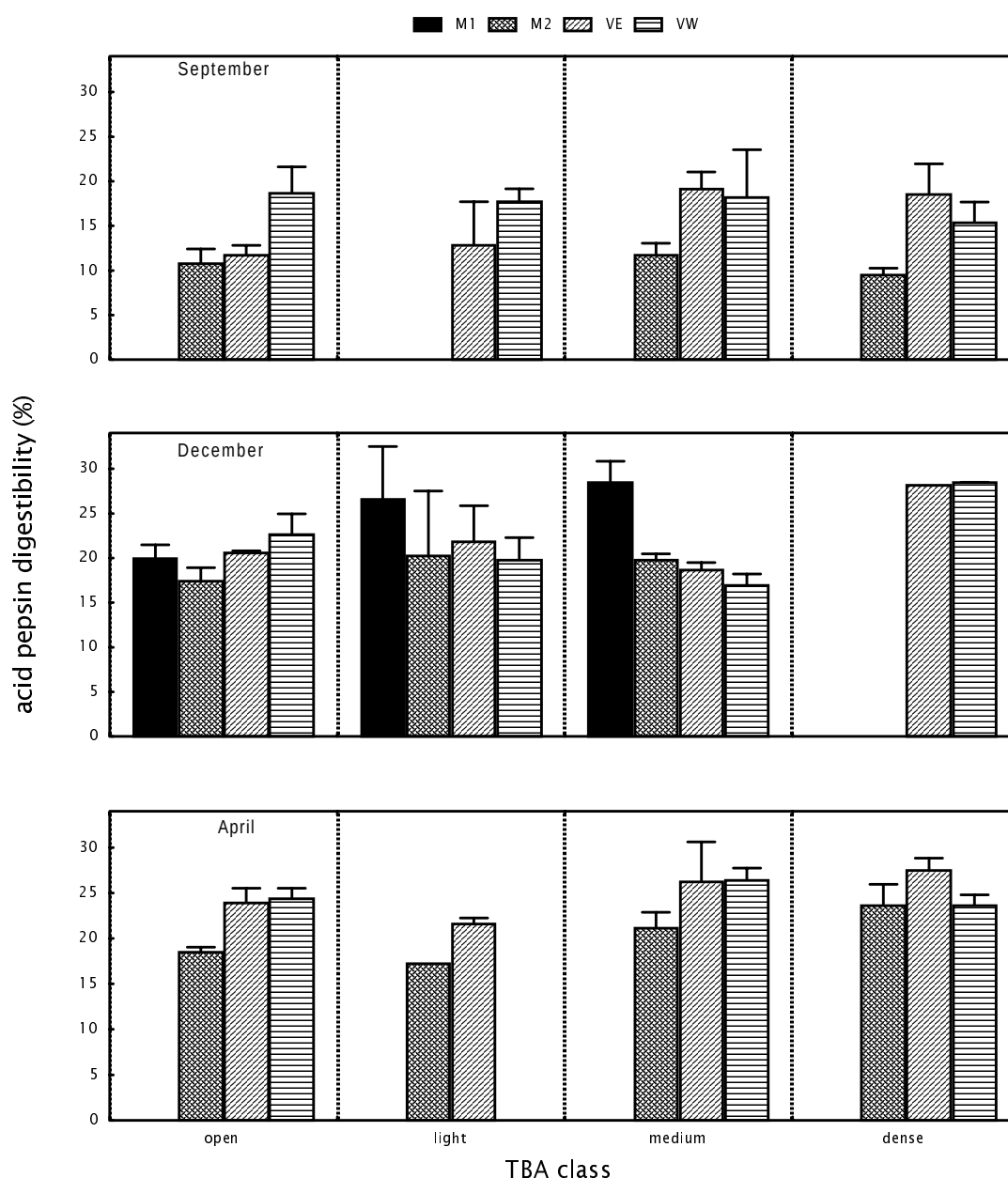


Figure 35 Mean ($\pm$ SE) acid pepsin digestibility of bulk pasture at three times at four sites in relation to tree basal area classes.

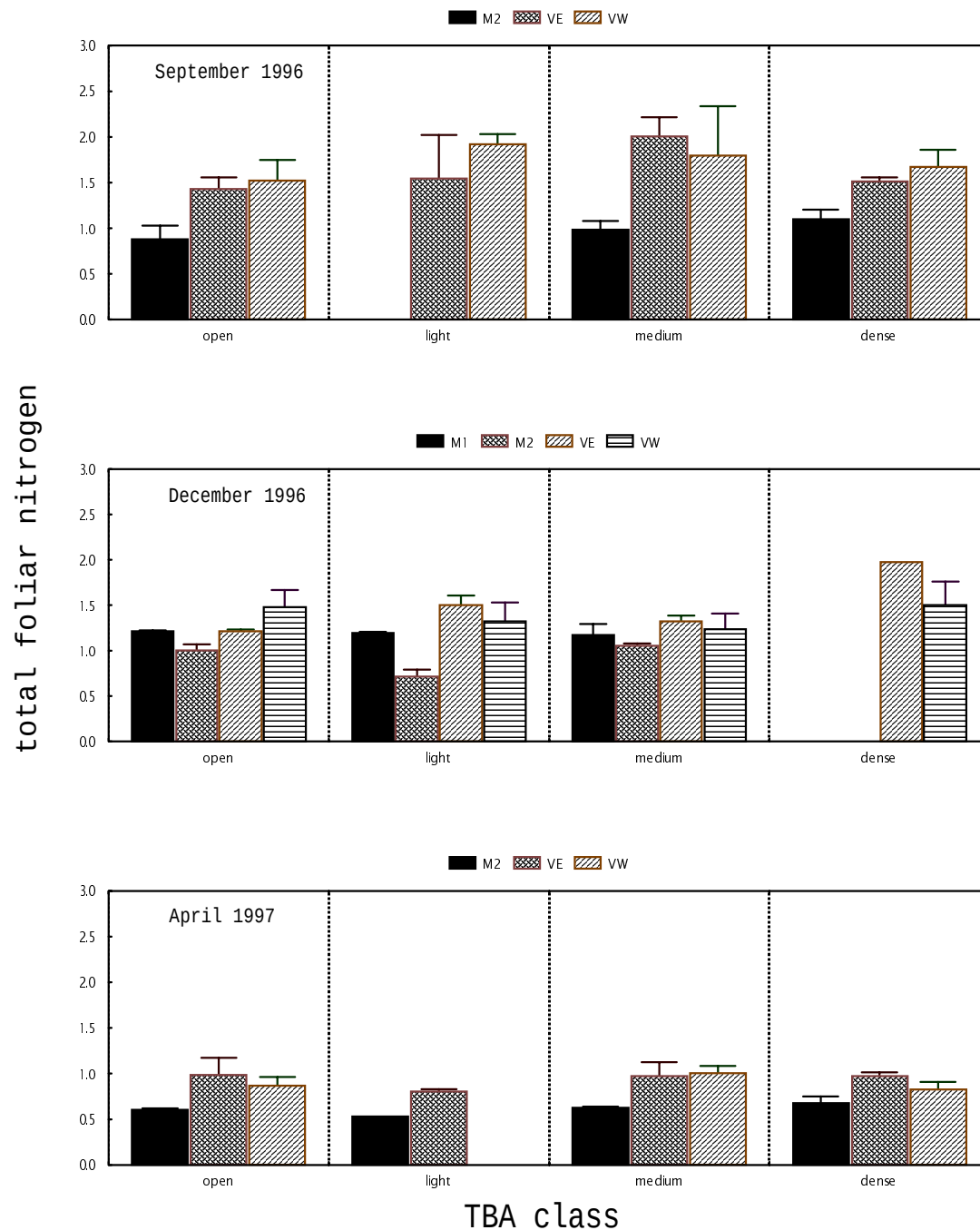


Figure 36 Total nitrogen content of bulk samples of pasture collected at three times in different tree basal area classes. No samples were collected from M1 in September and April due to low biomass. Error bars show one SE.

Pasture species

As with the bulk pasture sample, only one instance of the sample of the three species showed a significant relationship for digestibility (*Microlaena* at site M2, $p < 0.05$, $r = -0.93$). However, this result is of little significance as the species was a very minor component of that particular paddock. The digestibility means for the species are shown in **Figure 37**. The foliage TN for the three species also showed no relationship with TBA at any site or time (**Figure 38**).

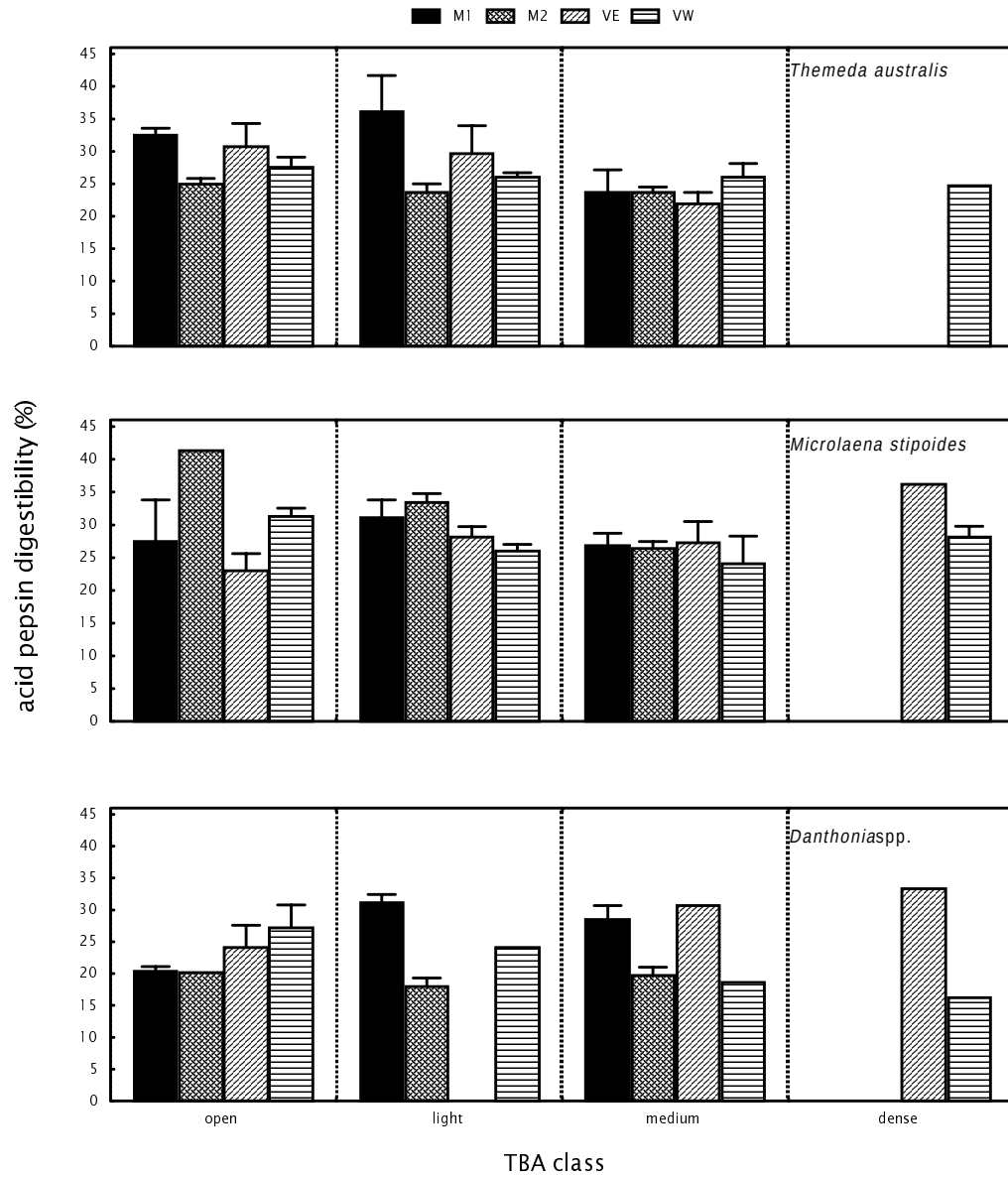


Figure 37 Mean ($\pm$ SE) acid pepsin digestibility for three pasture species at four sites in December 1996 in relation to tree basal area classes.

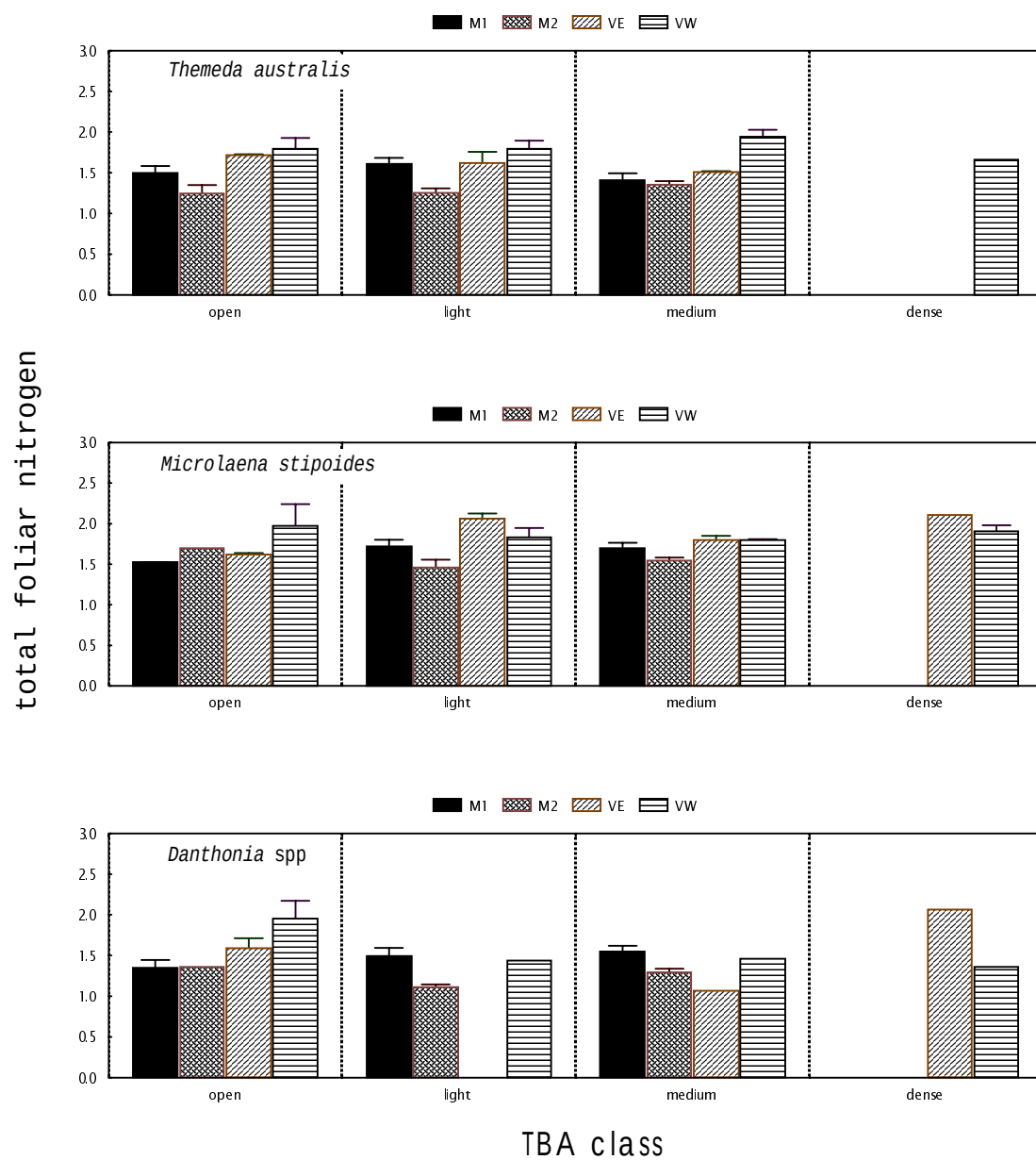


Figure 38 Total nitrogen content of samples of *Themeda australis*, *Microlaena stipoides* and *Danthonia* spp. collected in December 1996 in different tree basal area classes at each site. Error bars show one SE.

3.3 Simulation of Native Pasture Growth under Trees

Introduction

The data collected in the project were used in a preliminary evaluation of the capability of GRASP, a tropical native pasture growth model (McKeon *et al.* 1990), to simulate (1) growth of temperate native pastures, and (2) tree-pasture interactions in a temperate environment (i.e. the Southern Tablelands of NSW).

Only a brief description of GRASP is given here as each equation is described in detail by Littleboy and McKeon (1997). GRASP includes a one-dimensional model of soil water processes (infiltration, runoff, through drainage, soil evaporation, grass and tree transpiration; Rickert and McKeon 1982). Aboveground biomass pools (green, standing dead and surface litter) are simulated with sub-models of the processes of aboveground growth, senescence, foliage detachment, litter breakdown, animal intake and trampling (McKeon *et al.* 1982). Plant growth is calculated from soil moisture indices in combination with other climatic variables (solar radiation, temperature and vapour pressure deficit). Nitrogen availability for aboveground growth is simulated with empirical relationships describing nitrogen uptake per mm of transpiration. This approach allows for soil fertility limitations on plant growth to be represented in a simple way without simulating the whole nitrogen cycle. Only the competitive effects of trees are simulated in GRASP (Scanlan and McKeon 1993). Tree water use and resulting nitrogen uptake by trees are calculated as a function of tree basal area. In northern Australian rangelands these competitive effects dominate over the stimulatory effects of trees at a paddock scale (> 0.1 ha). Thus GRASP provides a simple, if not complete, analysis of soil water and pasture dry matter flow in native pastures and hence provides an approach for understanding the interaction of trees and pastures.

Although GRASP was developed for tropical perennial pastures it has been parameterised for temperate annuals in rangelands (Alice Springs, NT; Boolathana, WA; and Kinchega, NSW; McKeon *et al.* 1996). In these situations a general set of parameters was developed which simulated 50 to 70% of the observed variation in pasture standing dry matter (SDM or herbage mass) which is similar to the variation explained in independent validation studies for tropical perennial pastures (Day *et al.* 1997). With this type of parameterisation, GRASP has been used as a ‘minimalist’ approach to simulate pasture growth across Australia in lieu of more sophisticated regional models (Carter *et al.* 1996, Hall *et al.* 1997). In this study the above analyses of McKeon *et al.* (1996) were used as a starting point and further step-wise parameterisation was conducted.

Methods in model analysis

Because of the preliminary nature of this modelling study the procedure is described in detail and future action required to complete the study is discussed. The purpose of the preliminary study was to complete a first pass through the modelling analysis and the implications for long term simulations of pasture growth.

Climate Data

To reduce the time involved in constructing a complete daily climate record for each of the four sites (from 1995 to 1997), daily climate data were generated from the Australian daily climate surfaces (Carter *et al.* 1996) for one site only (VW, see **Table 4** and **Table 31**).

Table 31 Rainfall data sources for the four sites used in the simulation study. A = generated from surface for VW site; B= recorded for M2 site; C = recorded for VW site

Harvest date	M1	M2	VE	VW
13 Sep 1995	A	A	A	A
10 Oct 1995	A	A	A	A
27 Nov 1995	A	B	A	C
5 Apr 1996	A	B	A	C
15 May 1996	A	B	A	C
12 Sep 1996	A	B	A	C
3 Dec 1996	A	B	A	C
18 Apr 1997	A	B	A	C

Generated rainfall from the surfaces was used up to the time actual recorded data was available (November 1995). Hence simulations of the initial two harvests (August and November) are based on interpolated rather than actual rainfall. Actual rainfall was recorded at two of the four sites. The generated daily temperatures for 1996 have not been directly compared with actual temperatures but cursory analysis indicates general agreement at a monthly time scale (**Figure 39**). Radiation and vapour pressure deficit (VPD) generated from the surfaces have yet to be compared with actual data.

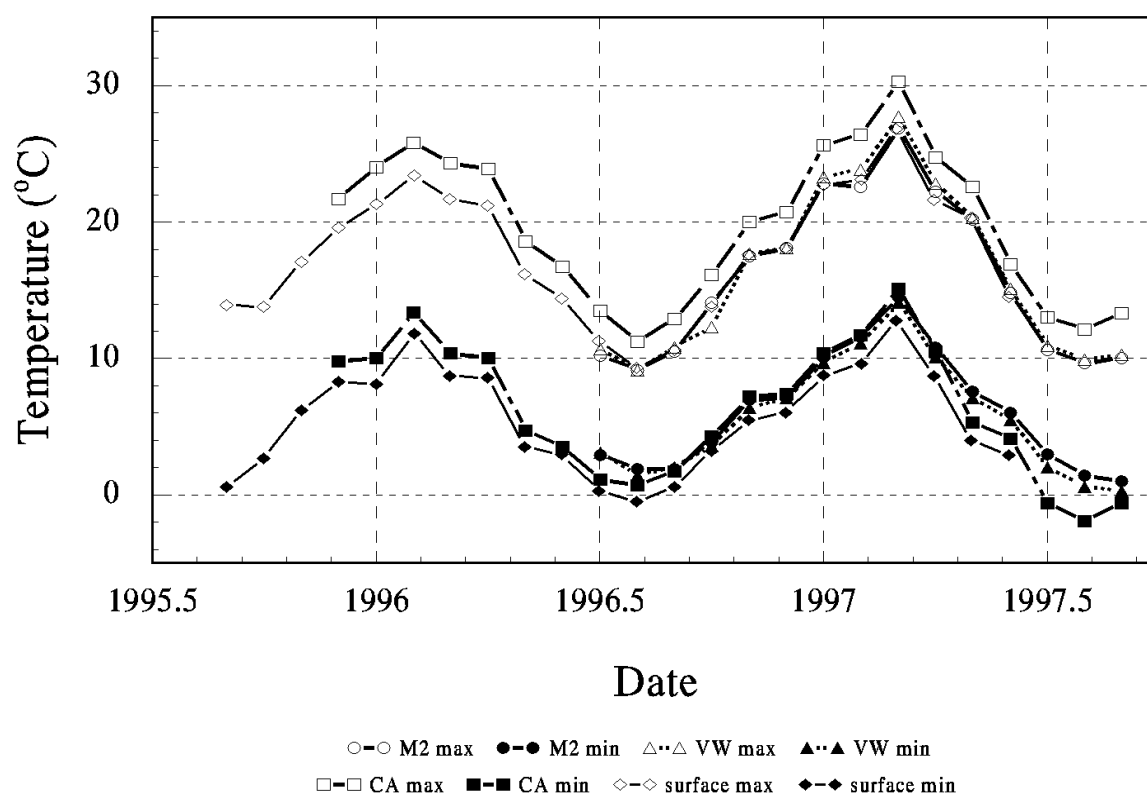


Figure 39 Average monthly maximum and minimum temperatures for M2, VW, CA (Canberra Airport) and climate surface.

Comparison of generated daily pan evaporation and calculated Penman evaporation indicated that generated values were too high, probably because of the bias resulting from using

Canberra Airport as the nearest meteorological station in constructing the surfaces (**Figure 40**). GRASP includes an option to calculate pan evaporation directly from VPD and hence this option was used to match the calculated Penman annual values reported earlier in **Table 4**. However, the use of a single coefficient ($Pan = \alpha.VPD$) did not capture all the within-year variation in Penman evaporation (**Figure 40**) and hence a multiple regression approach with solar radiation and VPD will be constructed for future use.

GRASP parameters (see **Table 32**) for this study were derived as follows:

1. Plant available water capacity (PAWC) was taken as 10 mm per 10 cm, typical for granitic-derived soils with the profile assumed to be 1 m in depth. Trees were assumed not to affect PAWC.
2. The cover/yield relationship, which drives transpiration, was based on point cover estimates at four sites in August 1997. Harvestable herbage mass at 50% cover was 120 kg ha⁻¹. A value of 100 kg ha⁻¹ was used in the following studies.
3. The soil water index at which plant growth stops was set at the average for perennial native pastures in northern Australia (0.3) and as used for temperate species in WA rangelands (McKeon *et al.* 1996).
4. The transpiration-based options for modelling plant growth were not used as this approach had not been successful in previous work on temperate rangeland species (McKeon *et al.* 1996).
5. The temperature effect on growth followed the study of Smith and Stephens (1976) in the Northern Tablelands of NSW.

Thus growth is calculated using a constant potential growth rate multiplied by a growth index (after Fitzpatrick and Nix 1970). This was the basis for previous studies in temperate environments (Smith and Stephens 1976) although it was found that potential growth rate had to be changed with season to simulate observed growth rates.

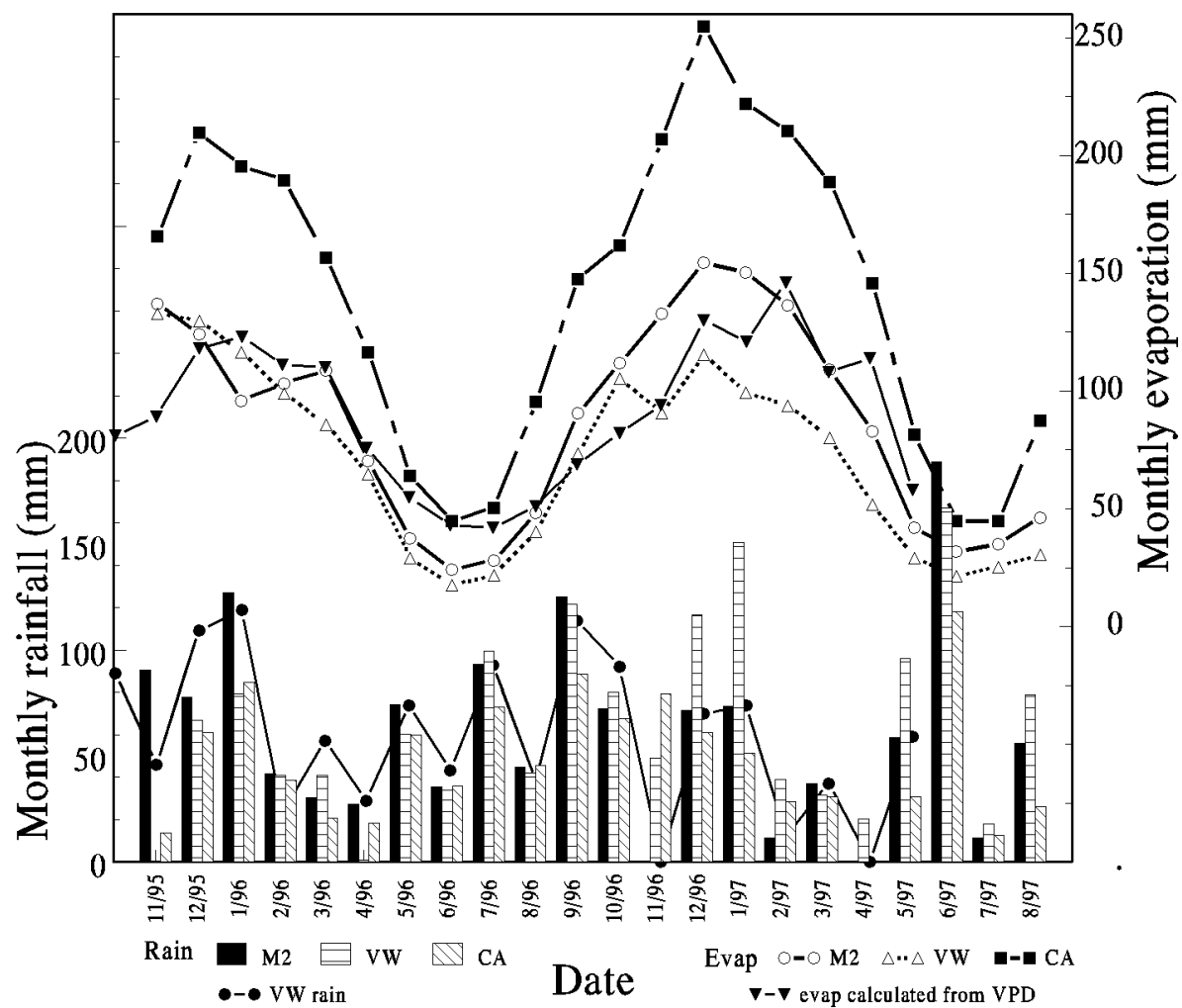


Figure 40 Monthly total rainfall and mean monthly potential evaporation for the study period at sites M2, VW, and Canberra Airport (CA), and the rainfall and evaporation used in the simulations.

Table 32 Parameter values used in GRASP for five pasture communities in Queensland, WA temperate annual rangelands and NSW Southern Tablelands (this study).

GRASP Parameters	GRASP Parameter No.	Black spear grass-lands	<i>Aristida Bothriochloa</i> grass-lands	Mulga grass-lands	Mitchell grass-lands	Queensland blue grass-lands	Average Qld native pasture	WA temperate rangelands	Southern Tablelands (Initial parameters)
Potential regrowth (kg/ha/day)	6	15.3	17.1	8.1	21.2	12.6	15.0	25	25
Potential regrowth per unit of grass basal cover	6	2.9	5.2	3.2	4.0	2.0	3.5	-	-
Grass basal cover per yield of 1000 kg/ha	159	0.8 - 3.2	1.4	2	1.2	-	1.3	-	-
Transpiration efficiency (kg /ha/mm @ 20 hPa)	7	11.4	12.3	7.2	19.8	16.7	13.5	-	-
Green yield at which potential transpiration is 50% of potential ET (kg /ha)	45	1060	560	950	1200	1100	1000	1000	100
Soil water index at which above ground growth stops	149	0.26	0.13	0.40	0.29	0.40	0.3	0.3	.30
Soil water index required to support 100% green cover	9	0.25	0.13	0.34	0.59	0.27	0.3	0.1	.40
Maximum annual N uptake (kg N/ha)	99	20.4	21.2	16.2	24.3	18.0	20.0	20.0	20.0
Rate of N uptake (kg N/ha per 100mm transpiration)	98	-	-	-	-	-	6.0	6.0	6.0
% N at which growth stops	101	0.44	0.41	1.20	0.86	0.47	0.68	1.00	0.70
Height of pasture at 1000 kg/ha	96	11	11	37	26	16	20	30	10
Radiation use efficiency (kg /ha per MJ/m ²)	8	-	-	-	-	-	12	12	12
Lowest temperature for growth (°C)	61	14	14	9	14	14	14	9	5
Temperature for 100% frost death (°C)	11	0	0	-9	0	0	0	-3	-15

Senescence parameters were set to commonly used values in northern Australia but the effect of frost on death of green tissue was removed. Detachment rates of standing dead material were set at values which are typical for short lived species in humid environments (e.g. 0.005 kg/kg/day or a half life of 140 days).

Data Organisation and Simulation of Field Procedure

GRASP has previously been used to simulate pasture yield measured in either exclosures which have been mown once a year or continuously grazed pastures. The field study in this project used cages for small time periods (27 to 136 days) to measure change in herbage mass (SDM), i.e. the green and standing dead pools). For the purposes of this simulation study, the

simulated green pool was reset to the initial yield of the plot (OY_1 , refer **Table 8**) on the date the enclosure cages were placed in the plots. GRASP has not previously been used to simulate pasture yields recorded using this methodology. Yields (CY_2) for the whole plot were estimated from the cage yield data at the end of the period. Simulated herbage mass was compared to measured at the end of the period.

A problem with this approach of simulating the actual field procedure with GRASP is that potential nitrogen availability is reset each time yield is reset (e.g. as is likely to occur due to mowing or burning at the start of the growing season). Changes to model code would be required to overcome this problem. However, preliminary analysis of data did not indicate there were periods where the lack of nitrogen availability was likely to be preventing growth.

Simulation analysis

The change in herbage mass measured in cages includes two distinct processes: leaf growth and leaf detachment from stems. The approach adopted here was to manually calibrate potential growth rate and detachment rates within the range of previously established values. More extensive calibration will be possible once soil moisture and nitrogen yield data have been included. **Table 33** shows the results of the step-wise calibration procedure.

Typical native pasture parameters were used initially with changes to temperature and frost responses (simulation 1, **Table 33**). Simulation of the components of the growth index shows the importance of temperature limitations in the Southern Tablelands environment (**Figure 41**). Although mean observed and simulated values were very similar, SDM was underestimated for 27 November 1995 at all sites and SDM was overestimated for 18 April 1997 for all sites (**Table 34**). For the measurement period ending in November 1995, rainfall for some of the period (starting 10 October) was derived from the generated rainfall surface, as measurements did not commence until early November. Hence rainfall errors could contribute to the lack of agreement. For the period December 1996 to April 1997, 150 mm of rainfall occurred in the first two months followed by a relatively dry period and low growth indices (**Figure 40**, **Figure 41**). There was little measured net change over the period in SDM indicating that detachment was equal to growth.

Table 33 Simulation studies of pasture standing dry matter (SDM) with different parameterisation of GRASP for Open and Treed sites. Each study involved four sites and eight harvest periods at each site.

Simula- tion study No.	Simulation parameters used	Potential growth rate kg/ha/day	Detach- ment rate (1 Dec. to 30 April) kg/kg/day	Root mean square	Mean observed SDM	Mean simulated SDM	R ² (n = 32)
1	Open plots, default parameters	25	0.005	349	1155	1144	0.573
2	Increase in potential pasture growth	35	0.005	432	1155	1338	0.585
3	Increase in potential growth and leaf detachment	35	0.010	257	1155	1162	0.776
4	Treed plots with calibrated parameters as for study #3	35	0.010	508	1069	732	0.490
5	Treed plots at zero tree density	35	0.010	303	1069	1038	0.637
6	Increased potential pasture growth	45	0.010	487	1069	798	0.358
7	Decrease leaf detachment rates	45	0.002	368	1069	1078	0.469

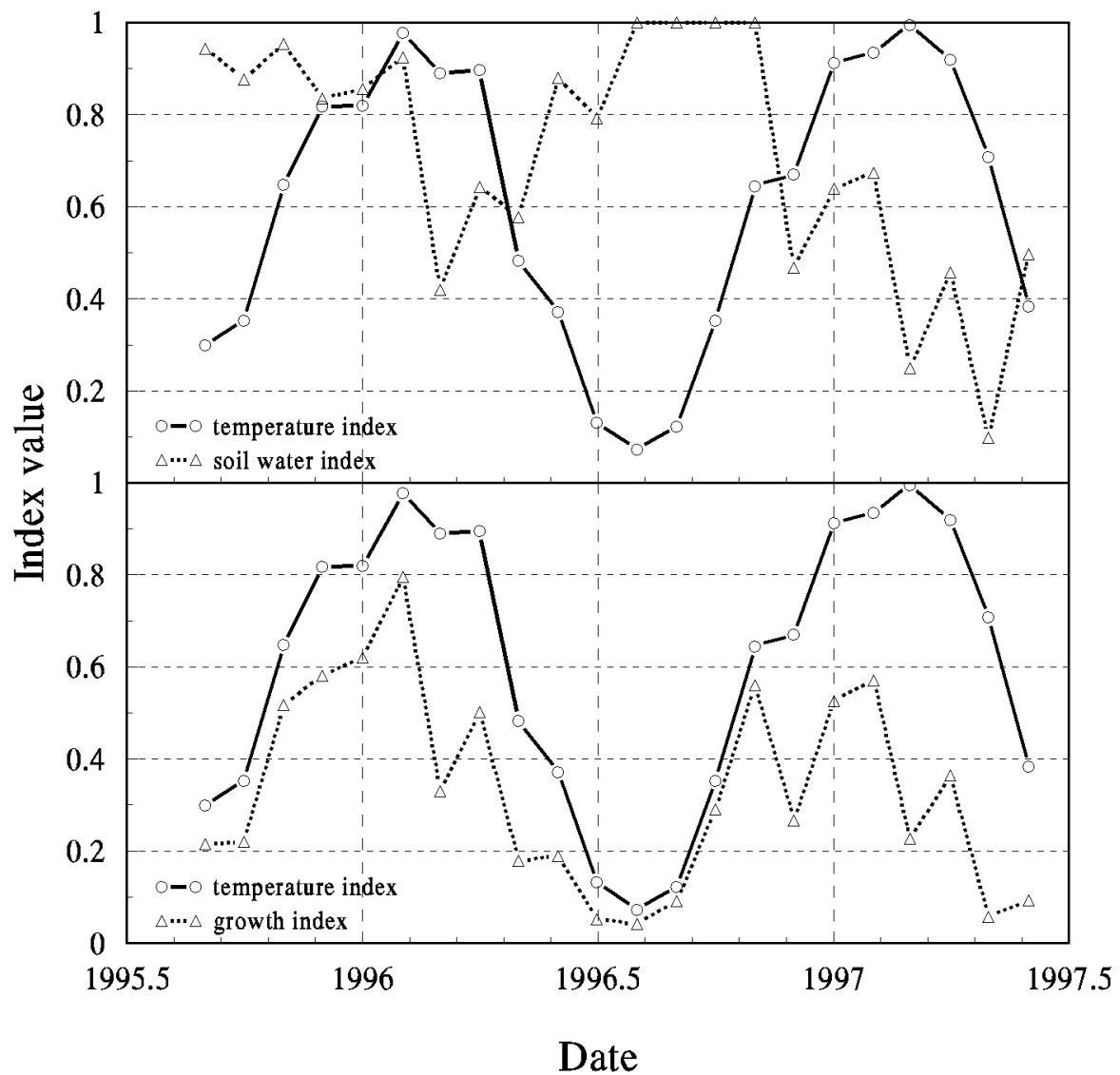


Figure 41 Temperature, soil water and growth indices for the M1 site in the Southern Tablelands environment.

Simulations 2 and 3 show possible approaches to improve parameterisation. In simulation 2 potential growth rate was increased to 35 kg/ha/day to account for the previous underestimation in November 1995. Such a value is a realistic potential growth rate for native temperate pastures (Mott *et al.* 1985). In simulation 3, detachment rates in the warm season (1 December to 30 April) have been increased to 0.010 kg/kg/day to represent the more rapid disappearance of dead material (half life 70 days). At most sites this parameter change resulted in improved prediction in April in both years (**Table 34**).

Table 34 Observed and predicted pasture standing dry matter (SDM) for open plots.

Site	Date	Observed SDM (kg/ha)	Predicted SDM for simulation No.		
			1	2	3
M1 Open	13 Sep 1995	693	889	964	963
	10 Oct 1995	425	534	615	615
	27 Nov 1995	1680	1074	1325	1325
	5 Apr 1996	1993	2120	2580	1823
	15 May 1996	1052	1078	1151	1064
	12 Sep 1996	1049	1083	1109	1109
	3 Dec 1996	1038	857	1103	1088
	18 Apr 1997	731	1168	1438	957
M2 Open	13 Sep 1995	479	600	683	683
	10 Oct 1995	698	812	906	905
	27 Nov 1995	1323	839	1128	1128
	5 Apr 1996	2105	2415	2920	2162
	15 May 1996	1002	1180	1246	1149
	12 Sep 1996	955	1043	1088	1088
	3 Dec 1996	1324	1115	1375	1356
	18 Apr 1997	1044	1875	2288	1550
VE Open	13 Sep 1995	463	368	450	449
	10 Oct 1995	316	434	517	517
	27 Nov 1995	1295	804	1072	1072
	5 Apr 1996	1601	1778	2232	1635
	15 May 1996	1265	1141	1214	1120
	12 Sep 1996	1348	1124	1150	1150
	3 Dec 1996	1445	1001	1240	1223
	18 Apr 1997	1049	1448	1719	1102
VW Open	13 Sep 1995	612	803	878	877
	10 Oct 1995	439	1063	1148	1148
	27 Nov 1995	1917	1343	1591	1591
	5 Apr 1996	2243	2183	2643	1856
	15 May 1996	1277	1074	1147	1060
	12 Sep 1996	1428	1096	1122	1122
	3 Dec 1996	1756	1183	1416	1396
	18 Apr 1997	925	1088	1357	916

This combination of parameters had a root mean square of 257 kg/ha, representing 22% of the mean SDM and explained 78% of variation in SDM measured at the end of each period. Some of the variation explained may be attributed to the fact that the simulated SDM was reset to the measured SDM for each site at the start of each period. However, initial yield explained only 22% of final yield variation (**Figure 42**), hence the simulation with GRASP accounts for a high proportion of observed SDM. Standard error of measured SDM ranged from 2 to 48% (mean 20%) of mean SDM values, which is comparable to the level of variation in results produced by the simulation.

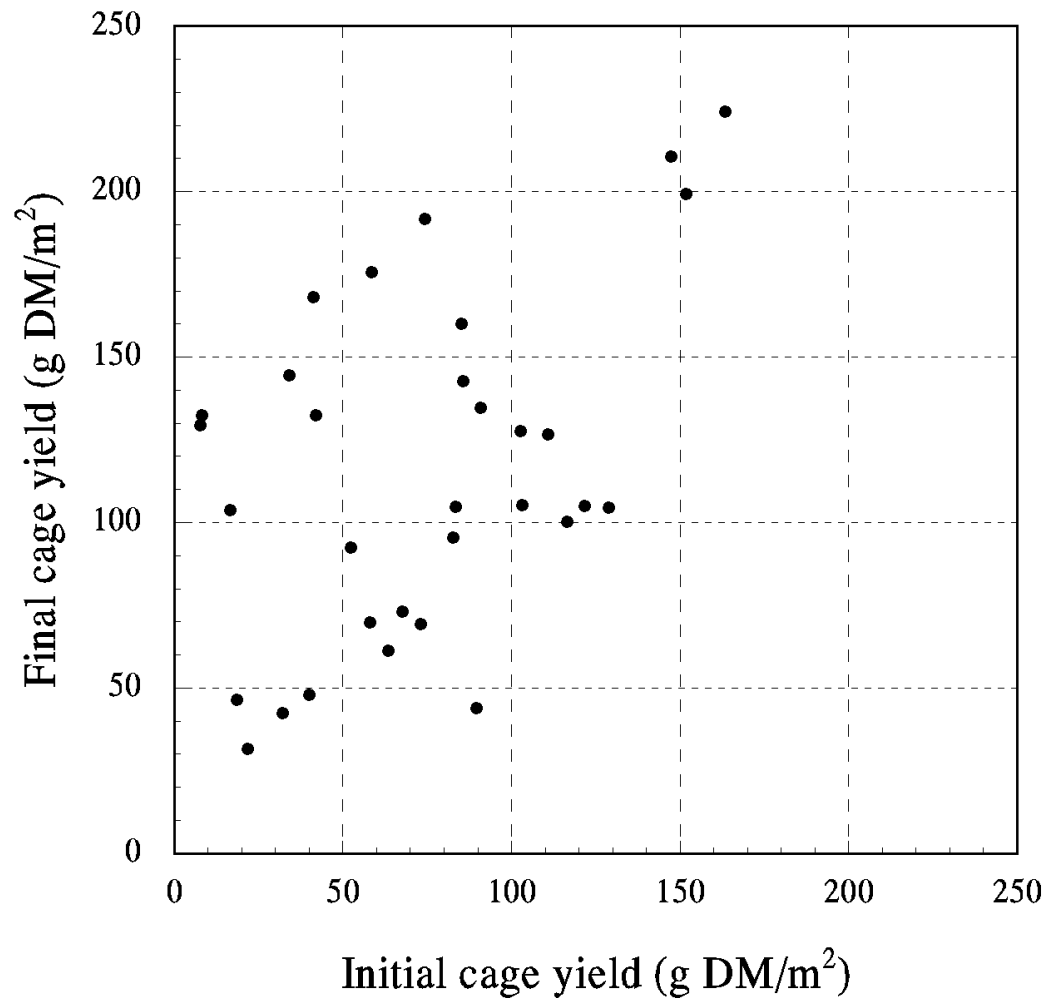


Figure 42 Relationship between initial cage yield and final cage yield for the four open plots.

The regression of observed and simulated indicated that the SDMs less than 1 t/ha are overestimated whilst SDMs greater than 1 t/ha are underestimated by the model (**Figure 43**). Other approaches to parameterisation could be explored once soil moisture and nitrogen parameters have been derived for each site. The above analysis suggests that compared to temperate rangelands, native pastures in this study had high potential growth rates with possibly rapid disappearance of dead material during the warm season.

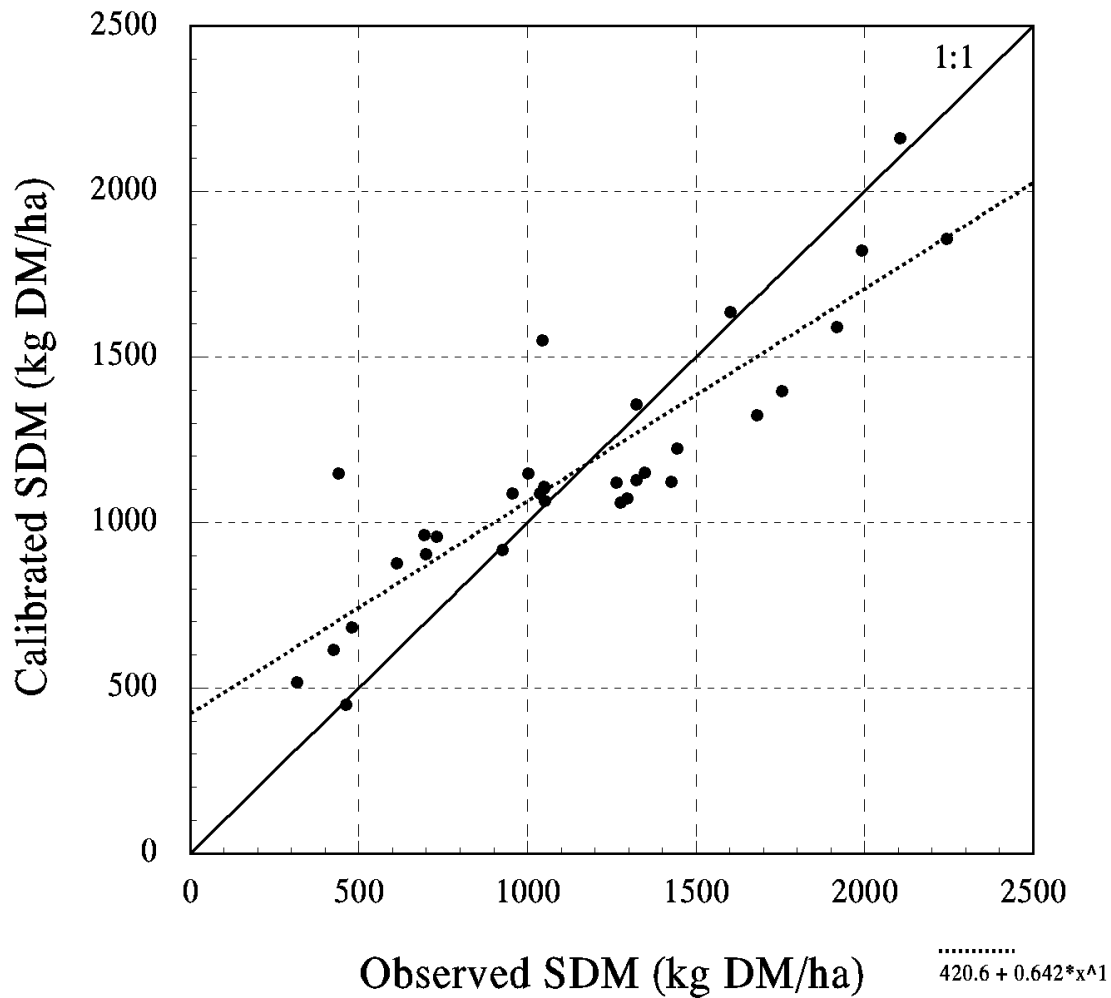


Figure 43 Relationship between observed and calibrated SDMs for the four open plots (simulation 3).

Simulating the Effects of Trees

GRASP simulates tree transpiration as a function of tree basal area. Hence relatively high tree densities result in lower soil water indices being simulated especially during spring and summer (**Figure 44**). The simulated growth index for the tree plots was highly correlated ($R^2 = 0.906$) with the open plots but was on average 23% lower (**Figure 45**).

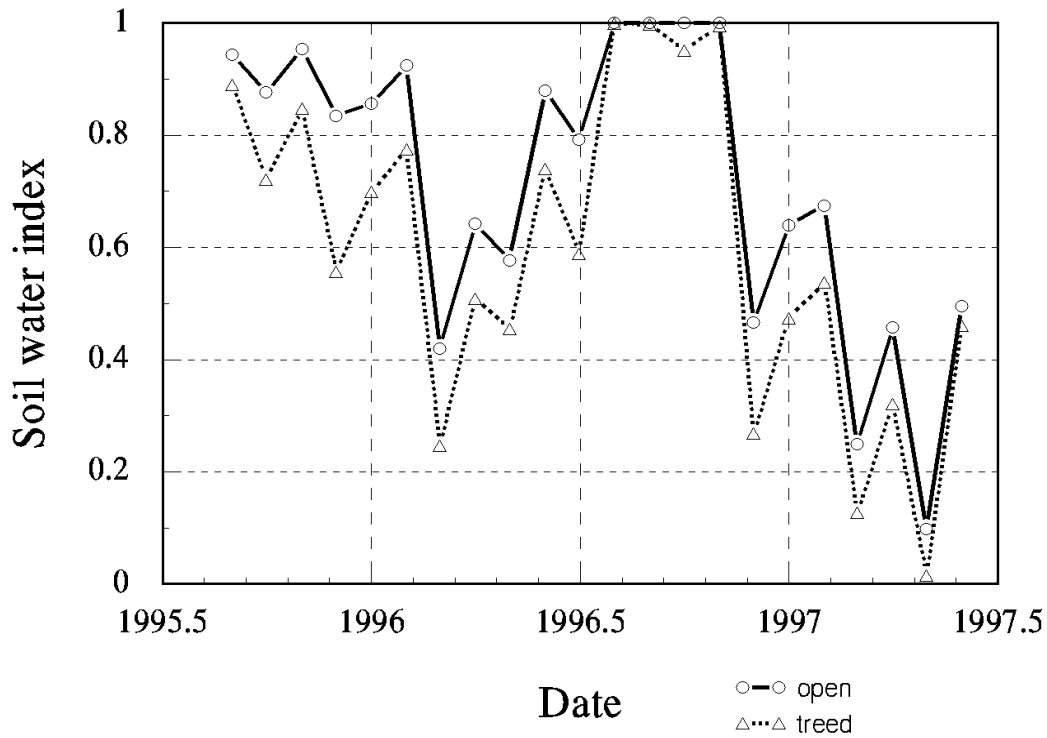


Figure 44 Soil water index for open and treed plots at the M1 site as simulated by GRASP.

Average measured SDMs at the end of each growth period were similar for treed and open plots (**Table 33**). However, the net changes in SDM (i.e. production) for treed plots were either equal (≈ 20 cases) or substantially greater than the paired open plots (≈ 10 cases, **Figure 46**). Not surprisingly the model substantially underestimated measured SDM when the effects of trees on soil water are simulated. When tree density was set to zero the simulated SDMs were similar to measured values (RMS=303 kg/ha, $r^2=0.637$, $n=32$). However, it is reasonable to expect that trees are using some water (and nutrients) otherwise available to pasture and hence some explanation of the lack of tree effect is examined further here.

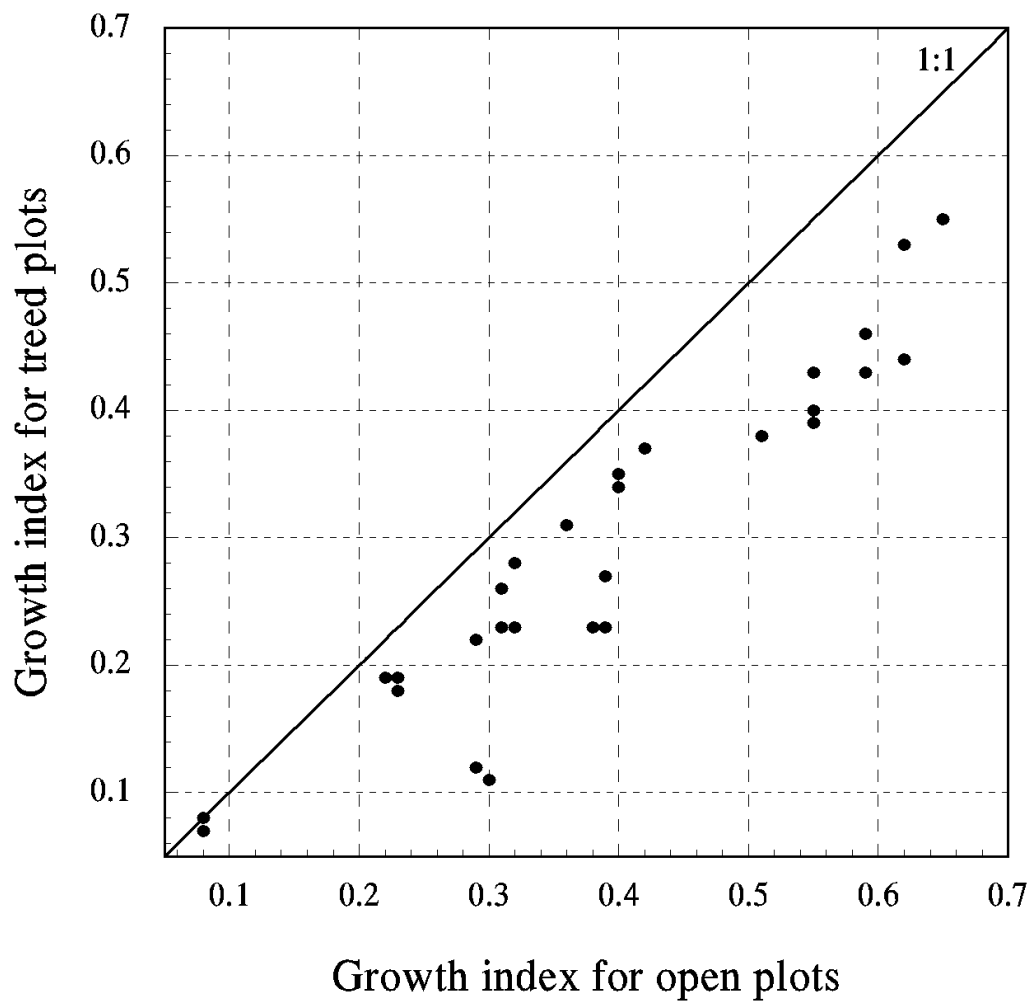


Figure 45 Relationship between the growth index for open and treed plots as simulated by GRASP.

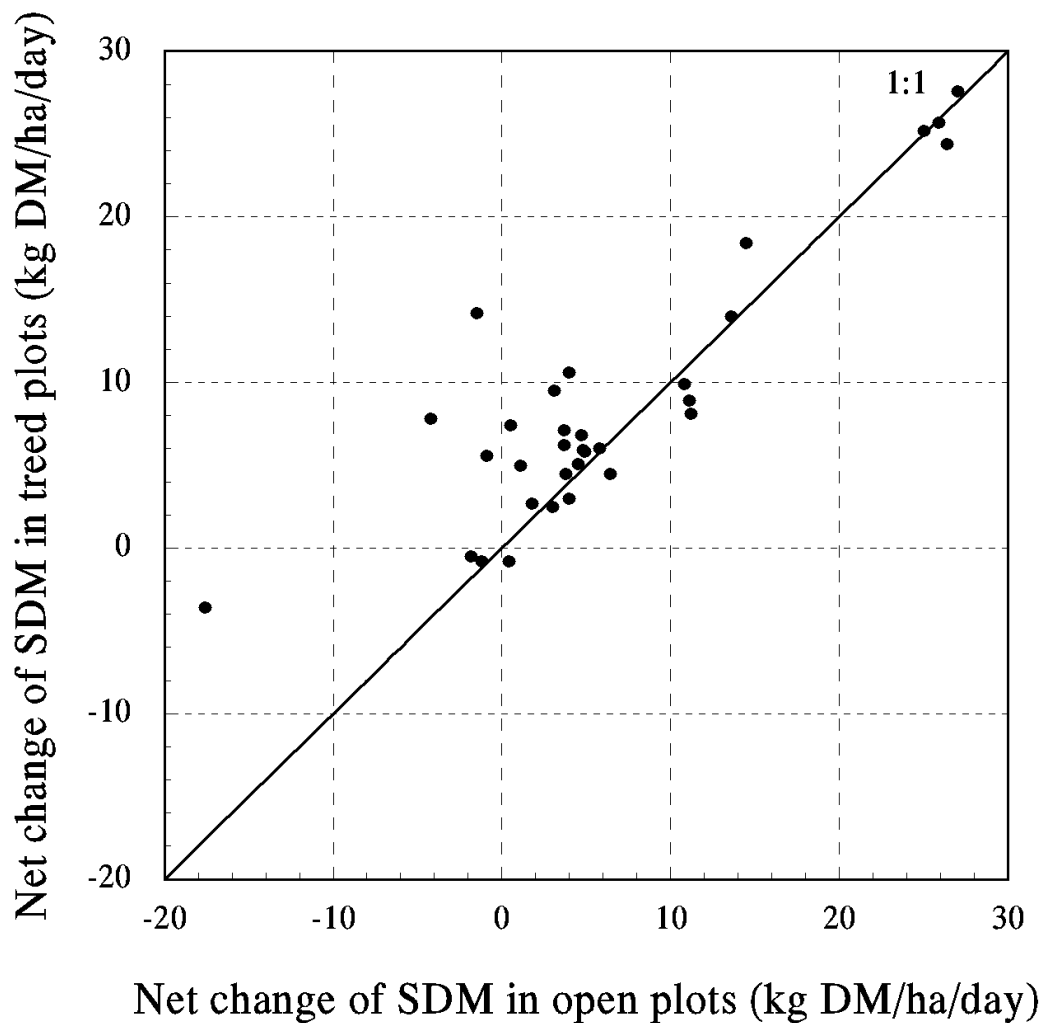


Figure 46 Comparison of observed net change in SDM for open and treed plots.

Several possibilities exist:

1. For several reasons, GRASP probably overestimates tree transpiration in cold temperate environments. If temperature restricts tree growth then transpiration may also be reduced as in C3 crop species (Meinke 1996). Also, potential transpiration is estimated directly from tree basal area. However, analysis of remotely sensed cover data (NDVI) suggests that different relationships exist between projected foliage cover (PFC) and tree basal area across the continent (J.O. Carter unpublished data) and hence the relationship used in GRASP for tropical woodlands may overestimate PFC and potential tree transpiration in southern climates.
2. Other supplies of water (e.g. deep lateral drainage) may be available to the trees thereby reducing competition for water in the top metre, and hence stimulatory effects of trees may dominate the interaction with pasture. Simulations of soil water in these studies indicated a reasonably high drainage component.

3. The potential stimulatory effects of trees on pastures such as increased diffuse radiation, frost protection, nutrient availability and lower evaporative demand all result in a greater potential pasture growth rate under trees.
4. These effects of trees on the pasture environment may result in pasture composition differences, for example, species with likely slower detachment rates, such as tussock grasses, had a greater contribution to SDM at moderate tree densities.

Points 3 and 4 were evaluated in simulation studies 6 and 7 by increasing potential growth rates and reducing detachment rates (**Table 33**). However, these attempts to re-parameterise GRASP for treed plots were not successful, as consistent agreement between years could not be achieved (**Table 35**). Further analysis will be carried out once soil water and nitrogen data can be included in the simulation analysis.

Discussion of simulation

The default parameters for native pasture used without calibration explained 57% of observed variation in SDM. With minimal re-calibration the variation explained increased to 77% which is similar to the variation explained in other studies of this type (McKeon *et al.* 1996), i.e. where general parameters have been used with independent data sets. The same rainfall data were used for three of the four sites and hence site variation in rainfall and other climatic elements could have contributed to the above unexplained variation.

GRASP did not model the stimulatory effect of trees on pasture SDM measured in this study. The use of parameters derived from the open plots in combination with simulation of tree transpiration resulted in simulation of about 30% less SDM than observed in the treed plots. Calibration of increased potential growth and lower detachment rates did not satisfactorily explain as high a proportion of site by season variation as achieved with the simulation of SDM in open plots.

Given the preliminary nature of this simulation study more detailed analysis appears warranted and considerable value is likely to be gained for a general model simulating native pasture growth across the nation, as well as providing insights into the effect of trees on pasture growth in different environments.

Table 35 Observed and predicted pasture standing dry matter (SDM) for treed plots.

Site	Date	Observed SDM (kg/ha)	Predicted SDM for simulation No.			
			4	5	6	7
M1 Treed	13 Sep 1995	726	553	629	644	658
	10 Oct 1995	550	475	567	540	555
	27 Nov 1995	1530	833	1181	1009	1063
	5 Apr 1996	1646	942	1593	869	1822
	15 May 1996	960	733	798	801	931
	12 Sep 1996	851	670	919	724	831
	3 Dec 1996	970	940	1088	1148	1276
	18 Apr 1997	474	657	930	734	1534
M2 Treed	13 Sep 1995	501	513	547	583	589
	10 Oct 1995	339	489	543	569	572
	27 Nov 1995	1278	996	1170	1173	1199
	5 Apr 1996	1521	741	1965	706	1540
	15 May 1996	914	686	738	749	867
	12 Sep 1996	1050	785	855	867	891
	3 Dec 1996	925	1070	1240	1258	1400
	18 Apr 1997	659	684	1401	649	1496
VE Treed	13 Sep 1995	453	276	494	294	317
	10 Oct 1995	155	230	340	300	302
	27 Nov 1995	1257	709	1067	880	910
	5 Apr 1996	1599	611	1628	591	1390
	15 May 1996	1118	953	1042	1015	1212
	12 Sep 1996	1652	820	1153	893	1094
	3 Dec 1996	1467	1055	1216	1126	1267
	18 Apr 1997	1049	627	1087	596	1524
VW Treed	13 Sep 1995	560	453	675	473	524
	10 Oct 1995	334	578	722	647	676
	27 Nov 1995	1553	1012	1286	1173	1236
	5 Apr 1996	1711	623	1622	604	1417
	15 May 1996	1192	965	1053	1026	1226
	12 Sep 1996	1830	942	1274	1015	1267
	3 Dec 1996	2024	1204	1363	1302	1480
	18 Apr 1997	1345	594	1044	562	1414

4. Discussion and synopsis

4.1 Key Findings

This section reviews key findings in relation to the objectives of the study.

Objective 1 : *To measure the microclimatic differences between stands of trees and adjacent more open sites so as to assess the likely effects of trees on pasture production.*

The comparison of climatic features between treed and open plots revealed slightly elevated ($\sim 1^{\circ}\text{C}$) daily and monthly average air temperatures under trees, as measured at 1.5 m aboveground. Variation during the day in windspeed and direction, solar radiation and actual evapotranspiration are all likely to drive these temperature differences. As expected, wind run was significantly and considerably higher in the open than under trees, as also was solar radiation, which in turn led to an increase in calculated evapotranspiration in the open.

The results showed that the tree cover on these sites was reducing the mean wind velocity at 2 m by 33%, compared with the open plots, a similar result to one reported by Bird *et al.* (1992) for a river red gum woodland. It would be expected that these open plots, in turn, were also gaining some wind shelter from the trees, as they were situated within the parameters defined for the quiet zone of a classic windbreak, i.e. within five windbreak heights (Cleugh 1998). Because of its extent, the tree cover would be providing a general increase in surface roughness (or regional shelter) and consequent microclimatic modification, both directly under the canopy and in smaller clearings over the whole paddock. This follows from the effect of a continuous tree canopy in decoupling the below-canopy air and that in the quiet zone from that above the canopy (Cleugh 1998).

The tree cover in these sites was variable in density and all the open sites were in a clearing of at least 0.5 ha, within what was generally an open to sparse woodland on the slopes and hills. Conversely, the treed plots were mostly within 50 m of an open area and hence did not have a long continuous tree-covered fetch on the western side. These variations in tree density (affecting porosity to the wind field) and the dispersion patterns of openings in the canopy in relation to prevailing winds, would be critical factors contributing to the microclimate patterns in such a landscape (Cleugh 1998). Although we did not set out to investigate this broader landscape pattern of tree/climate interaction, it is an important aspect that would be amenable to modelling to establish optimal configurations of trees and openings in a given landscape. Grass and surface soil temperatures would be important in such a study as these would be expected to show greater differences than the ambient temperatures measured here. Inclusion of the fog and dew components of precipitation may also be informative for localities at higher elevations, where fog interception by trees can be common.

Objective 2 : *To infer the effects of trees on soil condition from current soil properties.*

Analysis of surface soil properties revealed only small differences related to tree cover. Soil organic matter content was not significantly different between treed and open plots, but pH was significantly lower under trees in fixed comparison plots by a small amount (only 0.2 units). When surveyed across whole paddocks there was also no relationship found between soil pH, soil organic carbon and TBA. The amount of tree leaf litter on the ground ($\sim 1.5 \text{ t ha}^{-1}$ in treed plots) was apparently not smothering of grass growth nor appearing to have a large effect on soil organic matter and acidity levels. The total N and P levels in surface soils did not differ significantly between treed and open plots, although concentrations tended to be slightly higher under the trees. In the paddock-wide survey plots the soil TN and available P were not related to TBA. Differences in surface and sub-surface (15-45 cm) soil moisture

under trees and in the open were small (not significant), both in the fixed and survey plots, although the extent of the data on this was limited.

Although the level of difference between treed and open plots was rarely significant for the measured soil properties, there were parallel trends for some of the measures, which suggested higher fertility might be present under tree cover. This was evident as slightly higher organic matter content, TN and TP in the treed comparison plots. However, at the paddock scale, these trends were not evident. This could arise from the greater level of uncontrolled variation (survey plots were not paired) in soil properties occurring due to changes in parent material, soil profile development and other factors, such as nutrient transfer by grazing stock, which would pertain to the larger scale of the paddock surveys.

The static measures of soil fertility used here may, in fact, not be adequate to characterise the relative availability of nutrients to plants. For example, the speed at which mineralisation of soil organic matter occurs, is the principal determinant of N availability to plants. Given that i) the OM return to the surface from the tree layer would be of the same order of magnitude as that from the grassy understorey ($\sim 1 \text{ t ha}^{-1} \text{ yr}^{-1}$), ii) that no major differences existed in soil OM and TN levels between treed and open sites, and iii) assuming only limited consumption of leaves by stock, it could be deduced that the rate of OM mineralisation under trees is much higher. This would provide greater amounts of nitrogen in the soil and be expected to show up in greater pasture foliage N under the trees, a trend that was demonstrated only for some species at some sites in this study. The factors that could be responsible for greater mineralisation rates under trees have not been investigated here, but microclimate would clearly be implicated.

Objective 3 : *To quantify and model the effects of native trees on annual production, seasonal growth, digestibility and nitrogen content of native pasture.*

One commonly found effect of trees on pasture is to change the understorey species composition. However, in this study, although the species composition at a fine scale (quadrat) was found to vary, it was not consistently different between treed and open locations. Analysis of the floristic composition in the fixed plots also found no difference in species richness between plots under trees and in the open.

The importance of major pasture species as contributors to herbage mass also varied, but was not consistently related to tree cover. On average across the fixed plots, the dominant grass species (*Themeda*, *Danthonia*, *Microlaena*) contributed similarly to the biomass of treed and open plots, but in some sites these species individually contributed more in the open, whilst in other sites, more in the treed locations. The minor species tended to contribute biomass to either treed or open plots but not both and usually at one site only. This suggests that there is a suite of species, well distributed in these pastures, which are capable of increasing wherever suitable conditions prevail, whether under trees, in the open, next to logs, in wattle thickets etc. In this context, the open condition of the eucalypt canopy may be critical in allowing less shade-tolerant species to maintain their populations in treed areas.

These floristic and biomass results suggested that reduced light levels under trees, or other correlated factors, were not limiting the range of species which can grow in these locations. *Microlaena* in particular, which often shows a preference (but not exclusive) for shadier locations (see e.g. Gibbs *et al.* 1999), was not consistently preferential in this study. We suspect these findings may be partly related to site clearance history, where the tree cover has been both reduced, and allowed to increase, in various historical periods. Such a shifting mosaic of tree cover and density could mean that the pasture composition does not have time to come to equilibrium with tree cover. *Microlaena* in particular, may be able to maintain

itself indefinitely in the open, once it has been able to establish under more shaded conditions. There is also a high probability that some species (*Microlaena* for example) may have considerable genetic plasticity in optimising their growth in shade and full sun conditions. This requires more study.

Pasture quality (as TN) did differ significantly between treed plots and in the open, but only for some sites and species. As was found with soil TN, it tended to be slightly higher in pastures under tree cover. When surveyed across paddocks, there was no effect of TBA on pasture digestibility nor on TN. Probably for similar reasons, these results parallel those for soil properties discussed above, where the comparison plots showed a weak tree effect and the survey plots showed no effect. Where an effect was shown, it was commensurate, in that both the soil and foliage N content were increased under trees, reinforcing the suggestion that OM mineralisation is higher under trees. This has implications for the design of further field experiments: the use of paired comparison plots is highly desirable to minimise the inevitable high levels of variation in environmental features at larger spatial scales.

Microlaena stipoides had the highest overall foliar N content, followed by *Themeda australis*, *Poa sieberiana* and *Danthonia racemosa*. *Microlaena* was slightly higher in nitrogen in treed plots at VE and VW but the reverse at site M1.

Pasture mass in these grazed paddocks showed no overall statistical difference between treed and open plots, although the pasture mass varied significantly over time, being higher in the summer. However, little can be concluded from the level of pasture mass under continuous grazing, since it represents the resultant of both production and consumption.

Seasonal pasture productivity was found to be significantly higher under trees, being on average 27% higher respectively per unit ground area. If we allow about 1% of the ground being lost to tree stems, logs etc. (i.e. 100 m² ha⁻¹ or six times the TBA) the difference between treed and open productivity would be about 26%. This difference arose largely and approximately equally from higher productivity in the spring 1995, summer 1995/6 and winter 1996 periods. The following two seasons were less productive because of reduced water availability and there was no effect of trees apparent in those periods. Production was highest in the wet spring of 1995.

Pasture consumption was also significantly higher in treed versus open locations, on average also 26% higher per unit area (including trees). Relative consumption levels, between treed and open, were not as consistent as the production estimates, with the largest differences being in the first spring and winter of the study. This suggested that stock are adjusting their foraging location on a seasonal basis (at least) to preferentially graze locations with greater productivity. Consumption levels were, as would be expected, less variable through the seasons than production. The higher production under trees was almost exactly balanced with increased consumption there, and also equated with the finding of no overall difference in herbage mass between treed and open plots.

Given the seasonal variation in productivity we used modelling to gain a better understanding of the interacting factors involved, and to explore where tree cover may be influencing production. We found that with only minimal re-calibration of the tropical pasture growth model, it was able to explain 77% of observed variation in ungrazed pasture mass for the open plots. This was very acceptable for continued modelling effort, as it was similar to the level of variation that has been explained by modelling in other studies of this type (McKeon *et al.* 1996).

However, when trees were included in the simulation via their role as competitors for soil water and nitrogen, the model (as re-calibrated for open plots) predicted about 30% less ungrazed pasture mass (actually the increase in pasture mass) than we had observed in the treed plots. The potential stimulation effects by trees on pasture growth were then considered by modifying the parameters to allow for higher potential pasture growth under trees and also lower foliage breakdown rates. These simulations did not satisfactorily explain as high a proportion of site by season variation as was achieved with the simulation of herbage mass in open plots. These results suggested that other possibilities, such as tree use of deeper profile water, may be operating, or that the pasture-enhancing factors operating are site and time varying in their magnitude. This is highly plausible given the wide range of soil influences which trees have been demonstrated to produce in natural forest and savanna ecosystems (Rhoades 1997).

4.2 Overview of results

The main finding of increased pasture productivity under trees, overall and in certain seasons, was unexpected. We found that the treed pasture situation had higher productivity, mainly as a result of greater growth in various seasons when the soil water index was higher. Under drier conditions there was little or no difference between production in treed and open plots. Pasture consumption was also higher under trees by a similar amount. Pasture mass, on the contrary, showed no overall effect from tree cover.

The modelling effort has partially helped to explain this major result, in that the more obvious mechanisms of tree-pasture interaction included in the model, the transpiration-related ones, did not account for the increased production found in the field. The limited evidence we have on surface soil moisture differences also suggested that it was not a major factor. Other factors must also be involved.

Our results suggested slightly increased soil and pasture quality under trees, based on measurement of the pools of organic matter and nitrogen. However, these measures do not necessarily indicate the relative size of important nutrient fluxes, e.g. the flux of N from the stable organic matter pool to the labile pool. Other important fluxes are those which determine the amount of nutrients recycled in tree litter. This depends on the leaf nutrient concentrations, degree of resorption prior to leaf fall and the litterfall rate. The chemical quality of litter in turn regulates organic matter decomposition with species differences in N, P and lignin content shown to be important in influencing OM levels (Rhoades 1997). Given that total litterfall (grass + tree) is much greater under trees, yet the total N pool in the surface soil is similar, it is plausible that the production difference could be related to greater rates of nitrogen cycling under trees. Further work is required to quantify these rates.

Another possible explanation for production differences under trees is the development of a distinctive flora with different potential growth and turnover rates. In this study there were few consistent differences in composition between the fixed plots. In these plots, on which the production data were based, the dominant grasses contributed much the same overall amount to pasture mass under trees as in the open, although there were major differences in contributions within sites. However, surveys across whole paddocks showed that *Themeda* (a C4 species) contributed significantly less in the medium TBA class compared with the open and light TBA classes, while large tussock species contributed more. *Microlaena* contributed most in light TBA compared with the open and medium TBA classes. Whilst these species differences might influence potential growth rates under trees, our preliminary modelling to incorporate such an effect in treed plots was not successful. It is highly likely that the pasture composition under trees is dynamic in response to historical clearing and regeneration episodes, a suggestion recently made for the Northern Tablelands by Gibbs *et al.* (1999). If

this turns out to be the case and these compositional differences are partly responsible for increased production, then there is a heightened need to manage the tree cover with a good knowledge of its effects on pasture composition.

This study has clearly demonstrated the general level of understorey microclimate alteration provided by moderate tree cover on the Southern Tablelands. It showed a 33% reduction in mean wind run, slightly warmer air temperatures, 43% lower evaporation demand and 45% less radiation. The comparison was made with adjacent open sites which would, in fact, be equivalent to the quiet zone downwind of a windbreak, where enhanced plant production (compared with locations upwind or far downwind) usually occurs (Cleugh 1998).

The impact of this altered climate on pasture plant production is not straightforward to predict, as most of these and other environmental factors interact to determine canopy growth rates (Jones 1992). Species such as *Microlaena* can in fact produce more biomass at the light levels prevailing under trees than they do in full sun (Magcale-Macandog 1994 cited in Gibbs *et al.* 1999). *Themeda*, on the other hand, would show the opposite response, as C4 species are at an advantage under high light, water-limited conditions (Jones 1992), as would apply more to open sites. Such differences between dominant pasture species, indicates the potential in a treed native pasture system for the pasture species to occupy and exploit a variety of environments, thereby enhancing overall pasture productivity.

4.3 Implications

The key general implication arising from this study's main result is that native pastures growing under moderate tree cover are a productive resource that requires careful management and better understanding. The study has also pointed to the need for actual pasture production to be assessed in such studies, because pasture mass alone, is not informative of the growth dynamics in these perennial mixed pastures with several growth periods through the year.

There is an accepted need for increasing temperate pasture sustainability by using deep-rooted perennial components and a strong community response to this need (Reid *et al.* 1997). Given this, the implication from this study that tree cover does not necessarily compromise pasture (and likely animal) production is reassuring. There is also the implication that improved planning of properties and catchments will be facilitated by the knowledge that production need not be reduced by tree planting, and perhaps enhanced, where tree cover is presently low.

The open sites, as defined for this study, would themselves be likely to be benefiting from regional shelter effects, being located within several tree heights of treed areas. This underlines the importance of the findings here, for the reference condition in this study (open plot) is akin to the test condition (quiet zone) of a classic windbreak experiment. Just as an effective windbreak can provide increased pasture growth via microclimate amelioration, so this study has shown a general remnant tree cover may provide for additional increases in pasture growth. The implication is that dispersed tree cover may be more valuable to productive pasture than windbreaks, because it combines tree shelter effects with their potential to modify the soil and light regime as well as the pasture composition.

There is the suggestion from this study that tree cover, or perhaps historical fluctuation in its extent, has produced a well-dispersed pattern of pasture species, for example, it could have enabled the desirable species *Microlaena stipoides* to dominate some locations now found in the open, away from tree influence. This implies that the management of treed pasture needs to incorporate in its considerations not only the pasture, but the entire vegetation dynamic.

4.4 Recommendations

Refer to the executive summary for specific recommendations.

The results of this study raise questions about the precise ecological interactions and processes which enable pasture growth to be greater at times under trees compared to the open. Before the results presented here can be applied in land management, a better understanding of the precise nature of these interactions supporting production under trees will be required. The modelling has suggested that there may be a number of more subtle interactions, probably operating at the scale of valleys and trees, which combine to mitigate the expected reduction in pasture growth under trees from competition for water, nutrients and light. Key processes are likely to be the water sources and soil nutrient cycling rates associated with trees and their associated canopy fauna, the microclimate (including PAR regime) of the ground layer under trees, and the associated soil surface conditions for plant decomposition and hence nutrient turnover. Pasture species growth responses to reduced wind and light may also be involved. These processes will require validation under a range of site, soil, and climatic conditions on the Tablelands but should first be explored in a few sites so as to establish the critical variables required for defining and modelling the parameters of the system.

Following on from a better understanding of tree-pasture interactions, an improved capability to model grass quality and quantity in relation to tree density would be possible and is desirable. Improved models would enable graziers to predict the effects of tree cover on production under a range of soil and bioclimatic conditions. This will improve estimates of the real net benefits to graziers of trees in the rural landscape.

There is a need for increased understanding and prediction of the broad-scale patterns of microclimate, including ground layer conditions (grass and soil temperature and moisture) in various patterns of dispersed tree cover, including the size and location of openings. This vegetation is not equivalent in ecosystem terms to a system of multiple windbreaks, but is more a system of regional shelter using trees. Multiple windbreaks act largely on the microclimate, whereas a regional tree cover acts at a finer scale to influence not only the understorey microclimate, but also all tree- to landscape-level water and nutrient cycles.

The results have shown considerable small-scale variation in pasture composition, some of which is related to tree effects. However, very little is known about how to manipulate pasture composition in the presence of trees. A much better understanding of this is desirable so as to, for example, encourage optimal abundance of more nutritious shade-tolerant species such as *Microlaena*, and to discourage the larger tussock species. In this context, the role of shorter-lived tree species such as wattles and casuarinas in lifting pasture nitrogen levels needs to be considered. At the paddock scale, better information is needed on the patterns of utilisation of tree-covered pastures by stock, both for grazing and shelter. However, soil nitrogen levels in this study did not suggest a general nutrient transfer via stock is occurring between open and treed locations.

There is the need for management of tree cover to be integrated into best management practice for the pastures. This will be necessary to maintain an optimal range of tree basal area, tree dispersion patterns and pasture composition, with monitoring of tree cover especially important to detect trends in tree regeneration. Such an approach will lead to more sustainable agriculture, even more so if there are integrated wood products.

5. Glossary & abbreviations

<i>Consumption</i>	The herbage mass removed (consumed and trampled) by all or some class of herbivores in a given time period.
<i>Herbage or pasture mass, yield, standing dry matter, standing biomass</i>	Equivalent terms referring to the total aboveground standing biomass of pasture at a given time, measured as dry weight per unit area. As measured here, it does not include detached litter nor material < 10-15 mm from the ground.
<i>Production</i>	The amount of herbage mass produced aboveground in a given period such as seasons or years.
<i>Productivity</i>	The rate of biomass production, usually expressed as a daily rate of dry weight increase in herbage mass.
<i>Species richness</i>	The number of different species found in a sample or estimated from sample data to be present in an area.
<i>Tree basal area</i>	The sum of stem cross sectional areas measured at 1.3 m height for all trees in a given area.
<i>CY, OY</i>	Cage (ungrazed) yield and open (grazed) yield
<i>CYM</i>	Comparative yield method
<i>DMD</i>	Dry matter digestibility
<i>DWR</i>	Dry weight rank
<i>LSD</i>	Least significant difference at a stated probability level
<i>OM</i>	Organic matter (SOM for soil OM)
<i>PAR</i>	Photosynthetically active radiation i.e. between 400-700 nm
<i>SDM</i>	Standing dry matter
<i>SE</i>	Standard error
<i>TBA</i>	Tree basal area
<i>TN</i>	Total nitrogen
<i>TP</i>	Total phosphorus

6. References

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