Chapter 1: Introduction

This thesis explores elements of sustainable and profitable grazing enterprises using an experimental approach which focuses on comparisons of whole farmlets managed in different ways on the Northern Tablelands of New South Wales. It focuses especially on how pastures and grazing animals respond to different levels of inputs and types of grazing management and how a better balance between the competing needs of pastures and animals might be achieved.

High rainfall zone and the Northern Tablelands

Australia's grazing enterprises are based largely on pastures and rangelands comprising some 425 million hectares of the Australian landmass. Of this area, some 94 million hectares is so-called 'improved' pastures (of which 35 million hectares have been sown to introduced legumes and grasses) (Australian State of the Environment Committee 2001) while 331 million hectares is rangelands used by grazing livestock (Anonymous 2002). In the high rainfall zone (HRZ, >600 mm, annual rainfall) of temperate highland region of Australia, sown pastures cover 8.3 million hectares, support 59.2 million sheep and lambs, 7.3 million cattle and produce 253.2 kt wool annually (Sanford *et al.* 2003). As part of the HRZ in the tablelands of New South Wales, temperate perennial pastures sustain 23 million sheep and 3.5 million cattle (Michalk *et al.* 2003) which contribute significantly to the New South Wales economy (Vere *et al.* 2002).

The Northern Tablelands region is considered to be part of the temperate HRZ although, having summer dominant rainfall, it differs from the southern areas. The area covers some 3.1 million hectares of which 2.1 million hectares is occupied by agricultural establishments (Alford *et al.* 2003).

Agricultural commodities of the Northern Tablelands region have been reported to have contributed $218 million of value in 1996-1997 (Alford *et al.* 2003). Of this total value, sheep and cattle production were the dominant agricultural enterprises including wool production (41.7%), beef cattle production (36.1%) and sheep and lamb production (8.4%) (Alford *et al.* 2003). The major issues for Northern Tablelands agriculture relate mainly to the economic sustainability of beef and sheep grazing systems (Ayres *et al.* 2001).

The climate of the Northern Tablelands is characterised by relatively high rainfall with a summer dominant pattern. In this region, high evaporation rates during summer limit the

potential pasture growth while cold winter conditions, including a 200-day frost interval, limits growth from April through October (Ayres *et al.* 2001).

History of pasture development on the Northern Tablelands

Native pastures carry 59% of Australia's livestock (Hutchinson 1992). While Australian native and naturalised pastures have always been an important source of food supply for both wild and domesticated animals, it was only between 1950 and 1970 that attempts were made to improve their productivity through application of inorganic fertiliser and widespread introduction of new pasture species including legumes; better pasture management strategies and adjusting stocking rates were also emphasised during this period (Crofts 1997). These pasture improvement strategies on the Northern Tablelands were particularly important as opportunities for diversification were limited (Alford *et al.* 2003).

The Northern Tablelands region is suited to pasture improvement with introduced perennial species such as *Festuca arundinacea*, *Phalaris aquatica*, *Dactylis glomerata*, *Lolium perenne* and *Trifolium repens* commonly sown. These sown pastures occupy 23% of the total farm area in this region (Archer and Robinson 1988; Ayres *et al.* 2001). The rapid development of 'improved' pastures between 1950 and 1970 was promoted by some important research findings which revealed that the establishment of new pastures was vital to increasing the productivity and profitability of the Australia's pasture-based livestock industries (Crofts 1997). Together with the expansion of improved pastures, paddock subdivision and rotational stocking were promoted as grazing management strategies aimed at increasing production. Although only small responses were attributed to rotational grazing, such grazing trials demonstrated that the most crucial factor influencing both production per head and per unit area was the animal stocking rate (Crofts 1997).

Issues related to sustaining pastures

The early phase of pasture improvement in the temperate higher rainfall zone of NSW showed a marked improvement in productivity (Jones *et al.* 2006). In this zone, perennial grass-based pastures traditionally provided sufficient forage to produce premium livestock products (Michalk *et al.* 2003). However, since the mid-1970s, pressures to extract increasing profit from livestock enterprises have led to significant overgrazing and deterioration of both native and sown pastures (Michalk *et al.* 2003; Wheeler *et al.* 1987). A change in pasture composition, especially a decline in perennial grass content, has occurred in the HRZ since the 1980s and it has often been suggested that this is an indicator of productivity decline

(Anonymous 1992; Archer *et al.* 1993; Chen *et al.* 2002; Mason *et al.* 2003b).

Because of the expense of establishing perennial pastures and the loss in production that occurs when pastures have to be re-sown, it is important that they persist well, even under high grazing pressure. To be economically and environmentally beneficial, they need to persist for at least 10 years (Cullen *et al.* 2005); however, this goal is not achieved by many producers (Reeve *et al.* 2000).

Over recent decades, there has been a decline in the carrying capacity of these pastures as indicated by lower stocking rates (Vere 1998). Between 1970 and 1990, stocking rates were reported to have declined from a mean 8.5 DSE ha^{-1} to 6 DSE ha^{-1} (de Fe'gely 1997) and, according to Kemp and Dowling (2000), stocking rates at that time were well below potential. The carrying capacity of grazing lands between 1970 and 1984 were reported to have declined by 47% (Wheeler 1986) and recently more than 70% of the New South Wales grazing areas have been reported to be adversely affected by soil erosion, salinisation and woody weed invasion (Lodge 1996). In New South Wales alone, the potential production lost due to deterioration of perennial grass pasture is estimated to be $230 million annually (Dellow *et al.* 2002; Michalk *et al.* 2003).

Pasture decline, with its reduced productivity, has been attributed to a number of causes. Among these causes, poor adaptation of introduced perennial grasses and inappropriate grazing management have been suggested as important (Donnelly 1998). Inappropriate grazing management has also been reported as a major factor threatening the primary soil and plant resources and hence impacting on sustainability (Lodge *et al.* 2003b).

During the 1950s and 1960s on the Northern Tablelands, early pasture development efforts coincided with generally wetter conditions which created relatively little moisture stress on perennial legumes such as white clover (Blair 1997). In contrast, over recent decades, the region has suffered from generally lower levels of soil moisture resulting in a lack of persistent legumes. Scott *et al.* (2000c) showed the importance of a persistent legume component on the profitability and sustainability of perennial grass based pastures on the Northern Tablelands.

The intense research activity that took place across the temperate HRZ under the Temperate Pasture Sustainability (1994-1997) (Kemp and Dowling 2000) and Sustainable Grazing Systems Key Programs (1997-2002) arose due to the widely acknowledged problems of the sustainability of perennial pasture-based grazing enterprises (Kemp and Dowling 2000;

Mason and Kay 2000; Mason *et al.* 2003b).

Whilst it is generally accepted that high pasture and animal production can be achieved with high levels of fertiliser application and sown pastures, improved grazing management is also needed as a means of 'fine tuning' the system (Graham *et al.* 2003; Kemp *et al.* 2002; Lodge *et al.* 2003b). However, frequent pasture re-development may not be financially viable due to the high costs of fertiliser application and re-establishing pastures (Lees and Reeve 1994), the limited persistence of current cultivars (Waller *et al.* 2001a) and the time frame of 5 to 8 years to recover the costs (Vere *et al.* 1993). Consequently several researchers hypothesised that development of grazing management strategies that are sustainable would be a cost-effective means to manipulate pasture composition and at the same time improve the overall profitability and sustainability of grazing enterprises (Harris and Ayres 1997; Mason and Kay 2000; Mason *et al.* 2003b).

Some studies have reported as many as 66% of producers use de-stocking practices to ensure that a desirable pasture composition is maintained while at least 20% have adopted some flexibility in stocking rate to carry out improved management practices (Allan *et al.* 2003; Reeve *et al.* 2000).

There is renewed interest in the use of grazing management to increase pasture production and improve the persistence of deep-rooted perennial species to help create long-term, sustainable grazing systems (Waller *et al.* 2001a). The essence of grazing management is to achieve an effective balance between the efficiencies of herbage growth and herbage consumption by grazing animals. For the purposes of this thesis, the definition of grazing management provided by Mason *et al.* (2003a) will be used: 'set of management actions and decisions that links pasture production with pasture utilisation and livestock production'.

The grazing system chosen by the livestock producer is one of the main tools available to manipulate both the pasture supply and animal performance. One of the most important objectives of any grazing system is to try to optimise the length of any rest periods and to choose an overall stocking rate which will enhance whole-farm profitability and sustainability. In addition to choosing the most appropriate stocking rate for a particular livestock farm, the issue of grazing system necessarily involves the consideration of the most appropriate stock density which is imposed on the pasture as each paddock is grazed. This issue of the effects of stock density is one of the most contentious in the published literature on grazing management (Norton 1998).

Matching the pasture supply and persistence to animal production requirements suited to particular markets continues to present a challenge for most livestock producers. As will become apparent in this thesis, it is also a challenge for researchers, extension specialists and consultants.

For many years, there has been a worldwide debate in the literature, both scientific and non-scientific, concerning the benefits and drawbacks of different grazing practices for efficient livestock feeding (Brougham 1956; Graham *et al.* 2003; Mason *et al.* 2003c; McMeekan and Walshe 1963; Norton 1998). Within Australia, there have been many proponents of intensive rotational grazing systems such as 'time control grazing' and 'cell grazing' and yet there has been considerable scepticism expressed by some scientists (Jones 1993; Norton 1998; Savory 1983).

Sustainable and profitable grazing enterprises

Over recent years there has been increasing interest in extensive grazing management systems that may promote both productivity and sustainability in Australia and elsewhere. The concept of sustainability of grazing systems is of great interest not only to farmers but also to researchers. In the 1990s in Australia, sustainability has attracted considerable attention from researchers and funding bodies and became a major focus of activity (Mason *et al.* 2003c). In Australia, perceptions of what is a sustainable system vary depending on the priority of the particular enterprise and the graziers. On the Northern Tablelands of NSW in particular, graziers are reported to place a higher priority on livestock issues than on sustainable pastures (Lees and Reeve 1994; Scott *et al.* 2000c).

Sustainable and profitable grazing enterprises are difficult to define and attain due to the number of complex factors which affect them. Kemp *et al.* (2000) describe sustainable systems in terms of their having financial, biophysical, social and time dimensions.

According to Mason *et al.* (2003b), this definition embraces two key concepts; firstly, that sustainability is a mixture of social, environmental and financial considerations and secondly, that there can be no fixed definition of what is sustainable and in this regard, graziers are warned to balance the issues of sustainability for their own enterprises (Mason *et al.* 2003b).

Sustainability of pasture production has also become an increasingly important concern for Northern Tablelands graziers. In a study that investigated the whole-farm sustainability and profitability at a credible scale on the Northern Tablelands of New South Wales,

Scott (2003) noted some of the challenges of achieving more sustainable and profitable grazing enterprises. He pointed out the need to balance the biophysical components of the system with financial viability over the long-term. He has described the many factors which can influence the grazing enterprise system as a series of six interdependent layers comprising climate, soil, pasture, animal, management and economic categories. He suggested that, in order to understand sustainability and profitability, it is necessary to measure as many components as is feasible over time. MacLeod and Taylor (1992) report that graziers have a time perspective relating to sustainability of around 6 to 10 years, which is different to the time scale considered by others such as researchers and extension officers (11-20 years) and conservationists (100+ years).

Research scale and complexity

Mason *et al.* (2003c) emphasised that many factors affect the productivity and profitability of any grazing system and these effects are critical to the short- and long-term success of the enterprise. Grazing enterprises involve complex interactions between soils, plants, animals and factors such as climate, pests and diseases and fire with additional complexity added by economic and management issues. Hence, it is clear that solutions to the problems noted above will require an understanding of the interactions between these factors.

It has been argued by Norton (1998) that one of the main reasons for the substantial differences in opinion between graziers and researchers about the benefits of different grazing management approaches is the different scale commonly employed by these two groups when examining farm practices - either at full farm/paddock scale or in much smaller research paddocks.

Scott (2003) argues that in order to investigate issues such as the sustainability and profitability of grazing enterprises, it is essential to do so in a manner that allows investigation of the farm as a 'system'. Thus, investigators need to consider the many facets managed by farm managers (e.g. soil fertility, pasture persistence, pasture replacement, use of fertilisers, grazing management, multiple mobs, drought management, supplementary feedings, labour efficiency). He argues that, if the adoption of research findings is to be realised, it is important to conduct the investigations at a scale which farmers find to be 'credible'. This thesis will attempt to consider many of these complex interactions at a scale which members of the Cicerone Project find credible.

An ecosystem approach to research has been a feature of much grazing system research on the

Northern Tablelands for many decades. For example, Willoughby and McClymont were both committed to conducting research relating to livestock production by considering the grazing ecosystem as a '… study of the whole system, based on climate-soil-plant and grazing animal, as the essential experimental unit' (Hutchinson 1997).

Of course, a focus on inter-disciplinary investigations is not limited to this region or era. Vizard and Foot (1993) point out the complex challenges of balancing pasture and animal needs. Their experiences in western Victoria suggested an 'integrated approach to the animal/pasture partnership is necessary to ensure the long-term economic stability of the pasture-based grazing industries'.

In 1997, in a bid to remedy the decline in on-farm research into enterprise sustainability and profitability, a new partnership was forged between livestock producers, researchers, extension workers and consultants; this was called the Cicerone Project Inc. Together with its partners, it has aimed to carry out investigations of sustainability and profitability with an ecosystem approach that allowed different management systems to be explored within whole-farmlet systems that mimicked real grazing systems.

The Cicerone Project

Problems of long-term financial viability and the sustainability of pasture-based grazing enterprises were part of the reason for the creation of the Cicerone Project Inc. in 1997. In addition to these problems, it was clear that farmers had the view that much research was not being adopted and they identified a need to work more closely with research and extension personnel to address issues of importance to them.

With support from the International Wool Secretariat, a survey was conducted of some 300 graziers in the Northern Tablelands region by researchers from the University of New England's Rural Development Centre (Kaine and Doyle, unpublished report). The survey identified some of the most important issues which respondents wanted investigated; these included: the importance of fertiliser and grazing management on pasture persistence, especially through drought; how ewes can be maintained in 3 score condition by management of the animals and the pasture and supplementary feed supply; and how farmers can better manage drench resistance to enable continuing parasite control.

Following this survey, which found that more than 50% of respondents were interested in joining a producer-led research and adoption group, the Cicerone Project Inc. was formed as a not-for-profit group with funding from the WoolMark Company (supported later by

Australian Wool Innovation).

One of the aims of Cicerone was to 'provide access to a Central Farm which will facilitate the uptake of research by trials and comparisons under commercial conditions'. They adopted a motto of 'compare-measure-learn-adopt' which reflected their preferred approach of wanting to see the evidence demonstrated in a way which farmers found to be believable (Scott 2003).

Following a number of meetings between producers, researchers, extension specialists and consultants, a study of whole-farmlet systems was created to investigate the importance of fertiliser and pasture inputs and of grazing management. In this way, it was hoped that a better understanding would be gained of the influence of these two factors on the profitability and sustainability of Northern Tablelands grazing enterprises.

As noted by Scott *et al.* (2006), this whole-farmlet approach was adopted by the Cicerone Project in 1999 as, up to that time, there had been insufficient adoption of important findings from the Temperate Pasture Sustainability Key Program (TPSKP). Some of those findings came from a replicated field research trial conducted on the Northern Tablelands within the TPSKP, by a team of scientists who attempted to quantify sustainability as a matrix of parameters including soil, water, pasture, animal, production and financial components over time (Scott *et al.* 2000c). It has been suggested that the lack of widespread adoption of these findings may have been due in part to the lack of engagement with farmers in the research, the small size of the studies (total area less than 6 ha) and the fact that the complexities of real whole farms, such as fertiliser and grazing management and the need for periodic replacement of pastures, were largely ignored.

Scott *et al.* (2000c) suggested that more sustainable pastures are associated with the maintenance of deep-rooted, fertiliser-responsive perennial grasses with a persistent legume component. Consistent with work by Lambert *et al.* (1996), they suggested that this combination of plants provides enhanced long-term production through the fixation of sufficient nitrogen to promote the growth of deep-rooted fertiliser-responsive perennial grasses which, in turn, help to prevent leakage of that nitrogen below the root zone of the pasture. These pastures were also found to produce higher production per head and per hectare over time.

Because of the lack of scale and the absence of important management interventions such as the sowing of pastures and grazing management, it was difficult to extrapolate from the published findings, information considered by farmers to be relevant to longer-term

profitability and sustainability. It was therefore decided to investigate three different management treatments within whole-farmlets so that any systematic effects due to treatment could be separated from background variability.

In brief, the farming system approach chosen meant that all farmlets required as similar conditions as possible prior to the commencement of treatments.

Following careful planning of the soil and topography characteristics of the land and the recent fertiliser use, equal areas of land of equivalent capacity were allocated to each of the three farmlets. Once management guidelines were agreed to by the Cicerone Board, a series of complementary investigations commenced soon after the creation of the different farmlet treatments in July 2000. A more detailed description of how the farmlets were established is presented in Chapter 3 of this thesis.

This thesis concentrates on those parts of the investigations focusing on pasture inputs and grazing management as they affected pasture composition, the feed supply, animal performance and the balance between pastures and animals. The primary period of investigations reported in this thesis was from 2003 to 2005. Complementary investigations on the same trial were conducted by other researchers on aspects of the effects of the farmlet treatments on sheep internal parasites (A. Colvin [nee Healey]), patch grazing (A. Morrow), wool fibre diameter (J. Smith), the economic performance of each farmlet (F. Scott) and a bioeconomic modelling approach to optimising pasture improvement technologies (K. Behrendt).

To assist the research team, a centralised database was provided by the Cicerone Project and collaborators containing primary data from soil tests, pasture measurements, paddock treatments, animal and wool measurements, stock moves, labour used and costs of inputs and value of outputs.

To the extent possible, this thesis focuses especially on those aspects of sustainability that influence pasture production and animal performance and are necessary to understand the balance between feed supply and animal demand on a livestock grazing enterprise on the Northern Tablelands. In the sections relevant to pastures, particular attention is given to changes in botanical composition, herbage mass, pasture quality and pasture growth. The emphasis on animal measurements (e.g. intake, reproduction, wool, liveweight and fat score) is from the perspective that livestock performance provides an integrated measurement of the consequences of the feed supply at the level of the whole-farmlet. The final focus is on

managing the balance between supply and demand through pasture and animal management.

Throughout the thesis, there is an exploration of both intensive measurements of components of the farmlets or sub-samples of the animal flock as well as, wherever feasible, analysis of measurements made across all animals and paddocks to promote an understanding of whole-farmlet performance to be developed.

It is hoped that this approach will be found by livestock producers and especially producer members of the Cicerone Project, to provide credible evidence of the characteristics of different farm management treatments of interest to them as they strive for more profitable and sustainable grazing enterprises.

The structure of the thesis commences with a broad literature review (Chapter 2) with particular emphasis on the most important aspects of pastures, animals and managing the balance between supply and demand. The questions posed by the Cicerone farmlet experiment and influenced by the literature, are then developed into experimental hypotheses.

Chapter 3 contains a description of the general methods and materials relevant to the overall thesis, including a description of the management rules and guidelines for operation of the farmlet systems. It also contains a section on the methodology used to select representative paddocks from each farmlet for more intensive studies.

Subsequent chapters contain methods specific to the topic covered in that chapter, together with results and discussion addressing four principal research areas within these three farmlets which differed in levels of inputs and grazing management:

- Botanical composition (Chapter 4)
- Pasture supply (Chapter 5)
- Animal production (Chapter 6) and
- Process for balancing pasture supply and animal demand (Chapter 7).

An overall discussion and some conclusions are provided in Chapter 8.

Chapter 2: Literature Review

Introduction

This review will focus on those aspects of sustainability that influence pasture production and animal performance and hence attempt to match the conflicting needs of feed supply and animal demand in grazing enterprises. There have been several recent comprehensive reviews on the issue of grazing management for sustainable livestock production in Australia (Kemp and Dowling 2000; Lodge 1996; Michalk *et al.* 2003); however, it is still far from clear how grazing management can be used to meet the needs of both pastures and animals in a sustainable manner.

The following literature review will provide a general overview of pasture production in temperate regions of NSW, Australia and will also explore some of the effects of environmental factors (e.g. climate and soil) on pasture production. The review covers the processes of energy flow from the net primary production captured by the pasture through to secondary production. The impact of management practices (e.g. stocking rate, grazing management, soil fertility and sowing pastures) on pastures and subsequent animal production will also be addressed.

The primary focus of the review is to evaluate the key issues and concepts associated with grazing management for sustainable grazing systems in this summer-rainfall environment. An array of frameworks for measuring sustainable grazing enterprises and some major experimental programs established to address the problems of declining pasture productivity will be reviewed. In further addressing the issue of declining perennials in the Northern Tablelands, this review will look into the establishment of the Cicerone project which has focused on how pastures and grazing animals respond to different levels of inputs and types of grazing management and how a better balance between the competing needs of pastures and animals might be achieved. This project has emphasised an ecosystem approach to research, and hence issues of the most appropriate scale for research investigating these complex sustainability decisions will also be explored.

Pasture production is one key component of the inter-related layers of whole-farm sustainability which also includes soil, animal, production and economic parameters (Morley 1981) and the first section of this review will examine the key pasture species used within the temperate regions of NSW and the climate and soil characteristics important in determining the productivity of these species.

Key pasture species groupings important to grazing enterprises

Sown perennial grasses

One of the key factors contributing to higher pasture production in the higher rainfall areas of temperate Australia has been the establishment and maintenance of perennial grasses as well as vigorous legumes (Archer *et al.* 1993). Perennial grasses generally allow for deeper rooting and greater water uptake than native species (Scott *et al.* 2000c), which results in greater dry matter production as well as preventing rising water tables (Carter 1993). Perennial grasses are also claimed to minimise soil erosion, soil compaction, salinity and soil acidity and reduce invasion of pastures by weeds and annual grasses while maximising pasture growth (Archer *et al.* 1993).

Perennial pastures are an important component of any dryland grazing system (Lodge *et al.* 2003a; Michalk *et al.* 2003) and they play an important role in sustainable systems, being deep rooted and having the capacity to dry the soil profile (Harris and Culvenor 2004). In the higher rainfall regions of temperate Australia, pastures are based mainly on introduced temperate C_3 species such as *Phalaris aquatica*, *Festuca arundinacea*, *Lolium perenne* and *Dactylis glomerata* together with annual and perennial legumes; however, these pastures also contain less productive volunteer annual (e.g. *Bromus* spp, *Vulpia* spp. and *Hordeum leporinum*) and perennial species (e.g. *Holcus lanatus*) (Oram and Lodge 2003). Among these sown perennials, *Phalaris aquatica* and *Festuca arundinacea* have been shown to be the most promising for the temperate regions of NSW (Harris and Culvenor 2004).

Phalaris (*Phalaris aquatica*) is widely sown as a productive, drought-tolerant perennial grass in southern Australia (Culvenor *et al.* 2002). It is an important pasture species for winter-dominant rainfall and high summer temperature zones as it provides herbage in autumn (Read and Lovett 1980) and is productive throughout winter (Hill 1991). It is able to survive hot and dry summers that characterise temperate Australia (Kemp and Culvenor 1994) due to its ability to become dormant when low soil moisture and high temperature conditions prevail (Watson *et al.* 2001). For example, in the study of Watson *et al.* (2001) phalaris was shown to survive under critically low levels of soil moisture, while other species had considerable mortality. Although it grows well on a wide range of soils, it prefers heavy soils (Mason *et al.* 2003a). Persistence and high growth rate are two desirable characteristics which have contributed to the popularity of phalaris as a sown species across south-eastern Australia (Virgona *et al.* 2000). Among the main perennial pasture grasses sown in Australia, only

phalaris has been subjected to detailed and sustained research whereby breeders have provided a range of phalaris cultivars for early- to late-season environments with improved seedling vigour, winter growth and reduced anti-quality factors (Reed 1996).

Tall fescue (*Festuca arundinacea*) is considered by many researchers as the best introduced perennial grass for the Northern Tablelands of New South Wales where growth potential is maximised by summer rainfall and mild temperatures (Ayres *et al.* 2000b; Harris and Culvenor 2004). Its nutritive value in summer is higher than that of phalaris. In south-eastern Queensland, tall fescue has become the preferred temperate grass for winter feed as it has proven to be more productive and persistent than perennial ryegrass and other temperate grasses (Oram and Lodge 2003). In NSW, tall fescue is estimated to occupy approximately 0.94 million hectares (Hill and Donald 1998). It has also been widely used in south-eastern Australia since 1965 and in south-west Victoria where it is considered as the best perennial grass option for provision of herbage free of anti-nutritive factors (Reed *et al.* 2004). Like phalaris, tall fescue grows well in heavy soils as demonstrated in the experiment of Harris and Culvenor (2004).

In other temperate regions, such as New Zealand, tall fescue has proven to be more productive in summer (Oram and Lodge 2003). However, despite being a deep-rooted grass adapted to a wide range of soil types (Harris and Culvenor 2004), tall fescue has been shown to be less competitive when sown in seed mixtures with the other perennial grasses that have vigorous seedlings and a greater capacity to grow in winter (Reed 1987).

Perennial ryegrass (*Lolium perenne*) is a cool-season, long-lived and densely tillered perennial that prefers loam or clay soils. Perennial ryegrass is the most researched and valuable temperate pasture grass; it is distributed worldwide, including in North and South America, Europe, New Zealand and Australia. In Australia, it has been shown to be best suited to the basalt soils of western Victoria and is considered to be an economically important pasture grass grown in improved pastures in southern and irrigated areas of Victoria (Smith 1998). Perennial ryegrass is the most widely sown perennial grass in Victoria as it provides highly nutritive forage and has the ability to tolerate grazing (Cunningham *et al.* 1994; Reed 1987; Waller *et al.* 2001c). Perennial ryegrass is reported to be most productive in the 600-800 mm annual rainfall zone particularly in autumn and spring when growing conditions are most favourable (Waller *et al.* 2001a). However, it has limited growth in winter when air temperatures are low and in summer when temperatures are high. Moisture deficit and high temperatures have been found to contribute to the poor persistence of this

grass (Waller *et al.* 2001b) and generally its loss results in an increase in annual species (Waller and Sale 2001). While perennial ryegrass is often observed to be sensitive to low soil fertility, it is considered an important option for meat and wool producers in the less than 650 mm rainfall zone where soil fertility and grazing management are critical for achieving longevity (Reed 1996).

Cocksfoot (*Dactylis glomerata*) is a tussocky perennial grass native to Europe and northern Africa. It is ranked third after ryegrass and phalaris in importance among the sown temperate perennial pasture grasses and compared to ryegrass, cocksfoot has better survival over summer tolerates moderate soil fertility and prefers well-drained loamy or sandy soils, but is less drought tolerant (Reed 1996). It is well suited to acid soils in the 450-700 mm rainfall regions and is often sown as a mixture with phalaris (Avery *et al.* 2000), but its nutritive value is low compared to phalaris and perennial ryegrass (Reed 1996).

Perennial legumes

Legumes are included in temperate pastures because they add to the feed value (Archer 1989) and assist overall pasture growth by fixing nitrogen (Scott *et al.* 2000b). This increase in soil nitrogen in turn enhances the performance of perennial grasses and promotes the more vigorous and nutrient-responsive native grasses (Ayres *et al.* 2000a).

Of the temperate perennial legumes sown on the Northern Tablelands of NSW, white clover (*Trifolium repens*) is the most common. It has been recommended by state extension agencies since the 1930s as a companion to grasses such as *Phalaris aquatica*, *Dactylis glomerata* and *Lolium perenne* that have been fertilised with superphosphate (Ayres *et al.* 2000a; Donald 1970) in temperate regions. White clover has become increasingly important in the higher-rainfall (>650 mm), cooler tablelands regions (Kemp *et al.* 2002). Compared to other legumes, white clover is widely distributed across the world as it is adapted to a wide range of climatic and edaphic conditions as well as a wide range of management regimes. It has become a primary source of nitrogen for introduced pastures in the HRZ of temperate Australia (Lane *et al.* 2000). White clover-based pastures enhance soil fertility through nitrogen fixation, increase vigour of companion grasses, extend the seasonal distribution of pasture growth and provide a feed of high protein and mineral status and increased digestibility (Archer and Robinson 1989; Ayres *et al.* 2000a).

Native and naturalised pastures

Due to rapid increases in the costs associated with the establishment and maintenance of sown

pastures and a lack of persistence of some sown pasture species during droughts (such as in the early 1980s and mid-1990s), graziers have expressed an increasing interest in improved management practices and in the utilisation of native and naturalised pastures in many areas where they are still a major resource and especially on the Northern Tablelands of NSW (Lodge 1994).

Native grasslands comprise the majority of pastures on Northern Tablelands and North Western Slopes of New South Wales, occupying more than 70% of the agricultural area (Lodge *et al.* 2003c; Lodge and Whalley 1985). A number of the native perennial species including *Microlaena stipoides* and the C_4 species, *Bothriochloa macra* and *Themeda australis*, are increasingly being recognised as productive in northern New South Wales where the soil fertility is frequently low (Oram and Lodge 2003). In this region, some 90% of all native grasses are perennials (Lodge *et al.* 2003b). These native grass species reportedly have the advantage of being well adapted to survive the heat and moisture stress typical of many areas of Australia (Bowman *et al.* 1998).

Themeda triandra, a C_4 grass species, is reported to grow most during late spring to early autumn while C_3 species such *Austrodanthonia* spp. grow year-long with peak growth rates in spring (Lodge *et al.* 2003c).

Lodge (1994) emphasised that in regions where native pastures are only a small component of the pasture resources, such as in central and western Victoria, the south-east of South Australia and the south-west of Western Australia, native pastures can play an important role in the restoration of degraded grazing areas, especially those affected by acidification or salinisation. Nevertheless, fulfilling this role depends on either the commercial availability of quantities of seed of native perennial grasses suitable for resowing into problem areas or the collection of seed from local remnant populations of desirable native grasses (Lodge 1994).

Native grass-based pastures have a continuing role as a major pasture resource on most properties on the Northern Tablelands of NSW, especially where they are stable and productive (Lodge 1994). In low productivity native grasslands on the North West Slopes of NSW, graziers have adopted grazing management strategies which help to decrease the abundance of undesirable native grasses such *Aristida ramosa*, while increasing desirable grasses such as *Austrodanthonia* spp. (Lodge 1994; Lodge and Whalley 1985). According to Lodge (1994), such manipulation of species composition depends on matching grazing pressure to species phenology to enhance or discourage specific species. Similar principles

are being studied for a wide range of native and introduced perennial grasses in a Temperate Pasture Sustainability Key Programme (Mason *et al.* 2003c).

In one of the few comparative studies where data were collected from pure stands that had the same fertility and water supply on the Tablelands of NSW (Archer and Robinson 1988), the dry matter production and metabolisable energy of unselected *Austrodanthonia linkii* and *Microlaena stipoides* swards were found, in some seasons, to be similar to *Phalaris aquatica* and *Festuca arundinacea* (Lodge 1994). *Poa sieberiana* on the other hand, was the most productive species with high amounts of green leaf (Lodge 1994).

Simpson (1993) compared pasture production, crude protein, digestibility and metabolisable energy of *Austrodanthonia* spp., *Microlaena stipoides* and *Lolium perenne* and showed that the two native grasses were equal to or better than perennial ryegrass in most seasons. Further, Simpson (1993) reported that beef cattle production based on a native pasture (*Themeda triandra* and *Microlaena stipoides*) with subterranean clover and superphosphate applied was more economical than for a *Phalaris aquatica*, *Dactylis glomerata* and clover pasture.

In research conducted on the Northern Tablelands of NSW to compare the productivity, persistence and nutritive value of registered cultivars of *Phalaris aquatica*, *Lolium perenne*, *Dactylis glomerata*, *Festuca arundinacea*, *Austrodanthonia* spp. and *Microlaena stipoides*, the native grasses were found to have the slowest growing seedlings and the lowest initial dry matter yield (Jones 1996). However, the productivity of *Austrodanthonia* spp. improved over time; during the second year following establishment their growth was equivalent to that of the other species in the trial while the productivity of *Microlaena stipoides* continued to increase. After 2 years, the cumulative dry matter of *Microlaena stipoides* was reported to be similar to that of *Lolium perenne* and its crude protein content was equivalent to or higher than that of the other species, while the seasonal quality of *Austrodanthonia* spp. was similar to that of *Phalaris aquatica* (Jones 1996). In this study, the population density of all species declined except for *Microlaena stipoides*; the poor persistence of *Austrodanthonia* spp. could not be explained as it was reported to have persisted well in other trials (Jones 1996).

More recently, Garden *et al.* (2005) found over a range of sites, that under low-input conditions, a number of native grasses, including *Bothriochloa macra* and *Chloris truncata*, had low production in winter and spring and they were not preferred species for grazing sheep especially when compared to *Dactylis glomerata*. In contrast, some selections of *Elymus*

scaber and *Austrodanthonia* spp. had good growth rates.

Other recent research studies report that many native pastures are characterised by a low proportion of perennial grass (20-30%) (Dowling *et al.* 2006) while having high content of annual grasses such as *Hordeum leporinum*, *Vulpia* spp. and *Bromus* spp. (Dellow *et al.* 2002; Dowling *et al.* 2006; Kemp 1994). Further, although reported to require low inputs, typically sub-tropical (warm-season C_4) native pastures have low productivity on the Northern Tablelands as they have relatively short growing seasons in the warmer months and thus present high quality green leaf for a limited period of the year (Ayres *et al.* 2000a).

The previous section has provided a brief summary of some of the important characteristics of pasture species in temperate Australia. A general overview of factors affecting pasture production which include environment, climate, soil management changes and grazing management, is given in the next section.

Key determinants of pasture production

Effect of climate and soil factors on pasture production

Factors such as climate, soils, pastures and grazing animals all influence the pasture productivity of the inter-dependent system which is the grazing enterprise (Morley 1981).

Climate

The impact of climatic variables on pasture production has been reported in the HRZ (Sanford *et al.* 2003). Both climatic and soil factors are acknowledged to have significant influences on seasonal variability in herbage production, botanical composition and herbage quality (Garden *et al.* 2001; Sanford *et al.* 2003). In their paper on the overall findings relating to pastures in the Sustainable Grazing Systems program, Sanford *et al.*(2003) found that soil nutrients and growing season soil moisture were largely responsible for changes in the accumulation of herbage. In the more variable and lower rainfall environments of Australia, climatic effects on pasture growth are more clearly related to soil moisture than to total rainfall (Lodge *et al.* 2003c; Smith and Stephens 1976).

Temperature is considered one of the major environmental determinants of leaf growth. Increasing temperature over 25°C has been found to increase the rate of appearance and rate of extension of leaves for most temperate grasses in the United Kingdom (Parsons and Chapman 2000). On the Northern Tablelands of NSW, approximately 60% of annual rainfall is received over the warmer summer months (Lodge *et al.* 2003c; Smith and Stephens 1976).

In spite of this, there is generally a decline in soil moisture as mean monthly temperature increases to a peak of 20.4°C in January when evaporative demand exceeds rainfall with a consequent limitation to pasture growth (Smith and Stephens 1976). In winter in tablelands regions, low temperatures become the most limiting factor to pasture growth (Smith and Stephens 1976), particularly legume growth (Kemp and Dowling 2000).

Soil factors

While it is generally accepted that climatic conditions are not easily modified, soil management through extensive use of fertilisers can reduce soil fertility limitations, thus bringing about changes in total herbage production, botanical composition and nutritive value. In the HRZ of temperate Australia, increases in herbage production and quality due to the improvement of soil fertility and the sowing of deep-rooted fertiliser-responsive perennials are well documented (de Fe'gely 1997; Hackney *et al.* 1998; Scott and Cacho 2000).

In Australia, fertiliser practices normally aim at varying combinations of elements to manipulate the balance among grasses, legumes and forbs (Lodge *et al.* 2003b) and the addition of phosphorus, sulfur and/or potassium is seen to favour growth of legumes and broadleaf weeds, whilst increases in nitrogen promote growth of grasses and reduces legume content. However, Dowling *et al.* (2006) have recently suggested that the timing of phosphate fertiliser application is a key issue determining the success of grazing strategies in promoting legume and perennial grass components of pastures. They recommended that the pastures of the Central Tablelands be fertilised in autumn before the season break, with the rationale that both legume and perennial grass components will respond more rapidly than small seeded annual grasses (Dowling *et al.* 2006).

Evidence of soil fertility problems contributing to loss of pastures has been frequently reported in grazing studies. In the HRZ of southern Australia 70% of the variation in annual herbage accumulation measured within the Sustainable Grazing Systems national experiment was explained by positive relationships with soil phosphorus and legume percent and negatively correlated with the proportion of native species in the pasture and stocking rate (Sanford *et al.* 2003). In a survey of pasture composition, Quigley *et al.* (1990) reported deficiencies in soil P, K and S, which resulted in replacement of desirable species by less productive annuals. Results of soil analyses in south-eastern Australia have also indicated deficiencies of P, K and S being both common and widespread. Although the use of fertilisers to supply phosphorus for pastures in temperate areas is widespread (Cayley and Kearney

1999), phosphorus availability remains one of the most important factors limiting pasture production in grazing areas of Australia (Sale and Blair 1997).

Low soil fertility status is one of the main indicators of declining pasture productivity in the HRZ of temperate Australia (Quigley *et al.* 1990; Sale and Blair 1997). There is a perception that farmers often vary their fertiliser usage from year to year according to fluctuating financial circumstances in response to changes in commodity prices. Consequently, it has been noted that omitting or greatly reducing regular applications of phosphorus fertiliser may result in changes in botanical composition and reduced pasture growth (Cayley and Kearney 1999).

Micro-organisms interact directly and indirectly with both plants and animals. The maintenance of a healthy and viable population of soil biota is considered to be an important aspect of sustainability (Clarke 2002). According to King (1994), the main function of soil organisms in grazing systems is to sustain soil fertility by decomposing organic residues and thus releasing nutrients to the soil. In studies of production and energy flow carried out on the Northern Tablelands of NSW from 1958-89, Hutchinson (1989) reported that 71% of the energy flow was utilised by microbial decomposers. According to Pittaway (2004) 'feeding the soil' by including a pasture phase and maintaining an effective litter layer is an investment in soil health and, over the longer term, in economic and environmental sustainability of agriculture.

It is well known that the boundaries for growth of pastures are governed by environmental factors (supply of radiation, light interception, temperature and soil moisture) and levels of soil nutrients (Garden *et al.* 2001; Sanford *et al.* 2003; Smith and Stephens 1976). Within these boundaries, grazing management becomes a powerful tool to manipulate the quantity and quality of forage on offer (Harris 1978; Hodgson 1990; Morley 1981). The act of defoliation not only alters pasture components (herbage mass, growth, quality and species composition), but also reduces the leaf area with concomitant effects on meristematic tissue, carbohydrate reserves, tiller development, leaf and root growth (Hodgson 1990). The severity of defoliation of plant parts can affect the microenvironment and light intensity and as such, soil temperature and soil moisture can also be altered (Watkin and Clements 1978). The process of energy flow from the net primary production captured by a pasture through to the secondary production resulting from livestock grazing will be explored further below.

Energy flow within the grassland ecosystem

Pasture management is directed at maximising the capture and utilisation of net primary production of the pasture (Beattie 1993). In the grazing ecosystem, managing pastures is the principal means of enhancing net primary production. As pasture quantity and quality increase, a higher proportion of the pasture can be converted into animal tissue and this is commonly known as secondary production.

Leaf extension

Managing leaf area and growth through grazing management is traditionally done by adjusting the stocking rate (the number of livestock divided by the area of a farm) and stock density (the number of livestock grazing a particular paddock area over the short-term) within a grazing system; the combination of these two components helps to describe a particular grazing system.

Leaf Area Index (LAI) refers to the ratio of leaf area of the plant community to the area of land beneath that community and is a useful index of the photosynthetic capacity of a pasture. The pattern of uptake and loss of tissues in relation to LAI is greatly influenced by season (Brougham 1958; Lemaire and Chapman 1996; Parsons 1988). Seasonal changes in the photosynthetic potential of the leaves and seasonal changes in light energy received can substantially reduce carbon assimilation and gross tissue production in a pasture grazed to maintain a high LAI in autumn (Parsons 1988). In late-summer and autumn, reduction in light intensity can affect the photosynthetic potential of individual leaves while in winter, low temperatures and low light intensity combine to influence the development of photosynthetic potential in leaves (Parsons and Robson 1981).

Brougham (1959) compared seasonal changes of grazing intensity with year-round grazing and found that frequent hard grazing increased herbage production in autumn and winter but reduced it in summer. The autumn effect was attributed to removal of the more summer-active species such as cocksfoot and white clover allowing a shift to perennial ryegrass during winter. The winter effect was ascribed to increased light penetration to the sward base, which stimulated grass tillering and clover shoot production. Summer effects, on the other hand, were largely due to interactions between levels of defoliation and moisture stress (Brougham 1959).

The efficiency of leaves intercepting light depends mainly on their size, shape, position and structure of the photosynthetic organs (Morley 1981). Seasonal changes in the structure of

the sward canopy can greatly influence changes in the photosynthetic potential of the grass pasture. A marked increase in LAI in spring is related to an erect canopy structure partly as a result of high leaf angle and partly a result of stem elongation, both of which contribute to a more uniform distribution of light over the photosynthetic area of the canopy and can also result in a more efficient use of light in canopy photosynthesis at a time of high LAI (Parsons 1988). In an earlier study, it was reported that a change from a relatively prostrate to a more erect growth habit in a reproductive canopy during spring accounted for less than 10% of the observed increase in canopy photosynthesis (Parsons and Robson 1981).

During a period of regrowth in a vegetative sward in summer and autumn, leaves become progressively more prostrate (Parsons 1988). It has been suggested that as LAI increases during regrowth in summer and autumn, the top of the plant canopy is made up of an increasing proportion of old leaves whose photosynthetic potential has declined with age; this effect is more pronounced in late autumn as successive new leaves become shorter than their predecessors (Lemaire and Chapman 1996). It has also been noted that a combination of high LAI and a prostrate canopy lead to an inefficient use of light in canopy photosynthesis especially when the photosynthetic potential of those leaves which intercept the light is poor (Parsons 1988).

Whilst increasing leaf area is regarded as a precursor to increased production (Clarke 2002), increasing the LAI above an optimum level has been found to cause a net loss of fixed carbon by placing the lower leaves of the community below their light compensation point (Donald 1961) and consequently reducing pasture growth. While it has been reported that maximum light interception by grass and grass-clover pastures occurs in a range of LAI of 4 to 6 (Hodgson 1990), an intermediate LAI of 1 to 2 in dense pastures has been reported to provide the best compromise between biomass yield, herbage intake and foliage death (Vallentine 2001).

It has also been reported that the maximum rates of net accumulation occur in a pasture with a LAI at which 95% of incident light is intercepted (Brougham 1958); the rate of canopy gross photosynthesis may decline once complete light interception is reached (Lemaire and Chapman 1996; Robson *et al.* 1988). It has been suggested that maximum production over the season should be achieved in a sward maintained at close to full light interception (Lemaire and Chapman 1996). Conversely, Parsons (1988) indicated that maximum production per hectare is achieved in a sward maintained at a LAI which is below the optimum for photosynthesis and shoot growth, but provides the best compromise between

plant growth and plant harvest. Production per hectare has also been reported to decrease as the distribution of LAI in the pasture becomes less uniform; as the season progresses, the animals commonly harvest tissue from a restricted area within the total area of a pasture; thus areas of a pasture which are rejected by animals reach a ceiling yield (Parsons 1988).

A key determinant of regrowth after defoliation is the residual photosynthetic tissue within the remaining leaves; this is influenced by frequency and intensity of defoliation. More rapid pasture growth results in a rapid increase in LAI, mutual shading of leaves and ultimately reaching the ceiling yield (Parsons and Chapman 2000). Despite the high photosynthetic potential of individual leaves in a sward grazed to maintain a low LAI, gross photosynthesis decreases progressively as the intensity of defoliation is increased, which suggests that this high photosynthetic potential of leaves and the structural adaptation of the pasture compensate inadequately for the overall reduction in leaf area (Parsons *et al.* 1983). Ideally, grazing management needs to maintain the pasture within optimum limits to maintain maximum growth while reducing leaf death to a minimum.

Harris (1978) suggests that defoliation frequency should be such that the regrowth interval is extended until pasture growth rate begins to decline from its maximum, while defoliation intensity should be to a residual level equivalent to that which still permits maximum growth rate to be attained. The latter was investigated by Brougham (1956) who measured regrowth and light interception of *Lolium perenne*, *Trifolium pratense* and *Trifolium repens* swards allowing high light interception at various intervals and cutting intensities. Reducing the intensity of defoliation increased the herbage mass substantially at progressively higher cutting heights.

Energy reserves

The seasonal pattern of storage and utilization of carbohydrate reserves has been reported in temperate perennial grasses with more accumulation of these reserves during late spring towards the end of reproductive development (Parsons 1988). Carbohydrate reserves stored in the roots are formed by the plant from simple sugars during photosynthesis (Morley 1981) and are of great importance as available food reserves to support regrowth following defoliation. Recent studies have confirmed that carbohydrate reserves are utilised for regrowth following defoliation and are only replenished when photosynthetic gain exceeds pasture utilisation (Boschma *et al.* 2003).

The effect of grazing on carbohydrate reserves has been reviewed by Fulkerson and Donaghy

(2001). In their review, plant energy reserves were regarded as indicators on which to base sound grazing choices, the best choices allowing maintenance of root reserves that will allow maximum regrowth. These reserves are best replenished when the plant is allowed to grow 3 or 4 leaves per tiller prior to the next defoliation (Fulkerson and Donaghy 2001). It has been reported that grazing a pasture of high LAI with a small number of large tillers to a height of just 3cm, results in the loss of a substantial proportion of the leaf tissue; hence, the subsequent expansion and restoration of leaf area depends on the mobilisation of these energy reserves (Davidson and Milthorpe 1966).

Carbon balance of the pasture

The rate of net accumulation of dry matter in the field depends not only on rate of gross photosynthesis and the corresponding rate of gross tissue production, but also on the simultaneous rates of loss of dry matter through respiration and tissue death (Davidson and Milthorpe 1966). During spring, the photosynthetic rate increases initially as leaf area increases up to the point where the plant intercepts virtually all incident light; thereafter, the rate of gross photosynthesis remains constant or may even decrease as the photosynthetic potential of young leaves decline (Lemaire and Chapman 1996). At similar LAI, the maximum canopy gross photosynthesis has been found to be higher in warm-season grasses with the C_4 photosynthetic pathway than in temperate C_3 grasses (Lemaire and Chapman 1996). Gross photosynthesis has also been reported to be higher for pastures in the reproductive stage than for vegetative stage (Parsons and Robson 1981). During this period of reproductive development, there is a relatively small decrease in the rate of turnover of tissue in a grass pasture and this greatly enhances the net accumulation of dry matter (Parsons 1988). In autumn, the poor photosynthetic potential of the canopy combined with declining light energy may lead to a reduction and ultimate decline in canopy photosynthetic uptake. As the rate of death approaches or exceeds the rate of gross production of tissue, there will be a shorter period of growth and a lower ceiling yield (Parsons 1988).

Grasses display a rapid turnover of tissues and hence any accumulated herbage is soon lost through death, decay and senesce (Lemaire and Chapman 1996). It is generally accepted that the way the pasture is grazed on any occasion has a substantial effect on the proportion grazed and thus the amount subsequently grown prior to the next grazing. The rate of loss of tissue by death depends on the rate of turnover of the oldest category of tissue in the pasture and this increase in the rate of death is predominantly attributed to an increase in the size of leaves involved in the turnover of tissue (Davidson and Milthorpe 1966). It has therefore been

suggested that grazing management must strike a compromise between the conflicting demands of pastures which need to retain leaf area for photosynthesis and the essential need to remove leaf tissue by grazing animals; this conflict leads to a dilemma that is central to the management of grazing enterprises (Lemaire and Chapman 1996).

Assimilate partitioning

Changes in the partitioning of assimilates between the major plant fractions of leaves, stems and roots are reported to contribute to seasonal differences in terms of both herbage mass and species composition (Parsons 1988). There has however been much debate concerning the role played by seasonal changes in the proportional partition of assimilates between shoot and root in the seasonal pattern of production. It has been suggested that a large difference in assimilate partition between shoot and root in spring and in autumn might contribute directly considerable differences in yield (Parsons 1988). During regrowth after complete defoliation of *Festuca arundinacea*, the proportioning of assimilates allocated to roots has been shown to increase from 10 to 20% (Belanger *et al.* 1992). The partitioning of assimilates to elongating stems is also reported to result in marked increases in the proportion of the standing herbage which is more than 5 cm above the ground surface.

Thus, the energy that is captured through photosynthesis in pastures that will ultimately be available to the grazing animal, is highly dependent upon season and plant species as well as upon management. The amount of that energy captured which is available to grazing livestock is dependent not only upon the leaf area dynamics of the pasture but also the proportion of assimilate which is delivered to the below ground plant parts as well as the proportion of energy expended on stem growth and reproduction as well as on the proportion of leaf removed through grazing.

The promotion of various grazing systems to enhance the productivity and sustainability of livestock grazing enterprises has always been a controversial issue; the next section will briefly review some of the on-going worldwide debate about the biological aspects, productivity, and economic value of rotational versus continuous grazing systems.

Grazing systems and pastures

Historically, a number of different terms have been used to describe rotational grazing systems, including deferred grazing, high intensity/low frequency and high intensity/high frequency. These terms have mainly been applied to rangeland situations in South Africa and America (Edwards 1981) while, for pasture systems in Australia and New Zealand, terms

such as cell grazing (Savory 1988), short duration grazing and time control grazing (Hacker 1993; McCosker 2000; Morley 1995) have been used. It can be argued that these terms are similar in meaning; they all refer to rotational grazing with varying durations of alternating short grazing and long rest periods.

The claimed benefits of intensive rotational grazing systems such as cell grazing, time-control grazing (McCosker 2000) and holistic resource management (Savory 1988) have been widely promoted around the world. In addition to consideration of the grazing system, stocking rate, correct timing of grazing and correct decisions regarding surplus pasture management have been identified as key management aspects to consider in any grazing system (Clarke 2002; Fulkerson 1997; Lodge 2000; Sharrow *et al.* 1991).

Mason *et al.* (2003a) has explained that appropriate grazing management requires knowledge of the critical stages in the life-cycle of the key pasture species and their responses to different management strategies. Stocking rate and grazing management have been consistently noted as the most important management variables affecting the efficiency of pasture production, the persistence of perennial pastures and eventually animal performance (Peart 1968). Of these factors, stocking rate is the most influential and has been suggested to be a key driver of ecological sustainability in a grazing system (Sharrow *et al.* 1991).

Grazing management has been defined by Morley (1981) as 'the control of pastures and animals and their movements in a pasture ecosystem to vary the timing, frequency and intensity of grazing'. This definition links the relationship between pasture management and grazing strategy in order to manipulate botanical composition and increase pasture growth while maintaining and rationing the available herbage to grazing animals (Lodge 2000). However, Morley's definition does not include the timing, frequency and duration of rest periods which have been found to be of vital importance in maintaining pastures over the longer term (Kemp *et al.* 2000). Grazing management has been identified as a major contributor to the sustainability of grazing enterprises (Ayala Torales *et al.* 2000; Fulkerson 1997; Lodge 2000).

Impact of grazing management on pasture supply

Impact on species composition

Pasture longevity is regarded as the single most important issue determining the economics of grazed pastures for long-term productivity and sustainability of pastures (Johnston *et al.* 2003; Scott *et al.* 2000c). It has been argued that the sustainability component is linked inextricably

to the persistence and stability of fertiliser-responsive perennial grasses (Johnston *et al.* 2003) combined with persistent legumes (Scott *et al.* 2000c).

Rotational grazing has shown benefits over continuous grazing by improving the survival and persistence of perennial grasses under both sub-tropical (Donaghy and Fulkerson 1997; McKenzie 1997) and temperate (Waller *et al.* 2001a) climatic conditions. Some grazing experiments in the HRZ of temperate Australia have shown rotational grazing to be superior to continuous grazing due to a lengthening of the growing season for perennial-based pastures and further enhancing upright and erect growth of these perennial species whereas continuous grazing tends to favour more prostrate growing species such as clovers (Mason *et al.* 2003a).

In southern temperate Australia, rotational grazing is thought by many livestock producers to offer a means of retaining more desirable species in their grasslands; it is claimed that the frequency and selectivity of grazing of these desirable species is better controlled by rotational grazing than by continuous grazing (Dowling *et al.* 2005).

Continuous grazing has been largely condemned as having undesirable outcomes by allowing deterioration of both rangelands and pastures (Morley *et al.* 1969; Oram and Lodge 2003). At low stocking rates, continuous grazing is reported to have undesirable outcomes as it can result in the removal of the more palatable species through selective grazing of those species (Barnes 1977), leaving less productive and weedy species to invade (Morley *et al.* 1969; Oram and Lodge 2003). In contrast, in New Zealand's more reliable and favourable climate, continuous grazing is considered to be the most effective grazing management for promotion of high tiller populations and sward stability (Hodgson 1990).

On the Central Tablelands of NSW, Dowling *et al.* (2006) compared two grazing systems (continuous and tactical grazing) on four different pasture types (unfertilised naturalised, fertilised naturalised, fertilised introduced and fertilised chicory). Even though tactical grazing increased the content of perennial grasses more than continuous grazing, the system was reported to be less beneficial as it suppressed the legume component; on the other hand, pastures grazed to lower levels of herbage mass under continuous grazing increased their legume content and stimulated tillering (Dowling *et al.* 2006). Based on these findings, Dowling *et al.* (2006) concluded that in pastures with high perennial content, continuous or strategic heavy grazing is necessary to improve the legume component, while tactical rest during summer is appropriate for pastures with a declining perennial grass component.

Garden *et al.* (2000b) describe how rotational grazing methods such as cell grazing and time

control grazing have been promoted in Tasmania with claims of improving botanical composition and consequently enhancing the productivity of natural pastures. However, their study, which compared different forms of rotational grazing (seasonal rests, increased grazing pressure in spring, mob stocking and cutting for hay) with continuous grazing in south-east Australia, revealed that rotational grazing was not necessarily superior to continuous grazing in terms of botanical composition; a combination of dry periods with high grazing pressure was sufficient to bring about undesirable changes in species composition (Garden *et al.* 2000b). In south-western Victoria, while grazing method had no significant effect on the botanical composition of some species, such as deep-rooted perennial grasses (ryegrass and phalaris) and white clover, Clarke (2002) identified a significant decline of broadleaf weeds by 7.6% under rotational grazing compared to set stocking.

The debate about benefits and weaknesses of rotational grazing *versus* continuous grazing persists and at times includes discussion on the economic impact of having to create large numbers of small paddocks which are grazed at high stocking densities, presumably employing more labour and requiring a greater capital investment in fencing and watering points. There are a number of research studies which advocate the use of large numbers of paddocks (8-30) (Norton 1998); the underlying logic is to have short duration, intensive grazing periods followed by long rest periods in order to protect desirable grass species from being overgrazed (Acocks 1966; Carew 1980; Savory 1988).

Under rangeland conditions in South Africa, O'Reagain and Turner (1992) found no difference in defoliation pattern between a 4-paddock rotation involving 14-day grazing periods and an 8-paddock rotation with 7-day grazing periods. The implication from such findings is that grass vigour, pasture growth and tiller population are likely to be similar between the two systems irrespective of paddock numbers. On this basis, O'Reagain and Turner (1992) concluded that increased paddock numbers appear to have little effect on the defoliation process within the sward and hence had little economic or ecological justification.

Effect on sown perennial grasses

The means of improving the persistence of temperate perennial grasses using grazing management has been explored in recent years (Culvenor 2000; Culvenor *et al.* 2002; Lodge and Orchard 2000; Virgona *et al.* 2000). According to Blair (1997), rooting depth and growth habit are of major importance in determining the persistence of these pastures. On the other hand, Cullen *et al.* (2005) suggest that maintenance of tiller populations is vital for persistence

of these pastures. Marked reductions of tiller populations and death of individual tillers were manifested primarily as the interaction of stresses including grazing, shading, low levels of soil nutrients and soil moisture (Cullen *et al.* 2005).

Despite successful establishment, the application of fertilisers and the presence of legumes and the associated increases in carrying capacity, there is an increasing perception that the so-called 'improved' pastures - which were highly productive in the 1960s and 1970s - have, in recent decades, declined in quality, showing poor persistence and performing below expectations (Hutchinson 1992). According to Lees and Reeve (1994), approximately 44% of producers in south-eastern Australia expect their sown species to disappear within five years of sowing. Several researchers have suggested a lack of appropriate management of the pasture and a tendency for producers to concentrate more on the management of their livestock rather than their pastures and soils (Archer and Robinson 1989; Mason *et al.* 2003b; Watson *et al.* 2001). Animals have been noted to be the last factor in the soil-plant-animal continuum and the least sensitive signal that a system is becoming unsustainable (Lodge 1996; Lodge *et al.* 2003a).

Phalaris (*Phalaris aquatica*): The effect of grazing management on the persistence of phalaris has been the major focus of many grazing studies in Western Victoria, Central Tablelands of NSW, North West Slopes of NSW and south-eastern Australia. Tolerance to grazing and tolerance of soil infertility are suggested as contributing to the overall persistence of various phalaris cultivars (Culvenor *et al.* 2002; Oram and Culvenor 1994). Watson *et al.* (2001) reported that grazing phalaris to a residue of 1200 kg DM ha^{-1} can promote its photosynthetic efficiency as new tillers develop and thus enhance phalaris persistence. This study further confirmed that a suitable grazing management for phalaris was to graze it when it had 4-leaves per tiller (Watson *et al.* 2001). Like any other perennial grass species, phalaris is weakened by cutting or grazing during the period of stem elongation. On the North-West Slopes of NSW, Lodge (2004) observed that, with an increase in defoliation intensity of phalaris, there was a significant reduction in the total carbohydrate reserves of the plants.

To increase persistence and 'sustainability' of phalaris-based pastures, some researchers have suggested various forms of rotational grazing (Culvenor 2000; Morley *et al.* 1969; Virgona *et al.* 2000). In western Victoria, Chapman *et al.* (2003) reported a higher proportion of deep-rooted phalaris but lower levels of subterranean clover in rotationally grazed pastures compared to set stocking; based on this finding, Chapman *et al.* (2003) suggested that livestock producers might use temporal and spatial combinations of set stocking and

rotational grazing to manipulate pasture growth and species composition for achieving both satisfactory per head animal performance and persistent perennials.

In a summer-rainfall environment, where Sirosa phalaris pasture was grazed with sheep or cattle, tactical resting in spring and autumn markedly increased persistence compared to continuous grazing (Lodge *et al.* 2003a; Lodge and Orchard 2000). A trial on the North West Slopes of NSW investigated the use of strategic grazing management to improve the persistence of phalaris and subsequent effects on animal production. In this trial, Lodge *et al.* (2003a) discovered that continuous grazing at a high stocking rate (12.3 sheep/ha) markedly reduced the persistence of Sirosa phalaris as it was replaced by weedy species such as saffron thistle. In this study, while continuous grazing at a low stocking rate (6.1 sheep/ha) increased phalaris persistence, stocking at this rate particularly with wethers was considered to be not profitable due to a carryover effect of more accumulated herbage material (Scott *et al.* 2000a). Based on these findings, Lodge *et al.* (2003a) concluded that the persistence of Sirosa phalaris in summer-rainfall environments can be increased by strategic resting for a 6-week period in spring and autumn.

Tall fescue (*Festuca arundinacea*): Because of poor seedling vigour which results in slow establishment of temperate tall fescue, careful grazing management is normally recommended during the first 12 months after sowing. Once established, tall fescue is reported to be tolerant of heavy grazing (Harris and Culvenor 2004). For long-term productivity and longevity of this perennial, it is considered desirable to maintain herbage mass between 800 and 1200 kg DM ha^{-1} (Harris and Culvenor 2004).

In a study that evaluated the persistence and productivity of 6 perennial grasses under severe and moderate defoliation and controlled drought conditions on the Northern Tablelands, *Festuca arundinacea* was found to be one of the most persistent species (compared to *Phalaris aquatica*, *Lolium perenne*, *Dactylis glomerata*, *Microlaena stipoides* and *Austrodanthonia* spp) (Boschma and Scott 2000). In this study, tall fescue also maintained relatively high dry matter digestibility and hence would be likely to suffer from selective grazing if continually subjected to grazing animals. There has however been limited research work focusing on the impact of grazing management on the persistence and productivity of tall fescue in Australia.

Perennial ryegrass (*Lolium perenne*): Different forms of grazing management to alter the components of perennial ryegrass through tiller density, leaf size and growth and decay rates

of individual leaves are well appreciated by graziers (Waller *et al.* 2001b). In New Zealand, rotationally grazed pastures had a higher content of perennial ryegrass than continuously grazed pastures (Lambert *et al.* 1986). In contrast, in south-eastern Australia, Graham *et al.* (2000) showed that continuously grazed ryegrass could be as productive as rotationally grazed ryegrass if sward height and /or dry matter could be maintained at levels optimum for productivity and persistence.

In an attempt to improve the persistence of perennial ryegrass (*Lolium perenne*) in south-western Victoria, Waller *et al.* (2001b) used a tactical (flexible) grazing system that involved rotational grazing during the summer, autumn and winter months, followed by continuous stocking during spring. There was a significant decline in ryegrass content, irrespective of the grazing system. This decline was attributed to a number of factors including the drier than average seasonal conditions, the high stocking rates and the gravelly soil type occurring at the experimental site (Waller *et al.* 2001b). The disappearance of perennial ryegrass under these environmental conditions was associated with an increase in some undesirable species such as *Hordeum leporinum* and *Bromus* spp. which increased more under tactical grazing than with continuous stocking (Waller *et al.* 2001b).

Under dry and hot summer conditions in south-west Victoria and south-east Australia, poor persistence of perennial ryegrass has been attributed to high stocking rates (Waller *et al.* 2001b). There is evidence in the literature that more frequent grazing of ryegrass in spring can not only reduce pasture growth, but can also increase plant death over summer as the storage reserves are depleted (Waller *et al.* 2001b). As a result, less productive species have greater opportunities to invade.

Cocksfoot (*Dactylis glomerata*): In Australia and New Zealand, poor cocksfoot persistence and reduced tillering have been reported under continuous grazing by sheep. In New Zealand, cocksfoot is reported to be well suited to rotational grazing (Kemp and Culvenor 1994). To maintain its productivity and persistence, management systems combined with cultivar development have been suggested (Avery *et al.* 2000; Kemp and Culvenor 1994).

In the HRZ of eastern Australia, the impact of grazing management on cocksfoot was evaluated on five commercial farms. The results of this study revealed that continuous grazing prevented cocksfoot from flowering and setting seed. It was therefore concluded that the impact of this on the productive life of a cocksfoot pasture would depend on the life expectancy of individual cocksfoot plants rather than on seedling recruitment (Avery *et al.*

2000). The findings of this study further suggested that cocksfoot herbage mass can be improved through the implementation of strategic grazing management, particularly over summer and early autumn (Avery *et al.* 2000).

Effect on native grasses

Over recent years, there has been a perception that native pastures in the grazing lands of northern NSW have become degraded. However, Bowman *et al.* (1998) argued that there is no evidence to support or refute such a perception; rather they suggest that high productivity can be derived from native pastures provided that fertilisers are applied and legumes are present. Lodge *et al.* (2003c) support the argument of Bowman *et al.* (1998) by reporting that with application of fertiliser and subterranean clover, native pastures maintained stocking rates of up to 9.2 sheep ha^{-1} in both winter and spring on the North West Slopes of NSW.

While the year-long green perennials such as *Austrodanthonia* species, *Microlaena stipoides* and *Dichelachne micrantha* are reported to provide high grazing value in heavily grazed areas on the North West Slopes of New South Wales, *Austrodanthonia* can be replaced by *Aristida* and *Bothriochloa macra* in some situations (Lodge and Whalley 1985). Nevertheless, there is potential for increasing the amount of winter green forage and the relative abundance of *Austrodanthonia* species through correct grazing management (Lodge and Whalley 1985); heavy summer grazing with sheep coupled with winter rest increased the abundance of *Austrodanthonia*. In tableland regions of New South Wales, *Microlaena stipoides* has been found to be more tolerant of grazing pressure under continuous grazing compared to *Themeda triandra* (Garden *et al.* 2003).

In the south-eastern temperate woodlands and grasslands, the botanical composition of pastures dominated by *Themeda australis* (a C_4 species) has shifted to C_3 species such as *Austrodanthonia* spp with increases in grazing pressure (Moore 1970). In southern NSW, Garden and Dowling (1995) suggested that cell grazing may increase the content of species such as *Austrodanthonia*, *Microlaena stipoides* and *Elymus scaber* but this suggestion remains to be proven (Garden *et al.* 1996).

Recent studies in south-east Australia have revealed that some native grass species such as *Microlaena stipoides* and *Austrodanthonia* spp. are relatively tolerant of grazing in the absence of fertiliser, but less so when dominated by *Themeda australis* (Garden and Dowling 1995; Garden *et al.* 2000a; Garden *et al.* 2003). In general, the literature supports the view that the generally low carrying capacity of native pastures can be increased through strategic

grazing management and fertiliser inputs.

Effect on legumes

The impact of grazing management on legumes is of great interest to livestock producers (Waller *et al.* 2001b). Under moderate to intense grazing, grasses that are more productive rely on the nitrogen-fixing ability of legumes in order to remain competitive (Waller *et al.* 2001b).

Greater defoliation of white clover compared to grass under sheep grazing demonstrates the preference of sheep for white clover which is thought to be linked to its high feed value (Carrere *et al.* 2001). There is, however, considerable concern that the level of legume production and/or persistence of many pastures is below the requirements for sustainable and viable production (Kemp *et al.* 2002). For example on the Northern Tablelands of New South Wales, management of pasture legumes is consistently identified as a major problem limiting pasture productivity (Kemp *et al.* 2002; McDonald 1995). This has been attributed, at least in part, to drier conditions in recent decades compared to the early phase of pasture development in the 1950s to 1970s (McCaskill and Blair 1988).

Effect on weeds

Most pastures are a mixture of grass and weed species. Species such as *Juncus* spp., *Carthamus lanatus*, *Cirsium vulgare*, *Cyperus* spp and *Agrostis avenacea* increase with poor grazing management, variable rainfall and changes in soil fertility (Bowman *et al.* 1998). In south-east Australia, Garden *et al.* (2000b) compared the potential for a range of grazing management strategies (seasonal rests, increased grazing pressure in spring, mob stocking, cutting for hay and continuous grazing) to affect the botanical composition of native pastures. In this study, while grazing treatments alone had little effect on the changes in composition, the combination of drought conditions and increasing grazing pressure brought about a change in species dominance from *Aristida bipartita* to *Bothriochloa macra*. Resting the pastures from grazing in autumn favoured *Microlaena stipoides* while the content of undesirable species, such as *Vulpia* spp., declined. However, resting in spring, autumn and winter significantly increased the proportion of the introduced undesirable perennial grass, *Holcus lanatus* (Garden *et al.* 2000b).

Within the grazing ecosystem, pastures are vital components in the maintenance of net primary production and most grazing management is aimed at maximising this production (Beattie 1993). Grazing animals affect net primary production by defoliation, treading and

excretion of dung and urine (Chen and Ferris 1999) and these factors modify the pattern of energy flow in the overall ecological system by influencing nutrient availability. The intensity and frequency of defoliation by grazing animals significantly influence pasture components (efficiency of pasture utilisation, herbage mass, pasture growth, pasture quality and species composition). The impact of grazing management on these components is considered to be a critical factor influencing the energy available to grazing animals (Bell 2003) and will be the focus of discussion in the next section.

Grazing management and pasture utilisation

It is generally agreed that removal of foliage from a plant reduces to some degree the potential of that plant to compete and retain its status in a plant community (Caldwell *et al.* 1981; Hodgson 1990). Coordination of the rate of pasture utilisation with the rate of pasture growth through control of animal numbers will help determine the success or failure of any grazing system (Heady and Heady 1982). Therefore, choice of stocking rate is a key to optimal management of pasture utilisation and, ultimately, of whole farm productivity (Archer 1989).

In their review of pasture growth and utilisation, Fulkerson and Donaghy (2001) concluded that maximum herbage yield and utilisation by dairy cattle can be achieved most reliably when defoliating a pasture of perennial ryegrass to about 5 cm height of residual leaf area which allows a rapid return to maximum growth rate. Pasture utilisation levels for the intensively managed sheep and beef properties in New Zealand are estimated to range between 30-40% and this may be further increased by mixed grazing of sheep and cattle (Mason *et al.* 2003a). At the whole farm scale, Reid *et al.* (1997) suggest that the implementation of rotational grazing will increase pasture utilisation by maintaining higher stocking densities which reduce the potential for selective grazing by animals.

Regardless of the grazing system employed, pasture utilisation needs to be balanced with considerations of future pasture growth rate, persistence of desirable species, ground cover and nutrient recycling (Mason *et al.* 2003a). Importantly, the use of any grazing system affects the rate of transfer of green leaf and stem material to dead components of a sward and the build-up and eventual breakdown of plant litter into soil organic matter (Lodge 2000).

Grazing management, herbage mass and growth rate

Archer (1989) stated that pasture growth rate initially increases as green herbage increases, but eventually leaf death and the effects of shading mean that pasture mass stabilises at a 'ceiling yield'. It is commonly accepted that pastures that are grazed 'too low' experience

slow regrowth, while pastures that become 'too tall' can potentially have a negative net growth due to shading and to more rapid senescence of older leaves than growth of new leaves.

In New Zealand, where there is a long growing season with comparatively uniform pasture production, rotational grazing has been accepted as a suitable method of pasture management (McMeekan and Walshe 1963). In Australia, rotational grazing has been suggested by Moore *et al.* (1946) as a practice that promotes high yields and vigorous pasture growth.

Rotational grazing has been advocated by some as the only system capable of maintaining a range of pasture species and high pasture production over the long-term (Barnes 1977; Booysen *et al.* 1974; Booysen and Tainton 1978). The system is claimed to satisfy the conflicting requirements of soil, plant and animal components which determine pasture productivity, longevity and profitability (Oram and Lodge 2003). Others have claimed that rotational grazing offers significant scope to cut costs compared to continuous grazing and where pastures are allowed a sufficient period of recovery, this system allegedly can promote regrowth and consequently greater herbage availability (Morley *et al.* 1969).

In the HRZ of temperate Australia grazing experiments have demonstrated higher pasture growth rates for rotational grazing compared with continuously grazed systems (Mason *et al.* 2003a). In Western Australia, a 3-year study on subterranean clover-based pasture at 3 stocking rates (4.9, 8.0 and 11.1 ewes/ha) revealed that there were greater amounts of pasture on offer in deferred (rotational) grazing systems compared with continuous grazing (Lloyd Davies and Southey 2001). Similarly, on the Central Tablelands of NSW, tactical grazing (a form of rotational grazing with relatively long grazing periods) produced superior plant growth compared with continuous grazing (Dowling *et al.* 2006).

In a number of areas of NSW, findings from the Sustainable Grazing Systems National Experiment confirmed that continuous grazing was commonly inferior to rotational grazing in terms of annual dry matter production. This comparison was based on continuous grazing of Sirosa phalaris at a high stocking rate (12 wethers/ha) resulting in less than 500 kg DM/ha remaining at the end of the study period, compared to a tactical rotation with pasture rest periods of six weeks in autumn (after tillering) and six weeks in spring (after stem elongation and flowering) which resulted in dry matter levels of 3000 kg DM/ha (Mason *et al.* 2003a). In a study undertaken in south-western Victoria, Clarke (2002) reported significantly higher pasture mass after a period of 5 years under rotational grazing compared to set stocking.

In southern temperate Australia, increased carrying capacities, increased forage production and quality and increased efficiency of harvest by the grazing animals have been suggested as some of the benefits of rotational grazing (Kemp and Dowling 2000). Declines in quantity and quality of grassland forage have been attributed to continuous grazing and high grazing pressures, particularly during times of feed shortage.

There are however some studies in the high rainfall perennial pasture zone across southern Australia (Dowling *et al.* 2005), in South Africa (O'Reagain and Turner 1992) and in the USA (Hart *et al.* 1993) where no cumulative increases in dry matter production have been reported from time-control grazing systems. For instance, the available empirical evidence from long-term grazing trials conducted on different pasture types in southern Africa confirmed that continuous grazing was not necessarily inferior to rotational grazing in terms of the impact on vegetation; out of 22 grazing trials, 5 showed superior range condition under rotational grazing, 3 indicated the opposite while 14 reported no significant difference (O'Reagain and Turner, 1992).

Grazing management and pasture quality

Digestibility is the most widespread measure of pasture quality; it is known to directly influence the rate of feed intake and selectivity (SCA 1990). In his observations covering a wide range of conditions, Birrell (1989) reported that digestibility is normally correlated with the stage of growth, proportion of legume in the sward and green-to-dead ratio. It is also directly influenced by grazing as animals typically choose to consume material of high digestibility.

It is generally accepted that for maintenance, grazing ruminants require pasture with at least 7% crude protein and 55% digestibility (Edwards 1981; Langlands and Holmes 1978). In the HRZ of temperate NSW it has been shown that the quality and quantity of available pasture in autumn and in early spring often do not reach these levels and therefore limit the nutrients available for pregnant and lactating ewes and also lamb growth to weaning (Morley 1994). However, there is considerable variation in pasture quality and this also changes rapidly with changes in seasonal conditions. In summer, annual pastures in southern Australia can have a digestibility as low as 41.5% with a crude protein level of 4.8% (Clarke 2002). Peak digestibility (79.9%) and crude protein (27.5%) have been reported from late autumn throught to spring (Clarke 2002).

Many studies have claimed that the quality of pastures can be enhanced by the use of

rotational grazing as the higher stocking densities reduce the accumulation of dead plant material while promoting growth of highly digestible pastures (Heitschmidt *et al.* 1982; Mason *et al.* 2003b; Oram and Lodge 2003). Conversely, some studies have reported that continuously grazed pastures are able to more consistently supply higher quality pasture than rotational grazing (Clarke 2002; Hodgson 1990; Nicol 1987) due especially to the promotion of a higher legume content (Graham *et al.* 2003).

Waller *et al.* (2001c) compared tactical and continuous grazing of perennial ryegrass-subterranean clover pastures grazed by sheep in south-western Victoria and found that, in the spring, both dry matter digestibility and crude protein were about 4 % lower with tactical stocking than with continuous stocking. The lower pasture quality in the tactical stocking treatment was attributed to higher levels of accumulated herbage mass with a higher stem:leaf ratio and more advanced reproductive growth than for the continuously stocked pastures (Waller *et al.* 2001c). Another experiment conducted in south-western Victoria reported that set-stocked pastures had a consistently higher crude protein than rotationally grazed pastures throughout a spring study period. Based on this finding, Clarke (2002) concluded that set stocking provided better control of spring pasture surplus while rotational grazing offered greater potential to increase stocking rate.

The above sections have reviewed the effects of variable climatic conditions, changes in soil fertility and grazing management on pasture production, persistence, botanical composition and quality. These factors have substantial consequences for animal performance (liveweight, growth rate, reproduction, wool quantity and quality). The impact of management practices (stocking rate, grazing management, soil fertility and sowing pastures) on animal performance will be considered in the next section.

Effects of changes in soil fertility and pasture species on animal performance

Most studies to date have shown that sowing of fertiliser-responsive perennial pastures is a good long-term investment (Chapman *et al.* 2003; Mason *et al.* 2003a; Sanford *et al.* 2003) as they can increase livestock production per hectare compared to that from annual or native pastures (Mason *et al.* 2003a).

The fertiliser regime is an important factor in determining animal production levels from grazing systems and particularly from those containing introduced perennial species. In the HRZ of temperate Australia, the application of superphosphate and replacement of native grasses with productive species such as *Phalaris aquatica* and white clover, has been

associated with large increases in the digestibility and crude protein of animal diets (Langlands and Holmes 1978).

On the North West Slopes of NSW, Lodge *et al.* (2003b) showed that the application of superphosphate and subterranean clover significantly increased animal liveweights and wool production and doubled stocking rate compared to animal performance on pastures where no fertiliser or legume was applied. Likewise, soil phosphorus levels have been positively correlated with the profitability of animal production systems (Graham *et al.* 2003). For example, Graham *et al.* (2003) reported an increase in carrying capacity from 14.4 to 22.2 DSE ha^{-1} when soil Olsen P levels were increased from 6.0 to 28.0 mg kg^{-1} . The latter appeared to be associated with an increase in legume content from 15% to 40%.

In many regions in Australia, high productivity from grazing animals is often related to the legume content of pastures (Kemp *et al.* 2002; Reed *et al.* 1972). On the Northern Tablelands of New South Wales, Cotsell and Edgar (1957) reported that providing sheep with part-time access to white clover-based pastures increased the carrying capacity of native pastures from 1.8 to 5 sheep $ha^{-1}$and wool production from 7.9 to 18.7 kg ha^{-1}. This trial was one of the first to demonstrate the large impact of white clover on animal production, with pure swards resulting in increased carrying capacity to more than 10 sheep ha^{-1}, increased reproductive rate from 73% to 81%, increased wool production by 21% per animal and a reduction in the mortality rate of mature animals from 5% to 1% per annum.

Graham *et al.* (2003) reported that animal productivity can also be enhanced by increasing the proportion of perennial grasses in the sward to around 60%; native grasses are generally believed to limit animal production as they supply low levels of green feed in winter and spring when the nutrient requirements of pregnant/lambing/lactating ewes are high. Nutrient-responsive deep-rooted, winter-green perennial grasses on the other hand can continue to grow through this period and overcome the limitations of native species. Increases in animal productivity of up to 150% per hectare have been reported compared with annual pastures and up to 300% compared to native pastures (Mason *et al.* 2003a).

Thus, increased soil fertility levels and the sowing of deep-rooted perennial grasses and legumes can improve overall pasture production, which can in turn enhance animal production. These changes are also influenced by grazing management practices such as choice of stocking rate and grazing method which both influence individual animal performance by affecting the amount of pasture available to the grazing animal. The next

section examines these effects in greater detail.

Key determinants of animal production

Stocking rate and grazing management effects on animal performance

Effect of stocking rate

From the standpoint of the maintenance of pastures, Ash and Stafford (1996) state that the selection of the correct stocking rate is the most important of all grazing management decisions; this concept has been affirmed by Mason *et al.* (2003a). In addition, stocking rate affects both individual and per hectare animal production. While graziers claim that similar production per head can be maintained at higher stocking rates under a cell grazing system (Norton 1998), the model of Jones and Sandland (1974) indicates that as stocking rate increases, per animal production will decline while per hectare production increases rapidly. As stocking rate increases above an optimum, both per animal and per hectare production decline (Jones and Sandland 1974) unless there has been a change in the productivity of the pasture base (Norton 1998).

In an attempt to explain the different experiences reported by researchers and graziers in relation to the claimed benefits of intensive rotational grazing, Norton (1998) speculated that a series of new lines might be drawn as paddock subdivision increases, due to the possibility of higher levels of herbage production brought about by rotational grazing at the farm scale. He suggested that this may be due primarily to the increased quantity of forage available for consumption which might be available under rotational grazing (Figure 2.1(ii)). While the curves of Norton (1998) imply increasing the quantity of forage with paddock subdivision, it must also be remembered that the ability of animals to select a high quality diet normally declines at higher stocking densities.

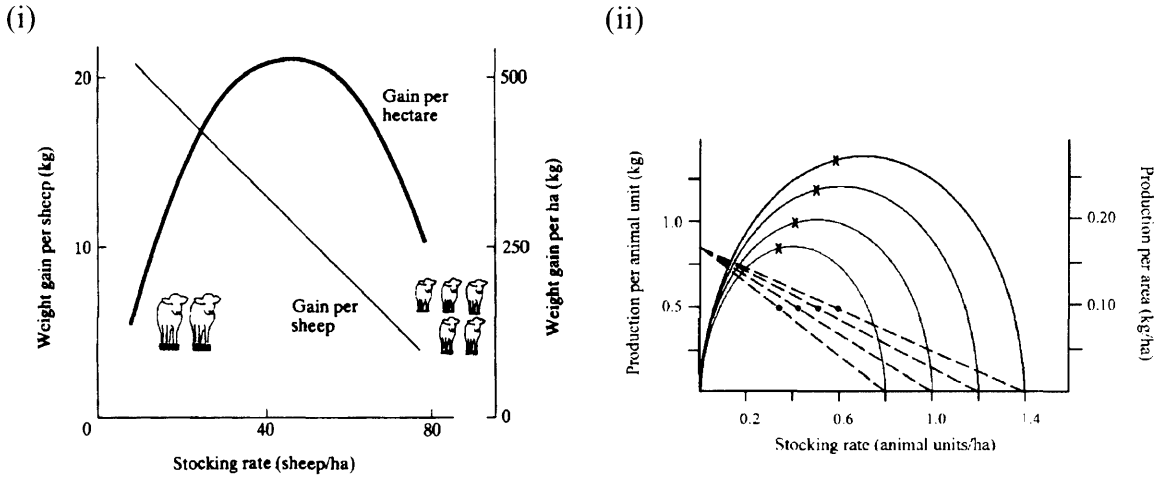


Figure 2.1 The relationship between stocking rate and weight gain per animal and per hectare according to (i) Hodgson (1990) for sheep and (ii) for animal units showing hypothetical curves representing a shift from continuous grazing in large paddocks to rotational grazing with increasing numbers of paddocks (Norton 1998).

In some grazing studies, low sheep fertility and high lamb losses have been associated with high stocking rates (Lloyd Davies 1968). In Western Australia, Lloyd Davies and Southey (2001) reported a significant reduction in joining and lambing weight of stock grazing subterranean clover-based pasture as stocking rate increased. These studies clearly indicate a relationship between stocking rate and animal production. However, O'Reagain and Turner (1992) in their review, cite many studies that suggest stocking rate to be only of secondary importance to the grazing system and that high stocking rates can be maintained under rotational grazing without any negative impact on pasture production and animal performance (Booysen and Tainton 1978; Savory 1983). Such conclusions are highly dependent on climatic conditions and the length of the study; a large number of papers have come to opposite conclusions (Carew 1980; Jones and Jones 1997; McMeekan 1956; McMeekan and Walshe 1963) suggesting that stocking rate has a greater influence on animal production than the grazing system.

McMeekan and Walshe (1963) measured the interaction between grazing method and stocking rate in the efficiency of pasture utilisation by dairy cows in New Zealand. Their results suggested that stocking rate was more important in affecting the efficiency of pasture utilisation than grazing management. In this early study on sown pastures, controlled rotational grazing was reported to be superior to uncontrolled continuous grazing both on a per animal and per unit area basis, but the impact was considered to be only half that of stocking rate. Nonetheless, the results of the study revealed a significant interaction between stocking rate and grazing method; with an increase in stocking rate, continuous grazing had significantly reduced production per unit area as a result of a decline in individual cow yield.

The authors concluded that the optimum stocking rate under controlled rotational grazing was 5-10% higher than under continuous grazing.

In contrast, the results of a study with sheep in Western Australia (Lloyd Davies and Southey 2001) compared two grazing systems (deferred grazing versus continuous grazing) and 3 stocking rates (4.9, 8.0 and 11.1 ewes/ha). They found inconsequential effects of the grazing system on animal performance. However, higher stocking rate significantly reduced ewe liveweight pre-lambing and resulted in a lower proportion of lambs marked (80%) compared to medium (95%) and lower (106%) stocking rates. Based on these findings, Lloyd Davies and Southey (2001) concluded that stocking rate is by far the most powerful factor influencing animal production from pasture.

Effect of grazing management

Total animal output has been reported by some to be greater under rotational grazing than under continuous grazing systems. It has been suggested that this is due to rotational grazing controlling the patterns of animal grazing, thus reducing the extent of species selection (Booysen and Tainton 1978) and hence increasing utilisation. Therefore, it is argued, rotational grazing can carry more ewes per hectare than set stocked systems because of better control of pasture allocation and utilisation (Chapman *et al.* 2003) and a greater capacity to balance pasture supply and animal demand (Norton 1998).

Booysen and Tainton (1978) have argued that deterioration of rangeland pastures is often associated with continuous grazing and, although animal performance may initially be high, long-term animal production is likely to decline with such management. On the other hand, rotational grazing should maximise the intake of animals when pasture growth rates are less than potential intake rates (Morley *et al.* 1969). This was confirmed in a study by McMeekan and Walshe (1963) in New Zealand where they found that rotational grazing allowed livestock carrying capacity to be increased by 5-10% compared with continuous grazing. In another study on phalaris-based pastures in western Victoria, rotationally grazed pastures supported higher stocking rates than set-stocked pastures but losses in pasture feeding value due to lower legume content under rotational grazing were noted (Chapman *et al.* 2003).

Not all studies support the claimed animal production advantage of rotational grazing over continuous grazing. Some reported benefits of continuous grazing include lower mis-mothering of twin lambs and consequently increased lambing percentages. In many regions of Australia, continuous grazing has become a preferred system for livestock producers. In their

comprehensive review of grazing management, Mason *et al.* (2003c) discuss the early literature on grazing management from the 1960s and 1970s. Those early studies found that, compared to rotational grazing, continuous grazing can consistently provide sufficient levels of herbage mass for satisfactory animal production from both cattle (at 1600 kg DM/ha) and sheep (at 800 kg DM/ha).

In southern Australia, animal performance has often been reported to be higher under continuous stocking compared with rotational grazing due to the increased legume content of continuously grazed pasture (Graham *et al.* 2003). Similarly, on the North West Slopes of NSW, Lodge *et al.* (2003b) suggested that rotational grazing may have a negative effect on herbage quality and consequently animal performance. Despite the marked reduction in the persistence of Sirosa phalaris under a high stocking rate on continuously grazed pasture, this was not reflected by a decline in sheep production (Lodge *et al.* 2003a); this finding supported the hypothesis that in the soil-plant-animal continuum, animal performance is the least sensitive indicator of unsustainable grazing systems (Lodge 1996; Lodge *et al.* 2003a).

Whilst the literature generally supports the view that rotational grazing has several advantages over continuous grazing, grazing experiments have nevertheless rarely been able to demonstrate greater animal production in either rangeland or sown pasture systems (Hodgson 1990; Morley 1981; Woodward and Graeme 1995). McMeekan and Walshe (1963) suggested that the claimed benefits of rotational grazing over continuous grazing have mainly been drawn from experiments measuring pasture production which have excluded measurements of animal production. Thus, according to McMeekan and Walshe (1963), the sometimes extravagant claims made for rotational grazing have not been substantiated by evidence from controlled experiments where animal performance has been measured. O'Reagain and Turner (1992) refuted the alleged benefits of rotational grazing by providing empirical evidence based on the analysis of over 50 grazing experiments conducted on different pasture types in southern Africa. In terms of animal production (meat and wool), their experimental trials revealed that, out of a total of 23 trials, 9 reported continuous grazing to be superior to rotational grazing while 7 indicated superior production under rotational grazing and 7 showed no significant difference between the two systems.

Norton (1998) highlighted the fact that rotational grazing strategies which many graziers claim are responsible for higher profits and better enterprise sustainability are the same as those which the research community has concluded can offer only marginal benefits to production and probably are not cost effective. There has been a tendency for there to be

contradictions between the experiences of graziers and the evidence from research trials concerning the benefits and drawbacks of these two grazing methods. In his comprehensive review of this topic, Norton (1998) pointed out that many graziers in several countries continue to claim that rotational grazing is one of the keys to successful, profitable livestock production and better planning and business management. However, he reasoned that the results from grazing trials conducted on a small scale have concluded that continuous grazing is actually no worse than rotational grazing and may even be preferable from a livestock production point of view. He suggested that the reason for the difference of opinion lies in the scale of the investigations.

Other comparisons of the benefits and drawbacks of the two grazing methods tend to be contradictory. While Hill and James (1999) reported a lower per head animal production from rotational grazing than from continuous grazing, Morley (1995) indicated that the benefits of both rotational grazing and continuous grazing depend on season, with rotationally grazed sheep performing better than continuously stocked sheep in poorer years and *vice versa*. While Hutchinson (1992) considered continuous grazing as an efficient method to manage ruminants, as it can maximise short-term animal production at low cost, continuous grazing is reported to neglect the regenerative needs of grazed plants, which are often grazed year-long, especially under climatic stress (Hutchinson 1992).

The reasons for the differences in advantages reported probably relate to seasonal and species differences. For example, in south-western Victoria, tactical (rotational) stocking was reported to have generally lower animal production compared to continuous stocking and this was associated with the negative impact on herbage quality. The ewes managed with tactical stocking were reported to be 3-6 kg lighter than those on continuously stocked pastures, particularly during spring and summer (Waller *et al.* 2001c); however, the results may have been different had seasonal conditions been better. Based on their findings, Waller *et al.* (2001c) concluded that soil fertility and pasture species were likely to have a much greater impact on animal productivity than changes to grazing method. In common with others (Chapman *et al.* 2003) these authors have suggested that different grazing methods needed to be used strategically in order to increase both animal and pasture production.

When comparing the benefits and weaknesses of the two grazing methods, Mason *et al.* (2003a) emphasised that the key issues to consider are animal performance and pasture persistence; this is based on the fact that when stocking rate is high, set stocking often leads to an increase in clover content which boosts per animal performance.

Lack of difference when comparing these grazing methods, might not be surprising where the scale of the study is so small that heterogeneity does not increase over time (Norton 1998).

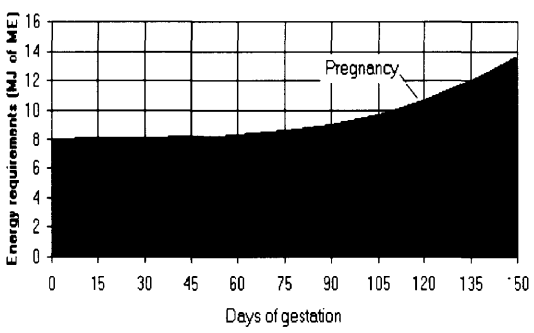
The next section gives an overview of the requirements for maintenance and production of livestock through liveweight gain, pregnancy and lactation.

Energy requirements of grazing livestock

The energy concentration of pasture and that required by grazing animals

The energy requirement of grazing animals varies with the size, age and physiological state of the animal as well as with the quality of diet and the availability of herbage mass (Hodgson 1990). The energy value of feeds is normally expressed as metabolisable energy (ME) content. The ME intake (the quantity and quality of plant material ingested) required by the animal is that which meets the requirements of an animal for maintenance as well as for any additional requirements such as to support growth, pregnancy and lactation. Thus, the ME required can change rapidly over time. For example, Figure 2.2 illustrates the increasing ME requirements of pregnant ewes and the great needs during lactation, especially during the first 60 days of lactation. The greater demand of twin lambs compared with single lambs is also shown in the Figure.

(i)



(ii)

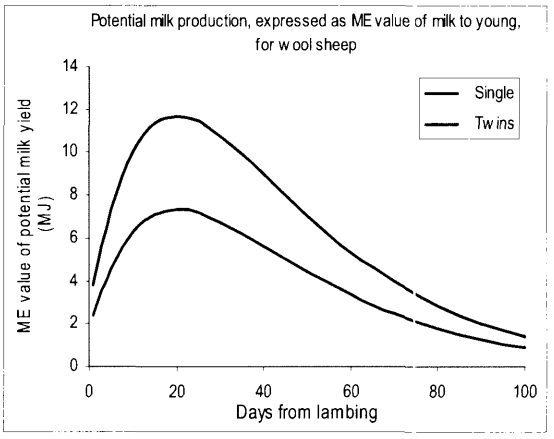


Figure 2.2 Daily energy requirements to maintain (i) a 50kg pregnant ewe, allowing an additional 2MJ above maintenance for grazing, with a single foetus weighing 4kg at term, on high quality (M/D = 11) pasture (Source: (SCA 1990)) and (ii) potential ME output in milk of a single- and twin-bearing ewe during lactation Source: (Freer *et al.* 1997).

The next section highlights the benchmarks which relate the amount of green herbage to the energy concentration of the pasture necessary to meet the ME requirements of different livestock classes.

Matching animal requirements with seasonal pasture supply

The nutrition of grazing sheep is mainly influenced by the availability of sufficient pasture and its quality, which is associated with the proportion of green and dead plant material present (Bell 2003). These components of pastures affect the intakes of metabolisable energy and crude protein that provide the requirements for maintenance, growth, pregnancy and lactation of grazing sheep (Caple 1994). For breeding ewes, late pregnancy and early lactation are two especially high demand periods, while young growing lambs have consistently high feed requirements throughout the year. The benchmarks below provide estimates of the appropriate minimum green herbage mass required to satisfy the nutritional requirements of sheep at various stages of their reproductive and growth cycle (Table 2.1).

Table 2.1 Minimum green pasture mass required for sheep (Source: Bell (2003)). The growth rates in brackets are based on a weaned 4-month-old merino lamb weighing approximately 32 kg (standard reference weight 55 kg).

Sheep category	**Growth stage**	**Minimum pasture (kg green DM ha^{-1})**
Dry sheep		400-500
Pregnant ewes	Mid pregnancy	500-600
	Last month	800-1000
Lactating ewes	Singles	1000-1600
	Twins	1400-1600
Growing stock		
	Percentage of potential growth rate:	
	30% (90 g/day)	500-600
	50% (150 g/day)	700-800
	70% (190 g/day)	900-1000
	90% (250 g/day)	1500-1600

The pasture benchmarks above are based on a rotationally grazed pasture in the HRZ of temperate Australia with digestibility ranging from 70-75%. The exact level of the benchmarks varies somewhat depending on pasture type, animal breed and weight, climatic conditions and grazing management.

The ability of the animal to consume sufficient pasture to meet its ME needs is reduced as the quantity of herbage on offer and, especially green herbage, declines; such a decline affects both intake and thus the liveweight gain of the animal. For instance, Bell and Blackwood (1993) reported declining liveweight of sheep as green herbage mass dropped below 800–1000 kg DM ha^{-1}. Caple (1994) reported the amount of green pasture required to maintain the liveweight of dry, pregnant and lactating ewes was 600, 900 and 1200 kg DM ha^{-1} respectively while Hamilton (1976) reported maximum body liveweight gain when green herbage on offer exceeded 1500 kg DM ha^{-1}.

Matching the nutritional requirements of grazing animals using the available pasture resource

without substantial loss of desirable pasture species is the key to successful grazing management. As pasture is the cheapest source of most of the essential nutrients consumed by grazing animals, it is vital that the grazing manager understands both the factors influencing pasture production and also the seasonal pattern of production (Hodgson 1990; Sollenberger 2002). Sheath *et al.* (1987) argue that pasture management is reliant on the knowledge of how and when to accumulate or transfer pasture, while allowing for a compromise between unrestricted feeding and the maintenance of pasture quality during periods of surplus.

The critical factors influencing the success of grazing enterprises, such as appropriate choices of stocking rate, grazing management and seasonal fluctuations in supply and demand are linked inextricably to feed planning (Sheath *et al.* 1987). In any grazing enterprise, the ultimate goal is to increase profit through the effective use of available feed resources. This requires feed planning by assessing both pasture availability and animal production requirements over both the short- and long-term.

Feed plans are based on estimates of present availability and future changes in feed supply and demand. Feed demand by grazing sheep is calculated from the energy required to meet production targets commonly expressed as desired levels of liveweight gain and body condition score. Feed demand can also be calculated for different mobs by taking into account the variation in liveweight of animals. Feed supply, on the other hand, is calculated mainly from estimates of the pasture growth rate. Annual pasture growth curves allow the calculation of the expected pasture available over a 12-month cycle which can be used to determine those time(s) of the year when pasture growth rate is most likely to become limiting to animal production (Dobos *et al.* 2004). The options to overcome feed shortages include either reducing animal demand or increasing feed supply.

Milligan *et al.* (1987) describe the tools of feed planning as feed profiling, feed budgeting and grazing plans. A feed profile is based on long-term (a year or more) decisions of stocking rate adjustments, time of lambing and weaning and transferring and rationing of pasture by use of long rotations. For example, it is common practice for producers to synchronise the increase in feed demand of lactating ewes with spring increases in pasture growth by prescribing appropriate mating dates (Rattray *et al.* 1987). Winter rationing can also enable the withholding of available pasture through into early spring when ewes start lambing. Such a strategy not only provides a direct increase in pasture supply during this nutritionally important period (early lactation), but also ensures optimum pasture cover (Milligan *et al.*

1987). Where pasture supply and demand are not well matched, such as when large surpluses are carried over from spring through summer, the integration of cattle with the sheep flock has been found to be beneficial (Sheath *et al.* 1987), ensuring better utilisation of the pasture.

According to the PROGRAZE extension package (Bell 2003), feed budgeting provides a basis for both medium- and long-term planning by balancing feed supply with demand. It involves assessing available herbage mass, quality and pasture growth rate and using this information to determine an appropriate stocking rate and number of grazing days for each paddock. This assessment is essential in making economic use of surplus pasture or identifying pasture deficits and periods of high nutritional priority to ensure optimal levels of animal production.

Grazing plans allow short-term decisions on how long a mob of animals should graze a particular paddock. Residual and pasture allowance methods are two approaches in setting up grazing plans and can be used to optimise paddock moves for livestock (Milligan *et al.* 1987). The residual method has been claimed to be more acceptable to producers because it involves the relationship between post-grazing herbage mass, which can be readily observed, to intake and animal production levels. In contrast, the pasture allowance method, whereby the number of days grazed is calculated based on pre-grazing herbage mass, area, number of animals and the allowance per animal, is reported to be more conceptually difficult (Milligan *et al.* 1987).

If grazing systems are to be sustainable, they are required to maintain productivity of perennial pastures in spite of the variable climatic conditions under which pastures grow. The concept of sustainability in relation to farming systems is reviewed in the next section.

Sustainable grazing enterprises

The development of sustainable productive and profitable enterprises without deterioration of fundamental resources has been a focus of attention both regionally and internationally since the early 1980s (Lawrence *et al.* 1994). Vizard and Foot (1993) indicate that the sustainability of a grazing system requires a biological and economically sound partnership between animals and plants. In recent years, there has been a growing interest in the on- and off-site impact of grazing systems on sustainability (Graham *et al.* 2003; Mason *et al.* 2003b). Scott *et al.* (2000c) have described the many factors which can influence the grazing enterprise as a series of six inter-dependent layers comprising climate, soil, pasture, animal, management and economic categories.

Soil is generally accepted to be the most fundamental natural resource, for which there are a

number of sustainability indicators (Freyenberger *et al.* 1997). As reviewed by Beetz and Rinehart (n.d.), the attributes of soil quality include soil health, nutrient and carbon balance and soil structure. A good quality soil provides a healthy environment for all of the creatures living in the soil (King 1994); soil quality also affects water infiltration and the water holding capacity of the soil, nutrient availability to plants and hence it helps support production from pastures.

Another important parameter of sustainability measurements includes pasture composition and especially the proportion of fertilizer-responsive, deep rooted perennial grasses and legumes (Lambert *et al.* 1996; Scott *et al.* 2000c) which greatly impact on ground cover as well as the quantity of soil water available to the pasture and the nitrogen supply dynamics which especially influences winter growth.

An overview of grazing management during drought suggests that planning for drought must take into account the amount and distribution of rainfall, stocking rate, pasture type and animal type (Morley 1994) as these decisions affect the sustainability of grazing enterprises across much of Australia. Managing complex mixtures of pasture species under variable climatic conditions is considered as one facet of the sustainability of grazed pastures. This is linked to greater species stability and deeper or more dispersed root systems that can better explore the soil volume and extract the limited water available for an increase in forage production and for survival. Perennial pastures are considered not only productive but also provide some drought forage in areas which experience highly variable rainfall (McKeon *et al.* 1996).

High stocking rates over long periods during drought can however trigger pasture degradation through the loss of these perennial pastures. Results from grazing trials confirm that the combination of heavily utilised pasture and drought during what should have otherwise been the normal growing season resulted in the loss of desirable perennial species (McKeon *et al.* 2004). In a 4-year study of perennial ryegrass in south-west Victoria, Waller *et al.* (2001b) reported its decline due to long dry periods combined with high stocking rates.

In a long-term grazing study of temperate pastures on the Northern Tablelands of NSW, Hutchinson (1992) reported that, at high stocking rates, phalaris was almost entirely replaced by annual species after drought leading to instability and loss of production. Likewise, in a study of 6 perennial grasses defoliated under drought on the Northern Tablelands of NSW, Boschma and Scott (2000) found that species differed markedly in their tolerance to drought

with losses ranging from 0 to 40% mortality in one season. This loss was most pronounced under severe defoliation during 'moderate' drought conditions (40 percentile rainfall) which allowed some regrowth of drought-affected grasses (Boschma *et al.* 2003).

The effects of drought have also been shown on legumes. In temperate pastures on the Northern Tablelands of NSW, Archer and Robinson (1989) found that white clover was particularly vulnerable to heavy grazing during extended dry periods over summer.

Prolonged grazing during drought is related to depletion of the carbohydrate reserves in shoot bases and roots, which affects their resistance to injury from moisture stress. Perennial grasses such as ryegrass and phalaris, when continuously defoliated in spring and summer, showed a markedly reduced level of reserves available for regrowth (Boschma *et al.* 2003; Fulkerson and Donaghy 2001).

The rationale for applying management changes to take into account the complexity of biological and ecological issues in grazing enterprises has not been fully researched in Australia and the limited adoption of controlled grazing systems in Australia may be due in part to the limited evaluation of such systems within whole-farm scenarios (Vizard and Foot 1993). The complexities of interacting factors that influence the results of whole-farm research make interpretation and extrapolation difficult. The next section will look in greater detail at the issue of the research scale that is needed to identify impacts of management for complex sustainability decisions.

Research scale and complexity

Livestock production in Australia occurs in a wide range of climatically and ecologically diverse regions. Vizard and Foot (1993) emphasise that the most important biological limitation to production is the mismatch between the energy and protein available from pastures and the nutritional demands of the different classes of stock. This mismatch is most often a result of seasonal variation in climate with erratic changes in rainfall causing major fluctuations in pasture growth.

The impacts of grazing management are difficult to measure and Kemp and Dowling (2000) have suggested that there is a need to investigate the effects of grazing management at an appropriate scale, in particular comparing the contrast of seasonal rests linked to phases of pasture development with a continuously grazed control treatment. Commonly, research experiments attempt to measure grazing enterprises on relatively small plots. It is generally accepted that extrapolating the results of small-scale controlled experiments does not always

translate to farm scale as it may not adequately take into account the spatial variation that occurs in realistic full-size grazing enterprises (Clarke 2002; Morley 1981; Norton 1998).

The distribution pattern and spatial management of grazing animals is one of the critical issues relating to the sustainability of livestock production systems. Uneven distribution of animals grazing large paddocks is well documented (Hodder and Low 1978; Orr 1980; Owens *et al.* 1991). Animals grazing large paddocks often exhibit spatial patterns of repetitive use as well as repetitive neglect of areas of the paddock. This phenomenon is one of the reasons given for adopting intensive rotational grazing systems by proponents of such practices. Norton (1998) indicated that large paddocks with low stocking density promote heavily grazed patches within the preferred communities, which has consequences for soil, plants and livestock.

Owens *et al.* (1991) argued that, as paddocks become smaller, the opportunity to improve the spatial efficiency of forage utilisation increases. The use of high stocking density in small paddocks to improve the spatial pattern of grazing animals has been supported by Norton (1998). His argument was based on the fact that whilst high stocking density for short periods may impose high grazing impact on vegetation, there is a substantial reduction in species selectivity by grazing livestock (Norton 1998). However, Taylor *et al.* (1985) argued that, even with small paddocks and moderate stocking rates, uneven distribution of grazing may never be eliminated because of the behaviour of grazing animals and the redistribution of nutrients as dung and urine. Their experiment provided evidence of the strong tendency of sheep maximising contact with neighbouring animals as they camped adjacent to fence lines (Taylor *et al.* 1985); hence, grazing management which overcomes problems of patch grazing remains a challenge.

One of the other arguments for increasing the scale of experimental processes is that presented by Scott (2003) who reported limited adoption by farmer members of the Cicerone Project of some of the findings of small-scale research conducted in the Temperate Pasture Sustainability Key Program. He suggested that there is a considerable gap between what scientists consider as valid research experiments and what producers see as evidence of improved farming practices at a credible scale.

This has been well illustrated in two national pasture research programs conducted in Australia between 1993 and 2002. These programs included the Temperate Pasture Sustainability Key Program (TPSKP) and the Sustainable Grazing System (SGS) Key

Program.

The TPSKP was introduced as the first phase of a grazing industry program from 1993-1997 to address the underlying problem of declining pasture productivity in the HRZ of southern Australia. The TPSKP concentrated on pasture rehabilitation by utilising grazing animals as the primary mechanism to bring about changes in the pasture through the application of strategic grazing management (Mason and Kay 2000). The impact of perennial grass content on the sustainability of temperate pastures was the second major research component in TPSKP (Kemp and Dowling 2000).

The subsequent SGS Program was established as a second phase, 5-year program (1997 - 2002) to further address the issues of declining pasture productivity and sustainability in the HRZ of southern Australia (Mason *et al.* 2003c). These programs found that, although the responses of different perennial grasses to grazing management were not consistent, more profitable and sustainable pastures could be achieved across the HRZ of temperate Australia by implementation of strategic grazing management.

In terms of economic returns, Mason *et al.* (2003c) indicated that rotational grazing methods appeared to have financial benefits provided they maintained high stocking rates, reduced the need for supplementary feeding and increased persistence and longevity of perennial grass-based pasture and thereby reducing the need for resowing. However, the impact of grazing method on 'whole of system' performance was believed to be different in whole farm, full-scale situations where the alleged benefits of rotational grazing are supposedly greater than in small experimental plots (Lodge *et al.* 2003a).

The absence of clear evidence from a 'whole farm' perspective that grazing management and/or the sowing and fertilising of pastures would lead to more sustainable and profitable grazing enterprises led in large measure to the creation of the Cicerone farmlet experiment described below.

The Cicerone Project

An attempt to assess whole-farm sustainability and profitability at a larger, more credible scale was set up by the Cicerone Project, a producer-led organisation on the Northern Tablelands of New South Wales, which commenced in 1998. The trial adopted a 'whole-farmlet' approach, which began following discussions at a number of meetings with graziers, researchers, extension workers and agribusiness representatives which determined that the main purpose should be to compare and measure management effects in different farmlets

across the soil-water-plant-animal-economic continuum.

Scott *et al.* (2006) reported that, following a survey of some 300 livestock producers from the region, the original aims of the project were to (1) create a learning environment in which researchers and producers could learn from each other and create new knowledge for the benefit of Northern Tablelands agriculture; (2) undertake training and increase awareness by conducting field days and skills workshops on topics determined by the project stakeholders; (3) provide access to a Central Learning Farm which would facilitate the uptake of research by trials and comparisons under commercial conditions; and (4) provide information through newsletters and other media to Northern Tablelands farmers.

The Project was funded by wool growers through Australian Wool Innovation. The entire project has been guided by a Board comprising a majority of producer members (with a producer as Chair), together with researchers from the University of New England and CSIRO, extension officers from NSW Department of Primary Industries, a lecturer from TAFE and a private veterinary consultant. Assistance was also provided from the Armidale Rural Lands Protection Board and the Sheep CRC (Scott *et al.* 2006).

The Cicerone research project has provided a unique opportunity to explore sustainability and profitability using a whole-farmlet approach on the Northern Tablelands of NSW which experiences variable and summer-dominant rainfall. There has been a lack of whole-farm measurement of grazing enterprises in this region. It is important to acknowledge that an investigation of this nature was particularly challenging to researchers, especially because it was not feasible (due to resource constraints) to replicate the differently managed farmlet systems. This whole-farmlet systems experiment is one of the few scientific studies conducted at this larger and therefore perhaps more credible scale; measurements were taken by various Cicerone Project team members over a period of five years.

To ensure the integrity and validity of the farmlet comparisons, a number of principles and guidelines were established for managing the farmlets. These principles and guidelines were designed to remain unchanged, even though at times the Cicerone Board determined that some changes in day-to-day practices were necessary. These guidelines specified most aspects of management such as policies on supplementary feeding, drought management, fertiliser applications, weed control and the sowing of pastures (Anonymous 2005).

The project has collected various measurements that relate to the productivity, profitability and sustainability of the farmlets including soil, plant, animal and economic aspects. Because

of funding constraints, few environmental parameters were able to be measured. Some results that have been published to date include animal health (Healey *et al.* 2004), wool production and quality (Lance 2005; Smith 2005), economic comparisons of the farmlets at farmlet and farm scale (Scott 2006), risk efficient frontiers (Behrendt *et al.* 2006) and an integrated overview (Scott *et al.* 2004).

In order to evaluate the sustainability and profitability of whole farmlets, measurements of as many components as was feasible have been taken since the farmlets were established on adjacent paddocks in July, 2000. The results from these farmlets present a rare opportunity to observe system differences at a scale larger and with more realistic whole-farm complexity than the traditional small plot scale commonly used by research workers. The scale and complexity of the farmlet systems were chosen in close consultation with producers, in the hope that the outcomes from the research might be more readily adopted by livestock producers than the results of small plot research.

Concluding remarks

This literature review has provided an overview of the impact of climate, soil fertility and pasture and grazing management on pasture production with a particular emphasis on the Northern Tablelands of NSW and Australia. Soil factors are more readily manipulated compared to climatic constraints but both have large effects on herbage production. However, the efficiency with which the herbage is converted into animal product is influenced by these two parameters as well as by choices of stocking rate and grazing management.

Within the boundaries set by soil and climatic factors, grazing management and stocking rate have been shown to be useful management tools to manipulate future pasture regrowth and animal production. The effect of grazing management practices on pasture components such as herbage mass, pasture growth, quality and species composition have been examined and there is considerable agreement that, compared to continuous grazing, rotational grazing can promote higher herbage mass, pasture growth and can enhance the persistence of perennial grasses.

The performance of the grazing animal ultimately reflects the balance between its nutrient requirements and the nutrients it is able to consume. This suggests that it is not only a question of how the pastures respond, but also how animals respond to the various management choices. It appears that pasture sustainability issues tend to favour rotational grazing over continuous grazing. Unfortunately, most of the reported benefits of rotational

grazing are based on evidence from producers' testimonials rather than from scientific work (Mason *et al.* 2003b). Furthermore, there is often a shortfall in animal production data. Relatively few experimental studies (Chapman *et al.* 2003; Lodge *et al.* 2003b) have incorporated both pasture and animal components and none has explored the interactions at the whole farm level.

Overall, this literature review has provided evidence that much of the decline in perennial grasses is due to the combined effects of grazing animals and drought and that good grazing management (including decisions on stocking rate, pasture subdivisions and animal movements) is the key to ensuring that the potential of the pasture is realised. However, the rules for managing sustainable grazing enterprises by enhancing the desirable components of temperate perennial pastures have not been sufficiently well documented. As explained in the study of Kemp and Dowling (2000), the best known exception is lucerne where the need for a grazing strategy is well appreciated by most graziers.

The following study will focus on how the components of pasture supply respond to different levels of inputs and types of grazing management and how a better balance between the competing needs of pastures and animals might be achieved under whole farmlet systems. A particular focus will be on how pastures and animal production have responded to three different management systems and how the competing needs of both pastures and animals might be better balanced in such a way that more sustainable production might be achieved.

The two forms of grazing management studied on the Cicerone farmlets (flexible grazing and intensive rotational grazing) were chosen for investigation with the agreement of farmer members of the group involved in the planning process who believed that continuous grazing was well known to be an undesirable practice on the Northern Tablelands of NSW and hence was of little interest to them. Rather, they wanted to compare systems which focused either on flexible grazing, guided by frequent measurements of pastures and livestock, or on intensive rotational grazing with its short graze and long rest periods, which has generated so much interest among graziers in this region over recent years.

Two hypotheses will be tested in this thesis:

1. That a high-input system (farmlet A), through sowing of perennial grasses and legumes and the maintenance of higher soil fertility, will improve the botanical composition and/or pasture supply and/or animal production and/or stocking rate compared to the typical management system based on moderate levels of inputs

(farmlet B) and

2. That intensive rotational grazing (farmlet C) with short grazing and long rest periods, will improve the botanical composition and/or pasture supply and/or animal production and/or stocking rate compared to the typical management system based on moderate levels of inputs (farmlet B).

The final experimental chapter of the thesis will examine a process for achieving a better balance between the pasture supply and animal demand, given the challenges of a highly variable climate.

It should be noted that the comparisons between farmlets will be between whole-farm management systems with no attempt to standardise the stocking rate between farmlets. This is because the number of stock that can be carried by each farmlet is likely, over time, to be affected by one or more of the management systems being explored and hence is viewed as an outcome of management rather than a controlled factor.

Chapter 3: General Materials and Methods

The Cicerone Project farmlet experiment

All the research experiments addressed in this thesis were undertaken on a farmlet systems experiment which was designed by Cicerone members and their research partners. The primary aim of the experiment was to assess whole-farmlet sustainability and profitability on a 'credible' scale on the Northern Tablelands of New South Wales and as such included grazing management rules and operational guidelines determined collectively by the Cicerone Project Board and farmer members from the region. The Cicerone Farm Manager had responsibility for the day-to-day running of the farmlets within the guidelines and consequently, researchers involved in specific components of the overall farmlet systems experiment were part of a team and, as such, did not have absolute control of many management decisions which influenced the operations of the farmlets. Thus, whilst the author of this thesis was responsible for most aspects of the integrative research reported here, it is important to note that the overall design and implementation of these farmlet systems was the responsibility of the entire Cicerone Project team.

The conception and planning phase of the farmlet experiment commenced in 1999 (Munro and Scott, unpublished). After allocation of the land to each of the farmlets, changes to fencing and watering points were made and the management treatments commenced on July 1, 2000.

The research layout

The study location and climate

The study was carried out on the Northern Tablelands of New South Wales, Australia, at CSIRO's Chiswick research property located 17 km south of Armidale. The experiments involved in this study were conducted over different time periods ranging from March 2000 to April 2005. This region is described as a temperate highland area of eastern Australia at an elevation of 1000 m a.s.l. with the experimental farmlets all having terrain which ranged from flat to slightly sloping. The area is located at latitude 30° 31′ S and longitude 151° 39′ E.

The climatic environment is characterised by relatively high rainfall with mean annual rainfall of 795 mm, of which about 60% falls between September and February. The area experiences a 200-day frost interval from April through October and intensely cold winter conditions (Ayres *et al.* 2001). During winter, the long-term mean minimum air temperature

is 0°C and the mean maximum is 12.7°C. Summer mean air temperatures range from 12.7°C to 26.1°C. The monthly climatic data covering the full experimental period of the Cicerone Project starting from January 2000 (6 months before the treatments officially commenced) are shown in Figure 3.1.

Seasonal conditions during the study comprised periods of marked drought recorded during autumn/winter months followed by periods with above-average rainfall frequently occurring during spring/summer months.

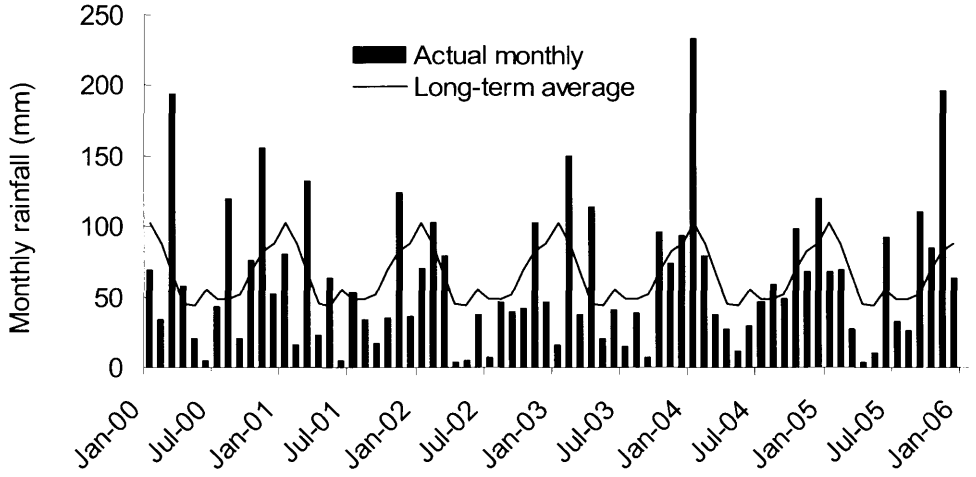


Figure 3.1 Actual and long-term average monthly rainfall from January 2000 to December 2005 for Armidale, NSW (Bureau of Meteorology).

Figure 3.1 above shows the actual and long-term average monthly rainfall for Armidale, NSW. It is noteworthy that in the years 2002-2005 inclusive, each year experienced a period with at least 5 consecutive months of below-average rainfall, whilst only once was a period with as many as 3 consecutive months of above-average rainfall experienced (in the spring of 2005 which was beyond the period of data collection reported in this thesis).

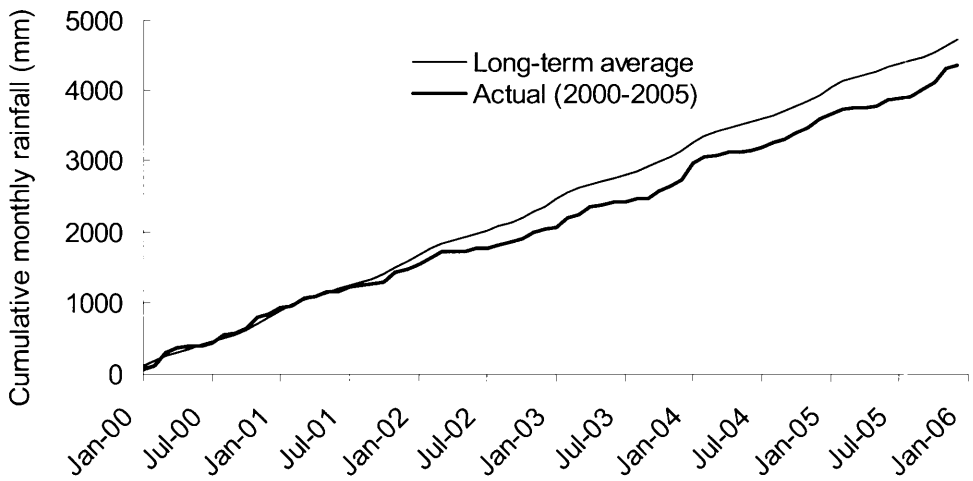


Figure 3.2. Cumulative actual and long-term average monthly rainfall from January 2000 to December 2005 for Armidale, NSW (Bureau of Meteorology).

The cumulative actual monthly rainfall shown in Figure 3.2 above, demonstrates clearly the below-average rainfall conditions that commenced in July 2001 and continued through to the end of the experimental period.

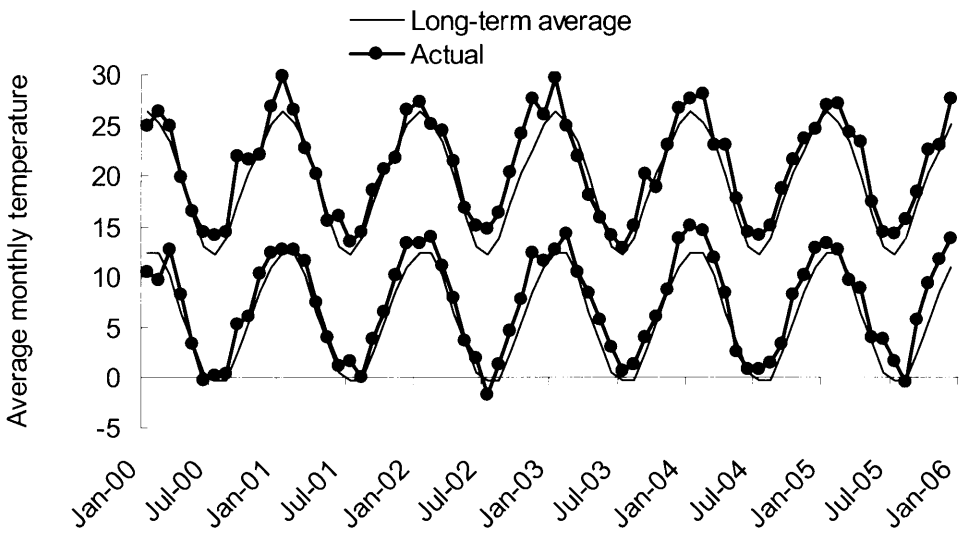


Figure 3.3. Actual and long-term average monthly maximum and minimum temperatures (°C) from January 2000 to December 2005 for Armidale, NSW (Bureau of Meteorology).

As shown in Figure 3.3 above, the average monthly maximum and minimum temperatures have frequently exceeded the long-term average temperatures over the past six years. When these above-average temperatures are combined with the generally below-average rainfall conditions, it is clear that conditions were dry throughout most of the 6 years reported here.

The soil type in the experimental area is characterised as a brown chromosol (McLeod *et al.* 2006) with a distinct texture contrast between the A and B horizons. The area originally

supported a wide diversity of native and naturalised perennial grasses dominated by *Bothriochloa macra*, lesser proportions of *Themeda Australis*, *Sporobolus elongatus*, *Sorghum leiocladum*, *Poa sieberiana*, *Agropyron* spp., *Vulpia* spp. and *Eragrostis* spp. (Taylor *et al.* 1985). More recently, the species growing in the region have been characterised and grouped as sown perennial grasses, legumes and broadleaf herbs, native cool-season perennials, native warm-season perennials, year-long green perennials, warm-season annuals, cool-season annuals, broadleaf weeds and weedy grasses (Table 4.1).

History of the site

Establishment of the farmlet systems

The objective of the Cicerone Project was to evaluate different management systems on a scale and complexity that would be seen as 'credible' by Cicerone members. However, to achieve this using a traditional replicated experimental design was considered prohibitively expensive.

It was, however, decided that the project's experimental results would provide a valid alternative to the traditional replicated experiments provided that sufficient care was taken in allocating land of equivalent productive capacity to each of the farmlet treatments and that modern statistical methods were employed for the analysis of the results.

To this end, the Cicerone Project leased 250 ha of land from CSIRO, Chiswick in 1999. During the initial establishment of the farmlets in 1999/2000, the base data gathered describing soil type, soil recharge, drainage, slope and fertiliser history were used in conjunction with a Geographical Information System (GIS) to enable the allocation of approximately 50 ha of equivalent land to each of the three farmlets (A, B and C) (Scott and Munro, unpublished). This distribution was based on three criteria:

- an electromagnetic survey conducted to determine soil conductivity across the 250 ha of land,
- topography and
- recent fertiliser history (Scott 2003).

Six iterations of data analysis across these three layers of information allowed the paddock boundaries of the three farmlets to be designed so that each farmlet contained equivalent soil resources (Munro and Scott, unpublished). Laneways were established to help with stock movements, while the peripheral area (approximately 100 ha) was used for agisting or

'selling' stock if changes to stocking rates were required. This area was also used for other animal-focused experiments and to provide an area of common grazing to permit the joining of ewes to the same rams over 6 weeks of each year, thus avoiding differences in animal genetic attributes between farmlets.

Fencing and water lines were installed between December 1999 and July 2000 and farmlets A and B were each originally subdivided into 8 paddocks and subsequently, in 2005, into 10 paddocks. Farmlet C was initially subdivided into 16 paddocks, then in 2001 due to a decision to increase the grazing rest period, it was increased to 33 paddocks and again in 2005, it was increased to 40 paddocks. At times during severe drought when longer rest periods were required, some further subdivision of this farmlet was done periodically using temporary electric fences. The first fertiliser applications and pasture sowings were carried out in the winter of 2000. Accurate records of stock movements, pasture and fertiliser input costs have been recorded since March 2000. The treatments were designated to have commenced on July 1, 2000 Figure 3.4).

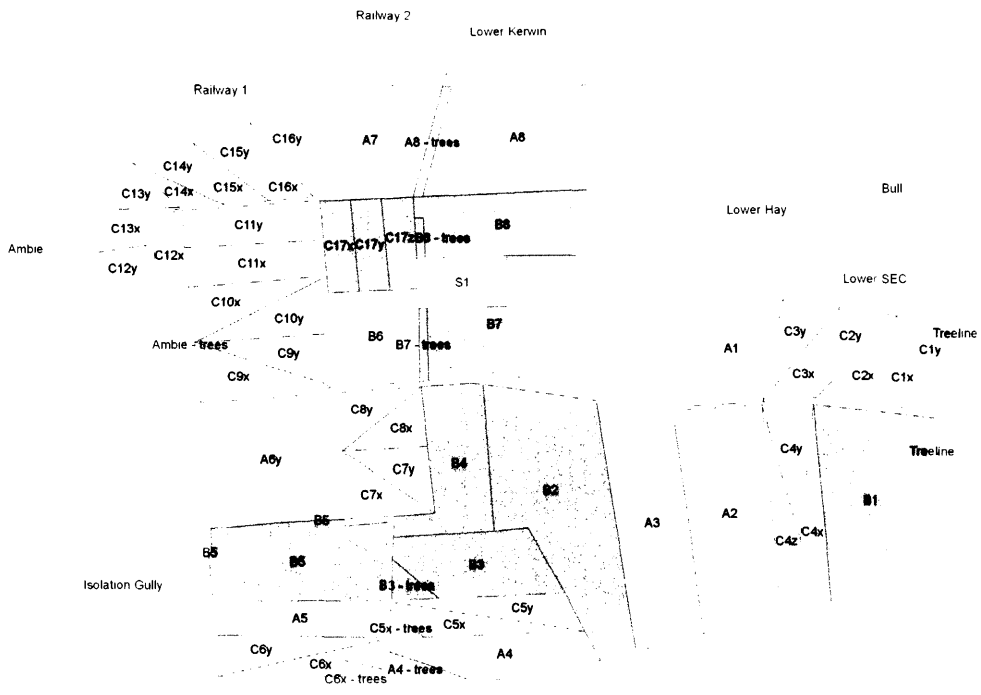


Figure 3.4 The final paddock allocation across the three farmlets with A paddocks shown in pink, B paddocks presented in green and C paddocks indicated in blue.

Livestock history

Merino ewes were initially bought from CSIRO's 'Chiswick' property and later, further ewes and rams were purchased from a range of traditional commercial merino flocks in the New England area. These sheep were randomly allocated into 3 equal mobs and were colour ear-tagged for identification according to the farmlets.

Farmlet management systems

The three farmlet systems involved in this study were designated A, B and C; farmlet A (high input system), farmlet B (typical district practice) and farmlet C (intensive rotational grazing). Farmlet B was chosen as the control treatment, designed to represent the management of a typical New England grazing property with maintenance of moderate levels of soil fertility (especially P and S), little sowing of replacement pastures and relatively low stocking rates with flexible grazing management.

Farmlet C was designed to have similar characteristics to Farmlet B, but having about four times as many paddock as farmlet B, thus enabling greater control of the intensive grazing practised on this farmlet. Farmlet A, on the other hand, had the same number of paddocks as farmlet B and similar grazing management but had higher target levels of soil fertility (60 ppm Colwell P and 10 ppm KCl40 S) and had a target botanical composition of 100% of sown pasture species. Following implementation of the management strategies, the target stocking rates for farmlets A, B and C were 15, 7.5 and 15 DSE/ha respectively.

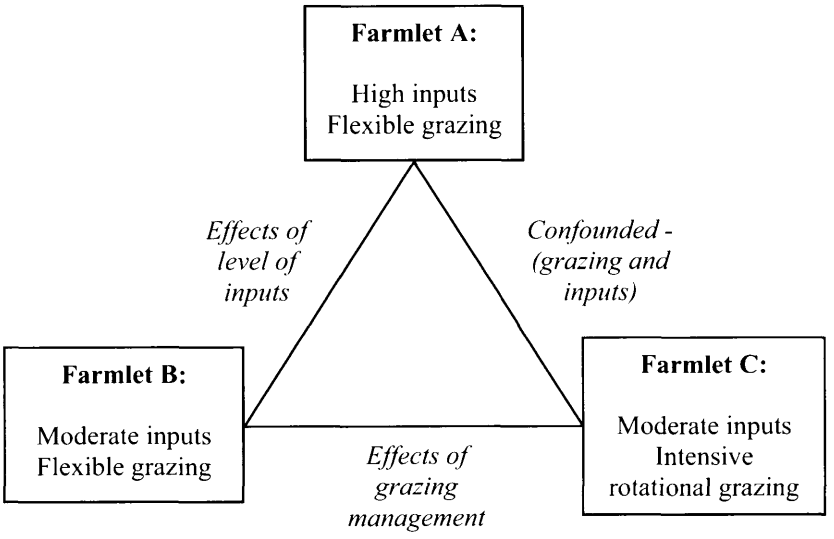


Figure 3.5 Summary of comparisons between the farmlet systems.

Therefore farmlets A and B differed in the levels of inputs (pasture and fertiliser) whilst farmlets B and C differed in grazing management as shown in Figure 3.5 above.

Fertiliser application, pasture sowing and management

During the establishment of pastures on the farmlets between 2000 and 2002 a variety of fertilisers were used to treat each paddock individually to meet specified threshold soil nutrient requirements (Appendix 1).

Generally for farmlet A, higher levels of fertiliser inputs were applied to achieve the higher soil fertility targets (60 mg kg^{-1} soil phosphorus and 10 mg kg^{-1} soil sulfur). Paddocks A6 (2001) and A1 (2002) were initially sown to short-term Italian ryegrass which lasted for only one year after being sown. Following the loss of these short-term ryegrass pastures, new pastures on farmlet A were subsequently mostly sown as a combination of deep-rooted, fertiliser-responsive perennial grasses (e.g. phalaris and tall fescue) and white clover, in order to attempt to reach the target set for farmlet A of having 100% of its paddocks as 'sown' pastures. As the regular checks of botanical composition up to early 2004 had shown relatively little legume composition, an effort was made to introduce a more drought-tolerant perennial legume, lucerne. Lucerne was sown into Paddock A1 in 2004 when the paddock was re-sown along with a summer-dormant phalaris (Atlas PG) and the deep-rooted herb, chicory. Sowing of paddocks A2 (2002), A3 (2000), A4 (2000), A5 (2000 and 2003), A6 (2003) was done using a mixture of tall fescue, phalaris and white clover. As paddocks A7 and A8 were found to have a sufficiently high level of sown species from the commencement of the trial (see Figure 4.2 in Chapter 4), these two paddocks were not resown over the life of the farmlet experiment.

The only herbicide use on the farmlets occurred prior to sowing pastures. Typically, weed control before sowing consisted of heavy grazing at the end of winter, followed by a short rest and then spray topped to reduce the seed set of annuals such as *Vulpia*. Pastures were then grazed heavily again, rested and then spray fallowed over the summer to accumulate soil moisture. Finally, pastures were sprayed in autumn about 10-14 days prior to sowing. Following early establishment, any initial grazing was usually brief and usually occurred in spring.

Farmlets B and C experienced no new sown pastures until 2004 when one paddock of each of these two systems was sown to a mixture of tall fescue, phalaris and white clover. Both farmlets B and C received moderate levels of fertiliser inputs (targets of 20 mg kg^{-1} soil

phosphorus and 6.5 mg kg^{-1} soil sulfur).

Grazing strategies

Two forms of grazing management were utilised on the farmlets - flexible grazing and intensive rotational grazing (Bell 2003). Neither of the grazing methods was formulated as 'put and take' systems; the systems implemented aimed to represent the typical commercial grazing systems commonly practised in the region with enterprises such as a self-replacing merino flock with opportunity cattle agistment and fattening.

The Cicerone Board decided to maintain what it judged to be at least a realistic whole farm stocking rate at all times. Thus, stocking rates were not reduced to the very low levels that can occur in some livestock experiments during drought times. The only exception was during the 6 weeks joining period each autumn, when ewes from all farmlets were run together on paddocks outside the farmlets in order to have access to the same rams thus avoiding possible problems due to differences in ram genetics between farmlets.

Initially, the grazing systems implemented were those imposed by the Cicerone Board and the Farm Manager. From 2003, attempts were made to base stocking rate decisions on pasture and animal benchmarks according to the PROGRAZE guidelines (Bell 2003), especially following several winter field days held for the purpose of estimating the needs of the livestock on each farmlet.

The farmlet systems A and B focused on flexible grazing whereby a monthly visual assessment of the availability of green herbage, along with the current stocking rate, physiological state of the animal, production required and paddock parasite load was used to determine how long a mob of animals stayed in a paddock. The aim of this form of grazing management was to attempt to apply PROGRAZE principles of herbage mass, digestibility and animal numbers and fat score. Whenever possible, the physiological stages of the livestock (e.g. young, growing stock, pregnant and lactating ewes) were taken into account when determining movements of mobs among the available paddocks.

However, explicit guidelines for implementing grazing management strategies with the added complexity of managing whole farmlet systems are beyond the scope of the PROGRAZE training manual (Bell 2003) and the Cicerone Board and the collaborating scientists were unable to collectively develop sufficiently rigorous rules that would apply under all circumstances. Hence, whilst the objective was to maintain the pasture feed supply with sufficient green herbage mass to meet the PROGRAZE benchmarks for the various classes of

grazing animals, there were inevitably times when the pasture supply was inadequate to meet the needs of at least some of the animal classes. At such times, supplementary feeding was carried out.

On the Cicerone farmlets A and B, 'flexible grazing' involved managing the various mobs of animals of the same stock class in separate paddocks. This approach allowed some paddocks of farmlets A and B to be rested while others were grazed at a density that was two to three times the overall farm stocking rate, for a shorter period. Stock movements among paddocks on these farmlets were not necessarily sequential, but were flexible and were targeted for specific purposes such as to allow for saving pastures for lambing and/or creating paddocks with lower worm burdens for weaning, grazing annual pastures to reduce seed set or resting perennial pastures to allow seed set.

Both farmlets A and B were generally managed with 4 mobs of animals (allowing animals with similar nutritional needs to be grazed together to avoid competition between adult and young animals) resulting in generally long grazing and short rest periods (Figure 3.6). The mean graze and rest periods on farmlet A were 52 and 63 days respectively whilst those for farmlet B were 81 and 97 days respectively. Because of the frequent resowing of pastures on farmlet A, the effective stocking rates carried on the grazed paddocks tended to be higher than the overall farmlet stocking rate. This was especially so for those paddocks which were never resown (A7 and A8).

Farmlet C employed intensive rotational grazing with usually 3 mobs of sheep rotating around its larger number of paddocks in a leader-follower pattern. These three mobs comprised weaner lambs, ewes and wethers plus cattle and they were normally rotated through paddocks in this order. The grazing method generally consisted of short grazing periods at high stock densities followed by long rest periods. This system was managed by weekly visual assessments of the pastures and animals, carried out by the farm manager. Depending on seasonal variations, the rate of pasture regrowth and the herbage available (green and dead), shorter grazing periods (of 3 to 5 days duration) and longer rest periods (80 to 200 days) were employed on farmlet C (Figure 3.6). Thus, the rest periods ranged from 40 to 80 days during more favourable pasture growth periods such as in spring and ranged from 80 to 200 days during periods of slower pasture growth (this frequently happened due to the extended drought periods which was exacerbated by cold during winter). The mean graze and rest periods on farmlet C were 8 and 117 days respectively. For this farmlet to achieve high stocking densities with 33 paddocks, three different mobs were needed.

In an effort to generate more objective criteria for moving livestock, commencing in autumn 2003, all paddocks were visually assessed by an experienced Technical Officer allowing a calculation of the ranking of paddocks based on green herbage mass. This assisted in choosing which paddocks of farmlets A and B would be grazed next. In the case of farmlet C, the rotation between paddocks tended to be in a fixed sequence around the farmlet.

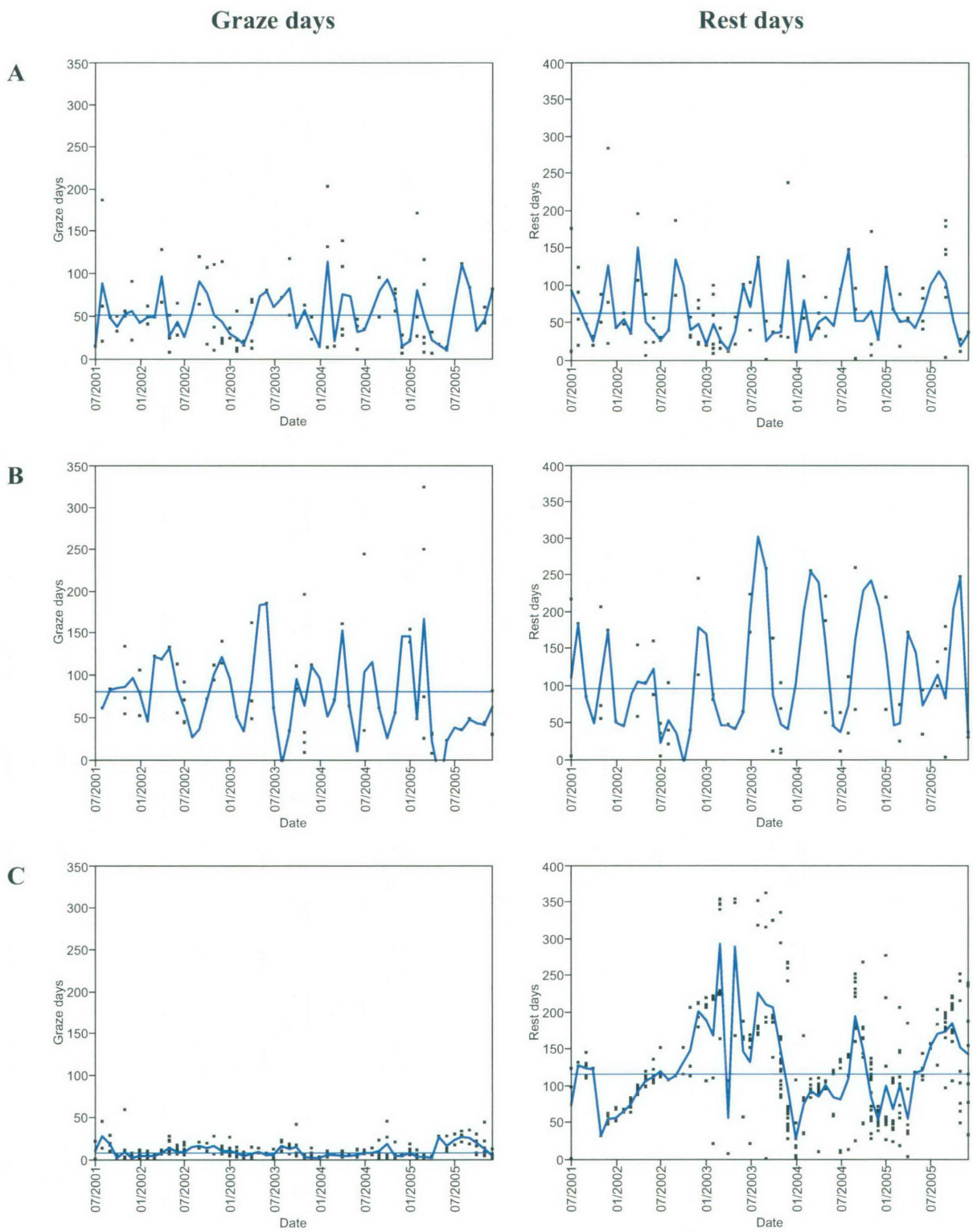


Figure 3.6. Records of paddock moves expressed as the length of graze and rest periods for all mobs of sheep on all paddocks of farmlets A, B and C from July 2001 to December 2005.

The symbol dots represent individual paddocks. The dotted line is the mean over the period whilst the solid line is a smoothing spline (r^2 values for splines varied from 0.41 to 0.60).

The intensive rotational grazing system used on farmlet C was based on the recommendations contained in literature on 'cell grazing' (Savory and Parsons 1980) and 'time control grazing' (McCosker 2000) which claims to allow for the recovery of the perennial pasture species. The aim was to allow the perennials to grow ungrazed to develop larger basal areas, presumably with deeper roots and higher energy reserves. When grazed, the individual paddocks were grazed at high stock densities (200-500 DSE/ha) to achieve even grazing and trampling of the dead material whilst providing litter, providing high levels of ground cover and opening up the sward to allow the pasture plants' growing points to have improved access to light.

At an early stage of the project (2002), a fodder budgeting strategy was trialled with the active assistance of NSW Department of Primary Industries staff (R. Marchant and C. Edwards) together with Cicerone farmer members, to assist in making decisions on the timing of stock movements among different paddocks. This was normally done two days after calibrated visual estimates of the herbage mass (total, green and dead) were carried out for all the paddocks, which enabled ranking of the paddocks to be grazed based on the highest green dry matter. The monthly measurement of the pasture growth rate using exclosure cages (described in Chapter 5) also assisted with the fodder budgeting which aimed at determining the appropriate stocking rate and number of grazing days for each paddock. Additional objective measurements included periodically using the median quadrat technique to assess the herbage mass (total, green, dead and legume) both prior to and after grazing on the 3 representative paddocks of each system.

Pasture measurements and techniques used

Details of the procedures used for the measurement of botanical composition, herbage mass, pasture growth and quality are provided in Chapters 4 and 5.

Animal management

The major enterprise conducted on each farmlet was a self-replacing merino flock (ewes, maiden ewes, hogget wethers, old wethers and weaner lambs) with some trading cattle bought and sold as opportunities arose to modify stocking rate as judged to be required by the Cicerone Board with the assistance of the Farm Manager. A description of the stock management practices and measurements is provided in Chapter 6.

Supplementary feeding

During the life of the project, the intermittent nature of the rainfall meant the stocking rate needed to fluctuate considerably whilst the level of supplementary feeding provided had the objective of maintaining the sheep in at least two score condition. However the members of the project did not desire a simple 'put and take' system where the stocking rate was infinitely adjusted (e.g. to very low stocking rates) to suit pasture benchmark figures. Stocking rates were changed in a manner that reflected commercial reality and this was achieved by the use of agistment cattle and the sale of culled sheep (usually cast-for-age and dry ewes). The stocking rate ranged in any one year from a low of 5 to a high of 20 DSE/ha on the A farmlet and from 4 to 16 DSE/ha on the B and C farmlets; nevertheless, the sheep needed supplementary feeding to maintain their body condition at score 2.

Supplementary feeding was provided mainly in the form of lupins, maize, cotton seed meal and hay; often the feed type was a balance of protein and energy in the form of a maize and lupin mix. As he was involved in all stock measurements, such as condition scoring and weighing, as well as all stock movements, the Cicerone Farm Manager (Mr. Justin Hoad) - in consultation with the Cicerone Board - was responsible for determining the levels of supplementary feeding for each class of stock within each farmlet. In the later years of 2004 and 2005, attempts were made to supplement pregnant ewes to at least 3 score condition, consistent with advice from the LifeTime Wool project (R. Marchant, pers. comm.). From 2002 on, ewes were scanned each year and twin and single bearing ewes managed in separate paddocks to allow for differential supplement to be provided to sustain each mob in a 3 score condition.

In general, the various animal classes run as separate mobs included single bearing ewes, twin bearing ewes, weaners/hoggets, wethers and cattle.

Farmlet A received relatively higher supplementation compared to farmlets B and C (Figure 3.7). Supplements changed over the lifetime of the project; in the early years (2000-2002) feed type was chosen to target the requirements of particular classes of stock; between 2003 and 2004 all stock were supplemented with lupins, whilst in 2005, the feed type was again targeted to classes of stock with a mix of 70% maize/30% lupins being fed to ewes and lambs where the total herbage mass on offer was less than 500 kg DM/ha. In cases where there was sufficient total herbage mass (> 1000 kg DM/ha) but insufficient green herbage (< 500 kg DM/ha), lupins and/or cotton seed products were fed as the supplement. The guidelines

developed at this time were focused primarily on feeding twin bearing ewes followed by single bearing ewes and lambs up to weaning. Feeding different rations to separate classes of livestock necessitated their separation into different paddocks.

In this latter period, farmlet A generally received higher levels of supplement, because of the higher stocking rate and the resulting limited herbage mass available. In general, Farmlets B and C had higher quantities of dry standing feed that needed supplementing with protein-rich feeds consisting of lupins, cotton seed meal and cotton seed pellets. In most years of the experiment, the feed was spread out onto the pasture. In 2005, confinement feeding was trialled whereby similar classes of stock were fed in a small paddock while allowing pastures to rest and grow in the ungrazed paddocks. This helped to accumulate sufficient herbage mass for lambing. This was beneficial as it meant that no feeding was required through to lambing and during early lactation as there was enough digestible green herbage mass. This resulted in less mis-mothering but nevertheless suffered from the high cost of supplementary feeding.

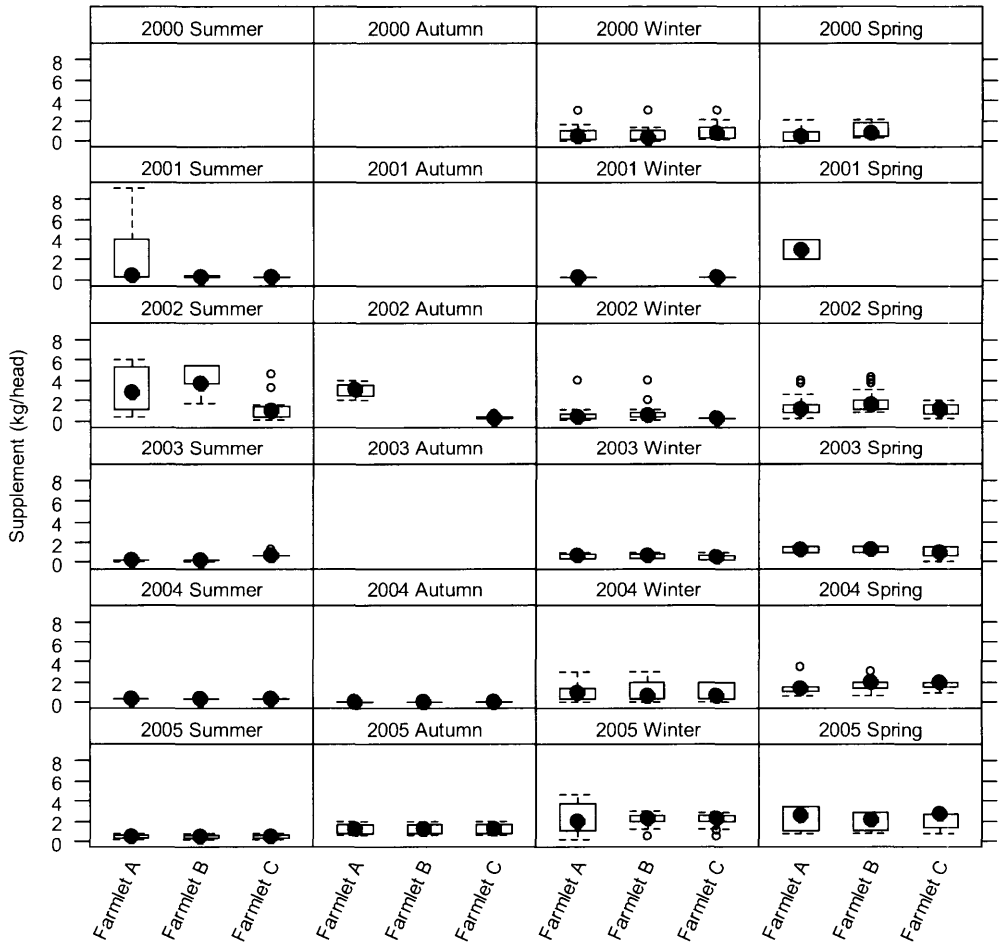


Figure 3.7 The supplementation provided (kg/head/week) to different classes of stock from July 2000 to October 2005 on farmlets A, B and C.

The variation is due to the amount fed to the various mobs within each week of each season. The dot in the box represents the median value and the height of the box is equal to the difference between the third and first quartiles of the data while the data points falling outside of the whiskers indicate the outliers.

Statistical methodologies of selecting representative paddocks

While the data for both pasture (herbage mass, pasture growth rate, quality and metabolisable energy) and animal production (liveweight, growth rate, wool quantity and quality) involved whole farmlet investigations, the research reported in this thesis focused largely on intensive investigations from three representative paddocks of each farmlet between March 2003 and April 2005. The following section outlines how the representative paddocks were selected.

Introduction

In this study, it was not possible to take measurements from all the experimental plots available due to resource constraints and the limit of 3 years of study. Therefore, the initial

objective was to identify 3 representative paddocks from each of 3 farmlets operated by the Cicerone Project. This was done by evaluating paddocks for a range of attributes where data were available to choose paddocks for more intensive study which were most representative of each farmlet. As with most real farms, paddocks differ substantially due to variations in soil type, topography, area, past management history, botanical composition etc. In general, the approach taken was to select paddocks from across the range of various factors, not those which were most similar to each other or those closest to the mean values. Thus, a deliberate choice was made to sample across the variation exhibited so that the paddocks chosen were the most representative of the candidate paddocks for each farmlet.

Data sources

The data used in selecting the paddocks (Table 3.1) were provided by the Cicerone Project for a period 2000 to 2002 and were generated from GIS maps. Physical visits to the research site were also conducted in order to make close observations of candidate paddocks.

Table 3.1 Criteria used for characterising each of the paddocks within each farmlet.

Natural resources	Management	Pasture	Others
Elevation	Soil phosphorus	Sown grasses	Time since sowing
Electromagnetic conductance	Soil sulfur	Introduced grasses	Paddock size
Slope	Fencing changes (leading to non-uniform botanical composition)	Native grasses	
Electrical conductivity		Legumes	
Cation exchange capacity		Weeds	
Soil pH		Herbage mass	

The data were evaluated with multivariate analyses (e.g. cluster analysis and principle component analysis (PCA)) using the statistics program 'R'. This was also done through serial iterative cycles of the PCA and exploration of single factor variations. Bar charts were also created to present the mean and standard errors (±) of the weighted criteria sorted in order from highest to lowest values for all the paddocks within each farmlet.

Results and discussion

The process of selecting three representative paddocks of each farmlet involved weighting and ranking of the data categories according to priorities chosen *a priori*. It should be noted that, where there was a confounding of two or more factors, a compromise had to be made to cover the range of values across the candidate paddocks.

Table 3.2 Ranking of the first three paddocks within each farmlet based on a range of criteria.

Criteria	Farmlet A	Farmlet B	Farmlet C
Recently sown paddocks*	A1, A5 and A6		
Non-uniform spp. composition*		B4 and B6	C6
Elevation	A4, A2 and A3	B5, B1 and B3	C5, C4 and C1
Electromagnetic conductivity	A8, A7 and A3	B8, B7 and B1	C3, C2 and C12
Sown grasses	A2, A8 and A7	B1, B7 and B8	C9, C10 and C11
Native grasses	A4, A8 and A7	B3, B5 and B2	C3, C5 and C7
Soil phosphorus	A7, A2 and A8	B2, B1 and B8	C9, C2 and C1
Soil sulfur	A2, A7 and A8	B1, B8 and B2	C2, C4 and C1

* Excluded as candidate paddocks

Paddocks which were clearly non-uniform in terms of botanical composition due to removal of several fences during the establishment of the new paddock boundaries (B4, B6 and C6) were excluded from the selection process. Each of these paddocks had a diverse species composition; for example, a section of one paddock comprised of about 70% sown grasses whereas another section had more than 80% native grasses. Sampling such paddocks becomes difficult as more than one transect per paddock has to be established.

In order to avoid having some representative paddocks with immature pastures, all of the A paddocks that had recently been sown (A1, A5 and A6) were also excluded as their pastures were not yet fully established.

Having anticipated that all the paddocks with heterogeneous species composition and those that were recently sown should not be included in the selection process, this was taken as the first criterion and such paddocks are not included in any further analyses.

Criterion priority 1 - elevation

For the purpose of paddock selection, elevation was given the highest priority, as it is the principal factor governing the potential for flooding and cannot be 'managed'. The elevation rankings of the first three paddocks for each farmlet were as follows: A4, A2 and A3; B5, B1 and B3; C5, C4 and C1. In general, the Cicerone site is located on gently sloping to level land, which is not likely to pose any topographical restrictions on the pasture preference by the grazing animals. Having anticipated the effect of any localised flooding which might occur during this extended field experiment, it was decided that only one of the three paddocks (A7, B8 and C9) chosen from each farmlet would be allocated to low-lying land (Figure 3.8).

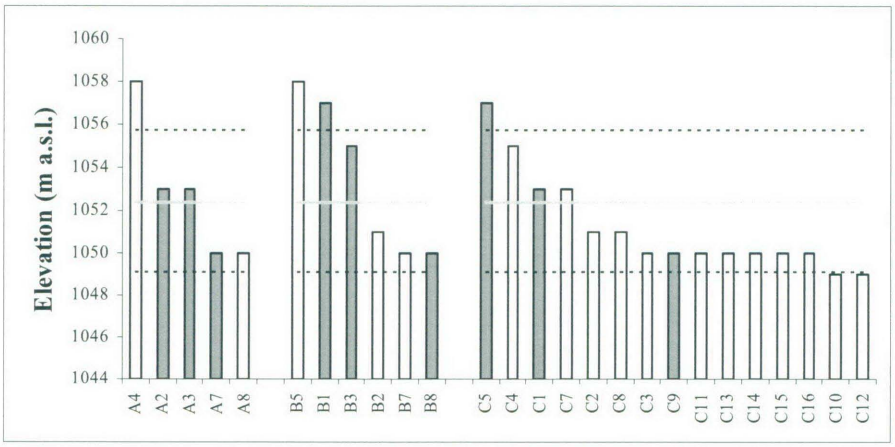


Figure 3.8 Data for individual candidate paddocks and the means (±se) of the elevation (m a.s.l) for the paddocks of the three farmlets.
Dark bars indicate the finally selected paddocks.

Criterion priority 2 - soil type

Electromagnetic conductivity was considered as the second most important factor after elevation; it relates to a basic natural resource such as soil quality. The importance of this factor is outlined in the next section. When examining electromagnetic conductance, it became apparent that this was confounded with elevation (Figure 3.9).

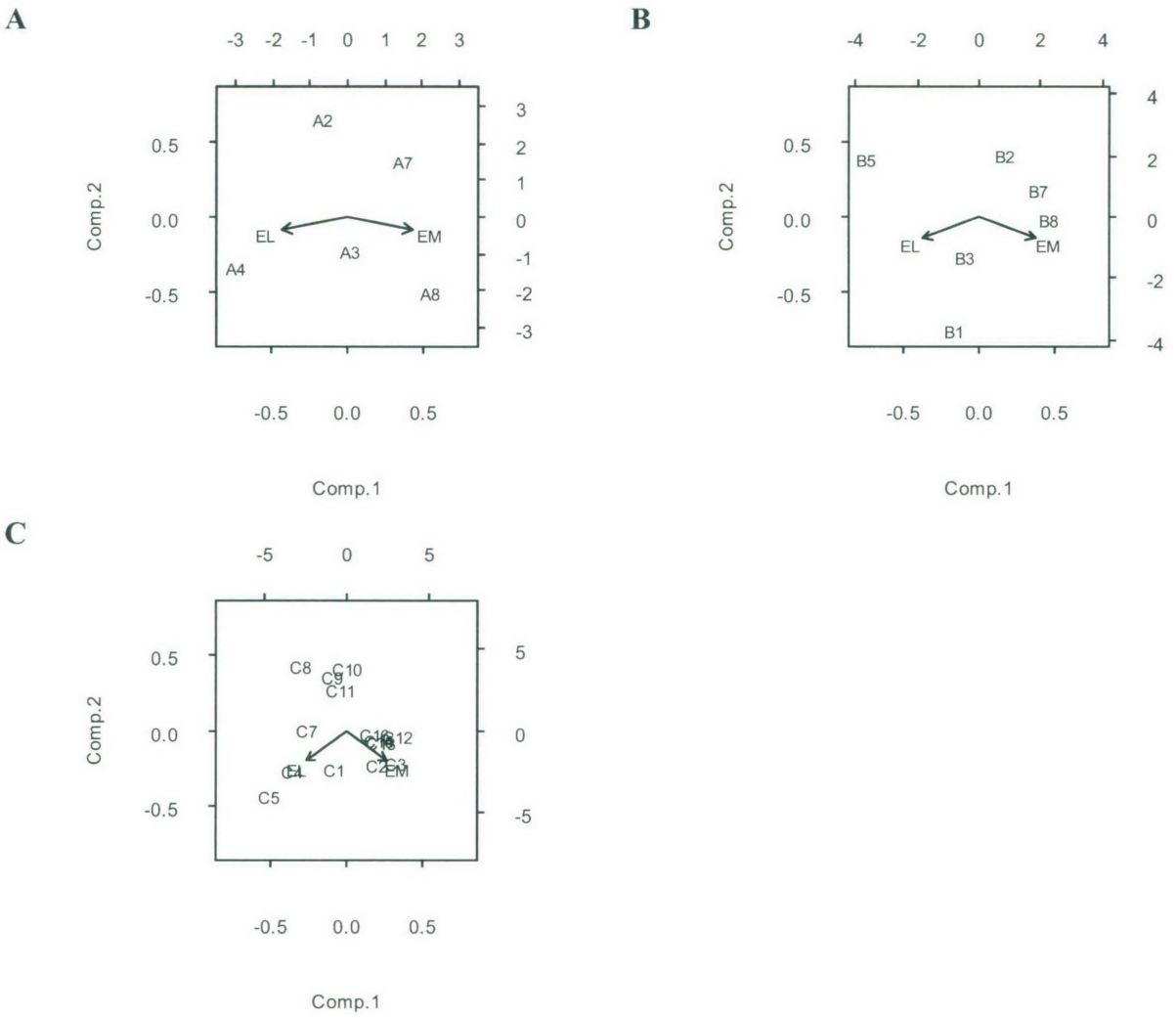


Figure 3.9 Principal component biplot relating the distances of the candidate paddocks of each of the three farmlets, A, B and C to the means of the two factors.

Component 1: electromagnetic conductance (EM) and component 2: elevation (EL).

When establishing the paddocks, electromagnetic conductance (Figure 3.10) was used to estimate the bulk electrical conductance of the subsurface soil; this was to identify the differences in drainage characteristics of the soils over the landscape in an attempt to ensure that each farmlet was allocated equivalent areas of various drainage classes.

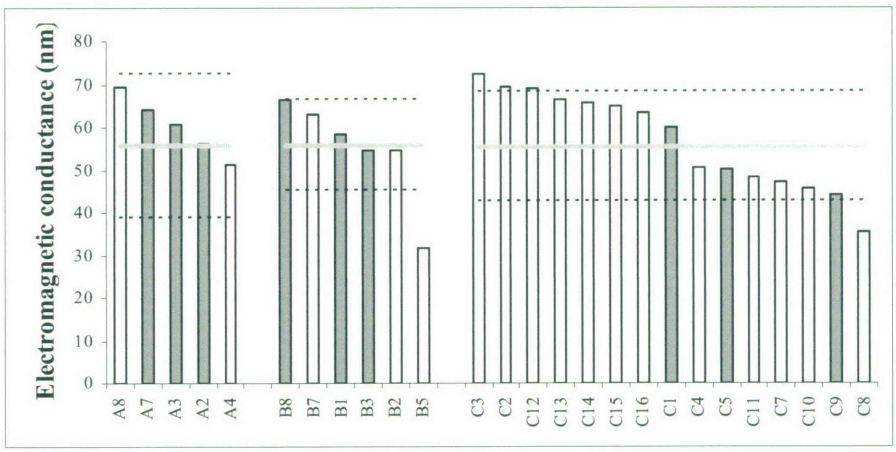


Figure 3.10 Data for individual candidate paddocks and the means (±se) of electromagnetic conductance (nm) for the three farmlets.
Dark bars indicate the finally selected paddocks.

Criterion priority 3 - soil fertility

Having established the criteria which allowed equal distribution of area across the farmlets during the initial commencement of the farmlets, the next step was to set targets for soil fertility levels to allow allocation of paddocks to the three different management systems. The target levels were based on soil phosphorus and sulfur and the influence of these two elements on changes in soil fertility as it affected the Cicerone farmlet systems is addressed in the next section.

Within one year of the commencement of the management treatments, the choice of representative paddocks for each farmlet also took into account the measured levels of available P and S (Figure 3.11 below).

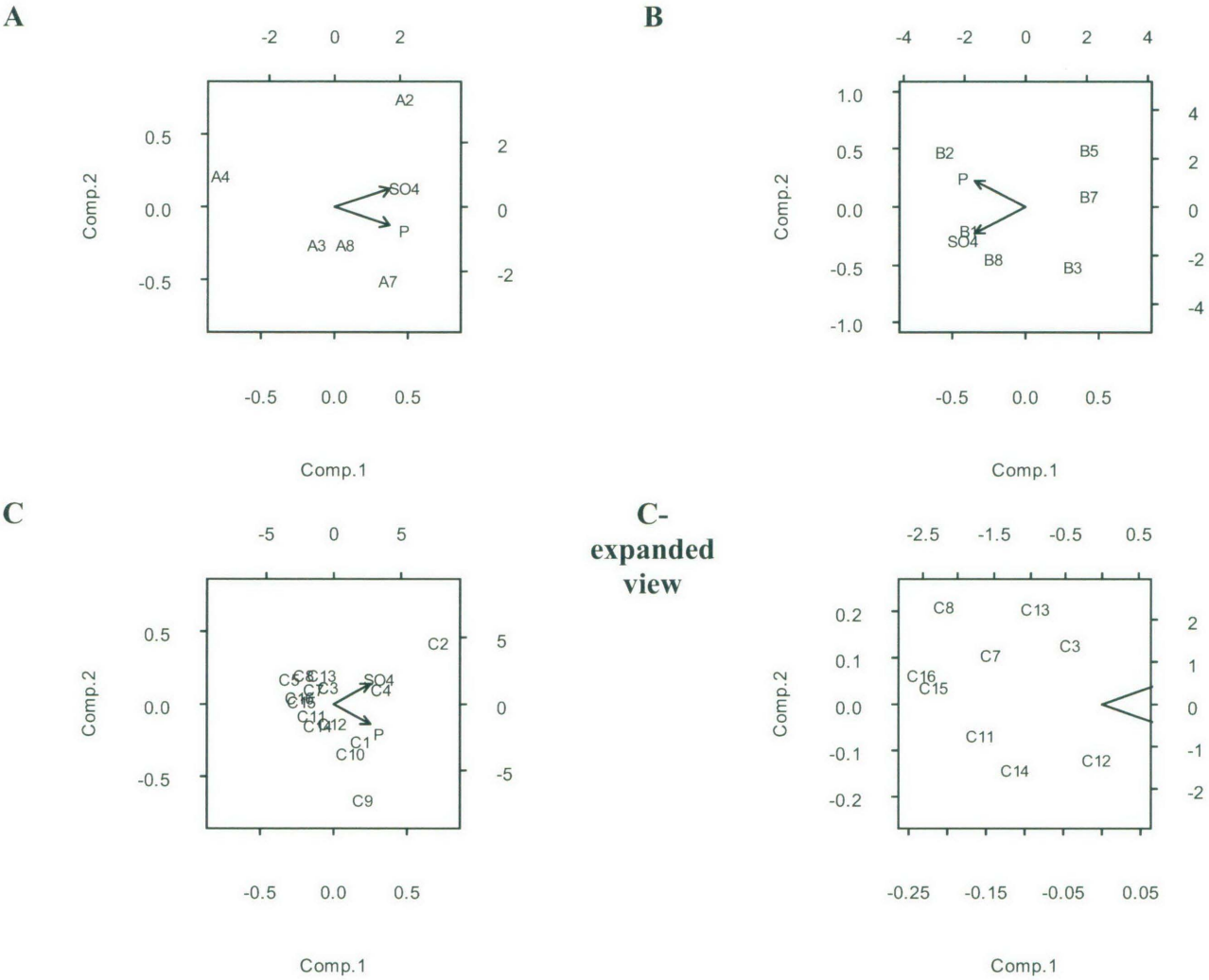
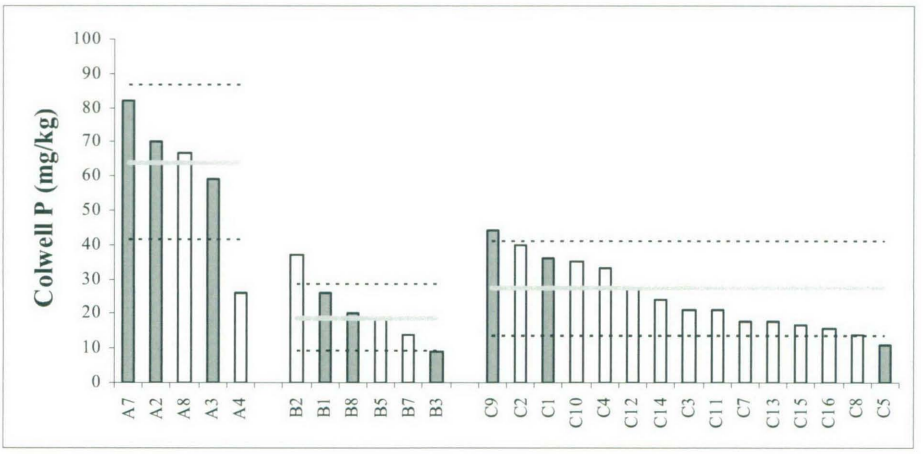


Figure 3.11 Two-dimensional plots of the factors, soil phosphorus and sulfur, from the principal component analysis of each of the three farmlets.

The P and S demonstrated co-linearity (Figure 3.11). For A paddocks, a similar ranking was observed for both the P and S criteria (Figure 3.12). The rankings were in a slightly different order for farmlets B and C.

(a)



(b)

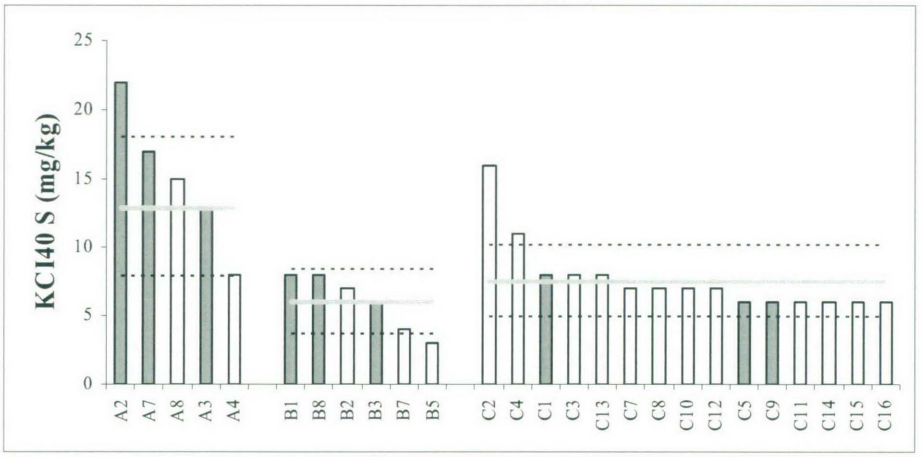


Figure 3.12 Means ±standard errors of (a) Colwell P and (b) KCl 40 S (mg kg-1) for individual candidate paddocks of each of the three farmlets.
Dark bars indicate the finally selected paddocks.

Criterion priority 4 - botanical composition

The fourth criterion used was botanical composition. One of the aims of the high input system (farmlet A) was to ensure that all of its paddocks, either through maintenance of existing sown pastures or by resowing new pastures, consisted of deep-rooted, fertiliser-responsive perennial grasses and perennial legumes. Following the sowing of some A paddocks in July 2000 and May 2001 the average composition from March 2000 to December 2002 of this farmlet was assessed at 52% sown grasses and less than 5% of legumes. Farmlet B had no newly sown pastures and it was assessed over the same period as having an average of 23% sown grasses and less than 5% legumes. Similarly, Farmlet C was assessed as having an average of 39% sown grasses and less than 5% legumes.

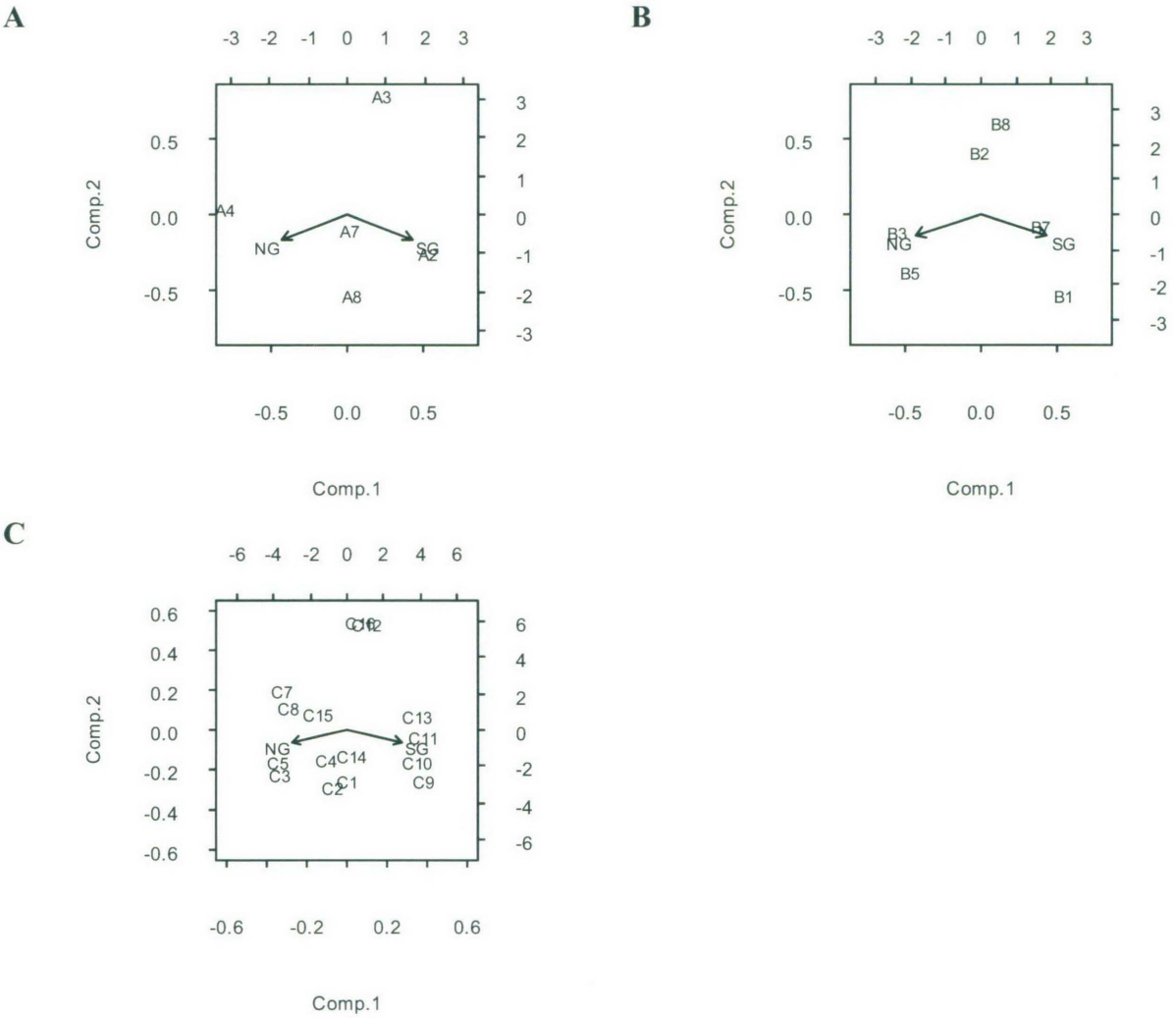
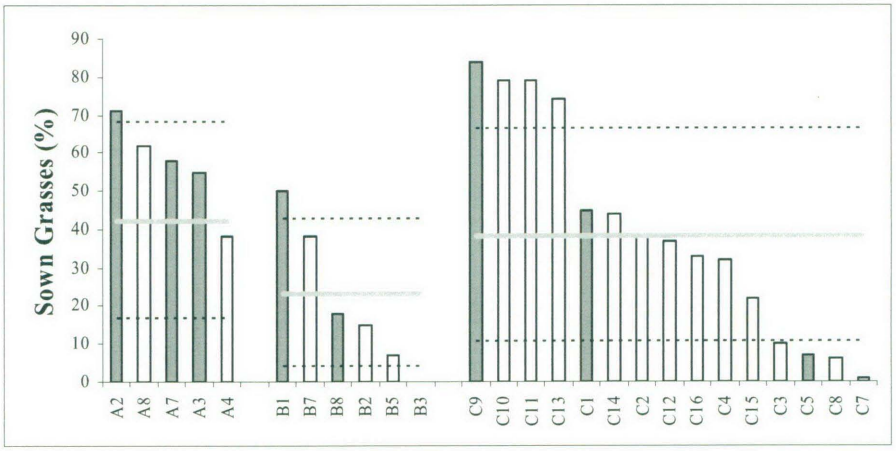


Figure 3.13 Principal component biplot relating the distances of the candidate paddocks to the mean factors, sown grasses (SG) and native grasses (NG) on farmlets A, B and C.

The proportions of sown and native grasses were found to be negatively correlated (Figure 3.13). When ranked by the sown grasses the first three paddocks were, A2, A8 and A7; B1, B7 and B8; C9, C10 and C11 and when ranked by native grasses the paddocks were ranked in order A4, A8 and A7; B3, B5 and B2; C3, C5 and C7 (Figure 3.14).

The proportions of introduced grasses (not sown), weeds and legumes were relatively low across all paddocks and therefore were not included in the selection criteria.

(a)



(b)

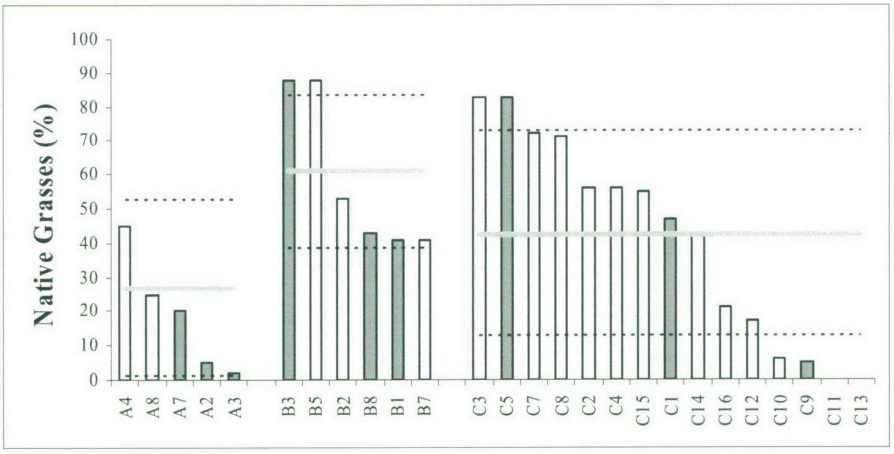


Figure 3.14 Botanical composition (mean % □ se) of (a) sown and (b) native grasses for individual candidate paddocks from March 2000 to December 2002 on farmlets A, B and C.

Other criteria

Soil pH, cation and anion exchange capacities and soil electrical conductivity are important soil characteristics which are related to soil fertility but which showed no consistent relationship between farmlets (Figure 3.15). Because of this, these factors were not used as selection criteria.

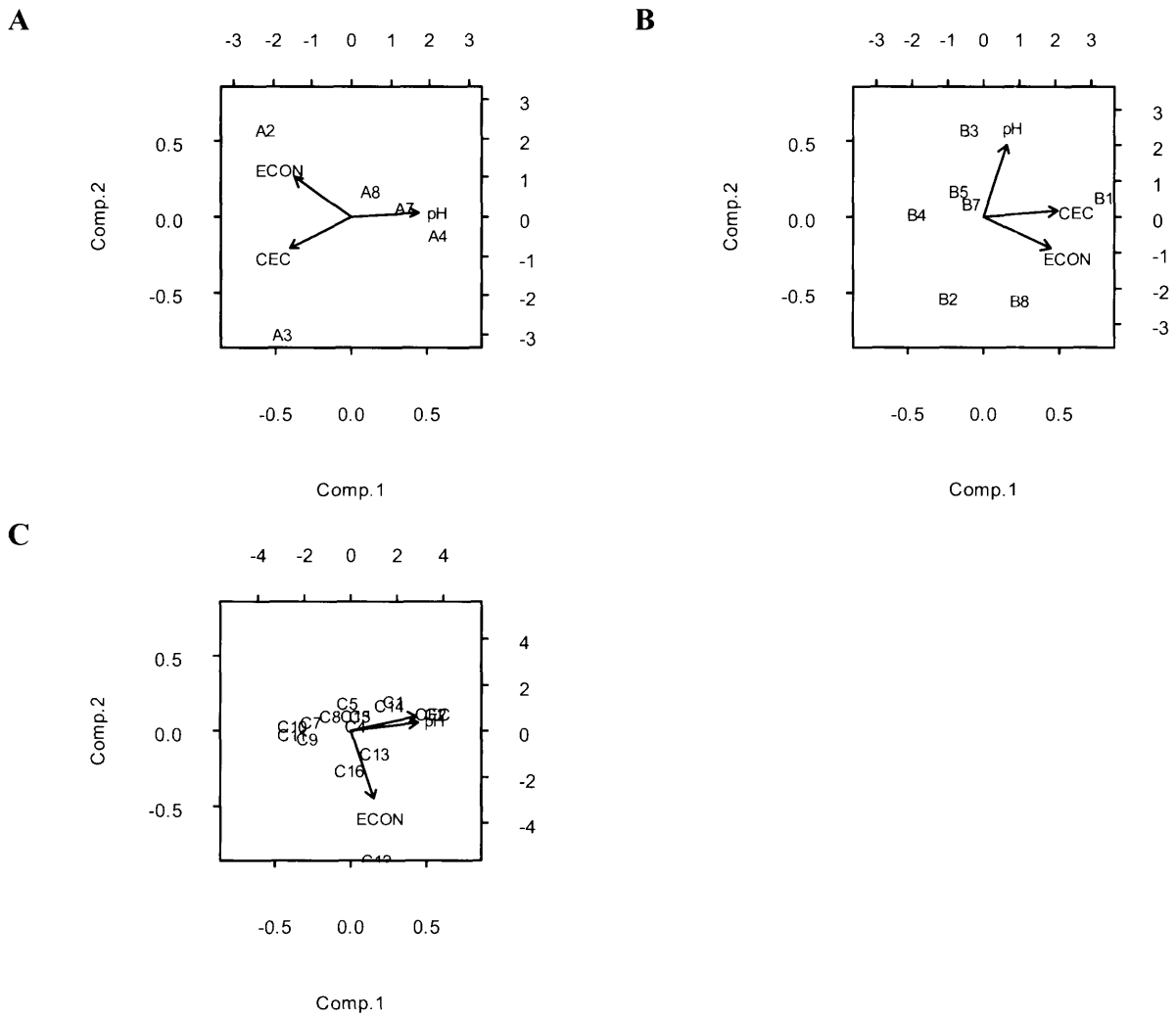


Figure 3.15 Principal component biplot of the factors, soil electric conductivity (EC), pH and cation exchange capacity (CEC) on farmlets A, B and C.

Although herbage mass was assessed across all paddocks, it was not included in the selection process as it needed correction for a number of factors such as grazing days, trampling and treading by grazing animals; the latter two factors were not measured during the establishment of the farmlet treatments.

Having established the criteria to be used for selection, the paddocks were individually evaluated to determine how many of the criterion thresholds were met. The exclusion process based on these criteria allowed three paddocks from each farmlet to be chosen for use as outlined in the next section.

Final selection of the representative paddocks

The process of selecting the three most representative paddocks from each farmlet involved

careful consideration of the multiple criteria described above and summarised in Table 3.3. The specific details of the process of deciding the most representative paddocks from each farmlet are described below.

Farmlet A

Recently sown paddocks (A1, A5 and A6) were excluded from the selection process. Paddock A4 had soil phosphorus and sulfur below the target levels for the high input treatment. The content of improved perennial grasses in this paddock was also lower whilst there was a high percentage of native grasses. Paddock A4 was also a smaller paddock than the others and was therefore eliminated.

It was planned that only 1 out of the 3 selected paddocks for each farmlet would be located on low-lying land to minimise effects if flooding were to occur. This meant that either of A7 or A8 had to be excluded as both were located at the lower part of the site. Whilst both paddocks satisfied a majority of required attributes, the choice was finally based on rankings and A8 was excluded. Eventually, paddocks A2, A3, A7 were chosen as those best representing the range of paddocks allocated to farmlet A.

Farmlet B

Paddocks with markedly different sub-sections in terms of botanical composition (B4 and B6) were excluded from the selection process. Although paddocks B3 and B7 had soil P below the set target level and paddocks B5 and B7 had soil S below the set target level, these levels could be remedied using the planned fertiliser strategies. Eventually, paddocks B5 and B7 were excluded because of irregular paddock shape, which would have required more than one transect for pasture sampling. Paddock B3 was noted to have a low content of sown grasses and 88% of native grasses.

Again, to ensure that the risk of flooding impacts were evenly allocated to each farmlet, the same principle of choosing one paddock only on the low-lying land was applied. The choice was between B8 and B7 and since B7 had a lower ranking, it was excluded. Paddocks B1 and B8 satisfied the majority of criteria. Paddock B2 was eliminated because more than 80% of this paddock was dominated by the low forage value species, *Poa sieberiana*. As a result, paddocks B1, B3 and B8 were finally chosen as best representing farmlet B.

Farmlet C

The choice of paddocks from farmlet C was wide because this farmlet had many paddocks of

more or less the same area (hectares) and relatively uniform species composition e.g. paddocks C1, C2, C9, C10 and C11. Paddock C6 was excluded because of its patchy botanical composition.

In terms of elevation, only one paddock was chosen in the low elevation area and therefore, paddocks C12, C13, C14, C15 and C16 were not chosen. Paddock C4 was excluded because it had a larger area than the rest of the paddocks. Paddocks C7, C8, C10 and C11 were excluded as they satisfied the least number of criteria compared to C9. Paddock C9 was chosen after applying the same principle applied to farmlets A and B of selecting one representative paddock with one of the highest percentages of sown grasses. There was no clear difference between paddocks C1, C2, C3 and C5 in terms of criteria applied and therefore a random selection was made. Thus, paddocks C1, C5 and C9 were ultimately selected as most representative of this farmlet (Table 3.3).

Table 3.3 Summary of the criteria used for making the final selection of a representative sample of 3 paddocks from each of farmlets A, B and C.

Paddock number	**Paddock area**	**Recently sown**	**Bot. comp. not uniform**	**Elevation**	**EM#**	**P#**	**SO_4#**	**SG#**	**NG#**	**Average**
	(ha)			(m a.s.l.) and (rank)	(nm) and (rank)	(mg/kg) and (rank)	(mg/kg) and (rank)	(%) and (rank)	(%) and (rank)	rankings
A1	3.8	**X**								
A2*	7.5			1053 (2)	56.08 (4)	70 (2)	22 (1)	71 (1)	5 (2)	2.0
A3*	8.5			1053 (3)	60.86 (3)	59 (4)	13 (4)	55 (4)	2 (1)	3.2
A4	4			1058 (1)	51.29 (5)	26 (5)	8 (5)	38 (5)	45 (5)	4.3
A5	3	**X**								
A6	6.4	**X**								
A7*	6.7			1050 (4)	64.18 (2)	82 (1)	17 (2)	58 (3)	20 (3)	2.5
A8	9.8			1050 (5)	69.33 (1)	67 (3)	15 (3)	62 (2)	25 (4)	3.0
		(not A1, A5 & A6)		**(not A7 or A8)**	**(not A4)**	**(not A4)**	**(not A4)**	**(not A4)**		
B1*	8.6			1057 (2)	58.45 (3)	26 (2)	8 (1)	50 (1)	41 (5)	2.3
B2	10.4			1051(4)	54.64 (5)	37 (1)	7 (3)	15 (4)	53 (3)	3.3
B3*	4.6			1055 (3)	54.82 (4)	9 (6)	6 (4)	0 (6)	88 (1)	4.0
B4	4.8		**X**							
B5	6			1058 (1)	31.66 (6)	19 (4)	3 (6)	7 (5)	88 (2)	4.0
B6	6.7		**X**							
B7	3.3			1050 (5)	63.11 (2)	14 (5)	4 (5)	38 (2)	41 (6)	4.2
B8*	5.8			1050 (6)	66.52 (1)	20 (3)	8 (2)	18 (3)	43 (4)	3.2
			(not B4 & B6)	**(not B7 or B8)**		**(not B3 or B7)**	**(not B7)**	**(not B3 or B5)**	**(not B3 or B5)**	
C1*	3.4			1053 (3)	59.96 (8)	36 (3)	8 (3)	45 (5)	47 (8)	5.0
C2	3.3			1051 (5)	69.28 (2)	40 (2)	16 (1)	38 (7)	56 (5)	3.7
C3	3.4			1050 (7)	72.59 (1)	21 (8)	8 (4)	10 (12)	83 (1)	5.5
C4	5.3			1055 (2)	50.67 (9)	33 (5)	11 (2)	32 (10)	56 (6)	5.7
C5*	3.8			1057 (1)	50.33 (10)	11 (15)	6 (10)	7 (13)	83 (2)	8.5
C6	3.1		**X**							
C7	2.3			1053 (4)	47.31 (12)	18 (10)	7 (6)	1 (15)	72 (3)	8.3

C8	2.3		1051 (6)	35.43 (14)	14(14)	7 (9)	6 (14)	71 (4)	10.2
C9*	3.3		1050 (8)	44.15 (15)	44 (1)	6 (11)	84 (1)	5 (13)	8.2
C10	3.4		1049 (14)	45.73 (13)	35 (4)	7 (7)	79 (2)	6 (12)	8.7
C11	4.1		1050 (9)	48.33 (11)	21 (9)	6 (12)	79 (3)	0 (14)	9.7
C12	2.3		1049 (15)	69.13 (3)	27 (6)	7 (8)	37 (8)	17 (11)	8.5
C13	2.7		1050 (10)	66.24 (4)	18 (11)	8 (5)	74 (4)	0 (15)	8.2
C14	2.6		1050 (11)	65.48 (5)	24 (7)	6 (13)	44 (6)	42 (9)	8.5
C15	2.5		1050 (12)	64.76 (6)	17 (12)	6 (14)	22 (11)	55 (7)	10.3
C16	2.4		1050 (13)	63.34 (7)	16 (13)	6 (15)	33 (9)	21 (10)	11.2
		(not C6)							

* Selected paddocks

[#] **EM** = electromagnetic conductivity; **P** = phosphorus (bicarbonate extract); **SO_4** = sulfur (KCl_{40} extract); **SG** = percent sown grasses; **NG** = percent native grasses.

Chapter 4: Botanical composition

Because of the expense of establishing perennial pastures and the loss in production that occurs when pastures have to be resown, it is important that they persist well, even under high grazing pressure. To achieve sufficient economic and environmental benefits from establishing perennial pastures, they need to persist for at least 10 years (Cullen *et al.* 2005); however, this goal is not achieved by many producers (Reeve *et al.* 2000).

The progressive decline in pasture productivity in the HRZ is evident in both sown and naturalised pastures and this is an indicator of productivity and sustainability decline (Archer *et al.* 1993; Dowling *et al.* 2006). Among all the factors influencing the changes in pasture composition, grazing management has been identified as the most important for sustainable grazing systems (Ayala Torales *et al.* 2000; Fulkerson 1997; Lodge 2000). In order to investigate the changes in pasture composition as an indicator of sustainability of grazed pastures under three systems varying in soil fertility status, sown pastures and grazing management on the Northern Tablelands of NSW, two experiments are reported in this Chapter and these include botanical composition on: (a) whole farmlet and seasonal measures on representative paddocks and (b) species detection and selective grazing.

Experiment I: Whole farmlet and seasonal investigations of representative paddocks

Introduction

Whilst there is a range of pasture parameters that are influenced by grazing animals, by far the most critical are species composition, pasture growth rate, available herbage mass and pasture quality. Pasture availability and quality are directly influenced by its botanical composition (Dowling *et al.* 2006).

It is well documented that environmental factors, particularly soil moisture and soil fertility are key factors influencing changes in species composition (Garden *et al.* 2001; Korte *et al.* 1987; Sanford *et al.* 2003). There is however some evidence to suggest that changes in botanical composition of pastures also occur as a result of the pattern of grazing (Greenwood and McKenzie 2001; Hodgson 1990; Michalk *et al.* 2003; Nicol 1987). Understanding how grazing pattern influences botanical composition and how best to manage key species to improve their persistence and productivity is seen as central to the development of more sustainable pasture systems (Kemp and Dowling 2000; Rook *et al.* 2002).

The aim of this Chapter is to examine the changes in botanical composition that occurred

under various pasture and grazing management regimes on whole-farmlet over five years of highly variable seasonal conditions. The availability of three farmlets varying in levels of farm inputs and grazing management provided an ideal opportunity to examine this question in great detail within a realistic whole-farmlet context.

The assessment of botanical composition was also conducted on three representative paddocks selected from each farmlet. This was intended to shed more light on what changes might have occurred particularly the decline of desirable species and their replacement by less productive species over the seasons of the year. Due to a lack of resources, this meant that fewer paddocks could be studied at this frequency. Hence it was important that the paddocks chosen for study were representative of each farmlet.

Two hypotheses were tested: Firstly, that a high input system (farmlet A), through sowing of perennial grasses and legumes and the maintenance of higher soil fertility, would improve the botanical composition (e.g. more persistence of deep-rooted nutrient-responsive perennial grasses and legumes) compared to the typical management system based on moderate levels of inputs (farmlet B). Secondly, that intensive rotational grazing (farmlet C) with short grazing and long rest periods would bring about improvements to botanical composition (e.g. more persistent perennial grasses and legumes) compared to the typical grazing management system (farmlet B).

Materials and methods

Measurements of botanical composition

The methods reported here relate to the measurement of broad trends over time in the botanical composition found in all paddocks of each farmlet. Because of resource constraints, it was decided to assess botanical composition using annual measurements of all paddocks conducted at a time when pasture species identification was easiest (from early to late summer). Changes in botanical composition were assessed using the BOTANAL procedure (Tothill *et al.* 1978) which is based on the visual estimation of the dry weight rank of pasture species. This technique is also well suited to the collection of rapid and non-destructive estimates of herbage mass (Waite 1994).

The BOTANAL technique was used to quantify the changes in botanical composition of pastures in response to different management systems and seasons. A preliminary examination of all of the experimental paddocks was made in order to identify species and gain a cursory overview of their relative abundance. Thereafter, a diagonal transect was

chosen for each paddock such that sheep camps were avoided and so that subsequent measurements could be taken along the same transect. When sampling, a 0.5 m x 0.5 m quadrat was randomly thrown at intervals of approximately 10-22 m along each transect such that approximately 20 quadrats were assessed across each paddock at each sampling time. In each quadrat, species were ranked 1st, 2^{nd,} or 3rd according to their estimated contribution to pasture dry matter. To facilitate calculations, a data entry form in a Microsoft Access database was used to convert the rankings to percentages of each species expressed on a dry weight basis using the constants 70.2, 21.1 and 8.7 for ranks 1, 2 and 3 respectively.

The initial measurement was conducted in March 2000 (early autumn) to provide the baseline data on the state of pastures before the farmlet treatments commenced (in July 2000). Sampling during the first 30 months of the experiment was initially conducted in early summer (December 2000, December 2001 and December 2002) after flowering of most species had commenced, to assist in plant identification. However, this sampling time was modified for subsequent assessments of botanical composition to late summer (February 2003, February 2004 and February 2005) as it was found that greater definition of some species, especially the warm-season native grasses, was possible at this time. It is acknowledged that this shift in the time of measurement from early to late summer causes a bias. Nevertheless, the important differences are those between farmlets and comparisons are only made using data collected at the same times for all farmlets.

The seasonal measurements of the three representative paddocks of each farmlet were conducted four times each year from July (winter) 2003 to April (autumn) 2005. The methodology of how these paddocks were selected is given in Chapter 3.

All botanical composition assessments from March 2000 were conducted by a retired Technical Officer with extensive experience working with pastures on the Northern Tablelands (Mr. Col Mulcahy, retired from CSIRO, Chiswick) and in conjunction with the author on all dates from February 2003 to February 2005 inclusive. In this way, errors and/or bias due to different operators were minimised.

Data analysis

Investigation approaches

Two analytical approaches were attempted in this experiment. The first approach was to examine the changes in species composition for all paddocks of each farmlet, including the A paddocks with different sowing times. Thus, the data were derived from all 8 paddocks of

farmlets A and B and 16 'major' paddocks (which were further subdivided into 33 paddocks) of farmlet C. In this analysis, the trend in botanical composition of sown grasses and native grasses was compared between the farmlet systems varying in levels of input and grazing management over time. The trends in species composition were fitted with the smooth spline regression curves.

The second approach was to examine the trends in botanical composition change only in the paddocks which had not been resown since the establishment of the farmlets in 2000. This limited the results to those derived from 2 paddocks of farmlet A, 7 of farmlet B and 16 of farmlet C.

In these two approaches, the individual pasture species were categorised into eight functional groups based on the published evidence of their response to grazing management, soil fertility, nutritive value and drought resilience (Lodge and Whalley 1989). These groups were fertiliser-responsive perennial grasses, legumes and broadleaf herbs, native cool-season perennial grasses, native warm-season perennial grasses, yearlong green perennial grasses, warm-season annuals, cool-season annuals and weeds (broadleaf weeds and grasses) (Table 4.1 and Figure 4.5). These species were further aggregated for each farmlet over time into five groups which comprised sown grasses, legumes and broadleaf herbs, introduced grasses, native grasses and weeds (Figure 4.1).

Statistical analyses

Before attempting any statistical analysis, data were screened and the marginal distributions of each of the eight species groups were examined using histogram, box and normal quantile plots. The exploration plots suggested non-normality of six out of eight species groups (Appendix 1) and therefore two different analyses were attempted. The statistical analyses were carried out using the statistics package R (R Development Core Team 2005) and SPSS (Field 2003).

Multivariate analyses of variance (MANOVA)

In the first statistical analysis, transformation across all the species groups was conducted using an arcsine root:

$$\textit{General Linear Model} = \arcsin\left(\sqrt{y}\right) \qquad (1)$$

Where y = farmlet, time, temperature, phosphorus, sulfur

The General Linear Model (GLM) procedure was followed to subject the transformed botanical composition data to multiple analyses of variance. Multivariate analyses of

variance (MANOVA) were used to analyse multiple related responses of the eight species groups to the effects of the three different management systems (farmlets) over seven different sampling times.

The multivariate outliers which influenced the normality were tested using Mahalanobis distance of the Bilodeau test. This was evaluated using chi-square tests with the degrees of freedom equal to the number of dependent variables. In addition, the multivariate homogeneity of the variance-covariance matrices was tested using Box'M test which assumed inequality of the response variables (species groups) across farmlets. All the main effects (three farmlets and seven sampling times), the covariate main effects and all factor-by-factor interactions were combined into a full factorial design using the following model:

$$Model = farmlet, sampling\ time, farmlet \times sampling\ time \quad (2)$$

To gain further insight into the relationships between species groups, a significant MANOVA of species groups was followed by estimation of canonical discriminant function coefficients which allowed separation of individual species between the farmlets at different sampling times.

Generalised Estimating Equation (GEE)

In the second statistical analysis, no transformation of the data was used; instead, the changes in botanical composition of species groups occurring over time were converted into frequencies. In this analysis the BOTANAL data were considered as consisting of repeated measurements from field plots of botanical compositions which were represented as percentages of the total vegetation in the sampling unit, i.e. the plot.

The purpose of this statistical analysis was to discern whether the different farming systems influenced the changes which occurred in botanical composition over time.

Because the fractions of many of the botanical components were small to negligible, only the dominant categories were subjected to statistical analysis. For instance, the proportions of legumes and broadleaf weeds were low in all the seasons and therefore these two groups were excluded from this analysis. At each sampling time, the response from each plot was a correlated binomial variable. The statistical model to compare farm systems had systematic components of (i) farmlet, (ii) trends with time and (iii) interactions of farmlet and time trends. There were two sources of correlation amongst the residuals: (i) due to the multivariate nature of the response and (ii) due to repeated measures from the same plot. The distribution of the errors included terms to account for these correlations.

In order to extend the GLM to accommodate significantly correlated species groups, the data were modelled using a Generalised Estimating Equation (GEE) (Liang and Zeger 1986). The working correlation amongst residuals was estimated by a 2-step process. At each sampling, the multivariate set of proportions (out of 100) were analysed using a Generalised Estimating Equation with unstructured correlation. The fitted correlation matrix was examined for a possible pattern of the correlation which could be represented by a model. This was refitted and the residuals from that saved. The correlation due to repeated measures was based on the correlation amongst the residuals from each sampling after fitting the GEE. The full correlation was regarded as the product of the between-components correlation and the between-samplings correlation. An exchangeable correlation was indicated at each sampling to measure the association amongst components and an autocorrelation structure was used to model the repeated measures aspects.

The treatments were compared using the log-odds ratios with corresponding confidence intervals for the regression coefficients and their standard errors of either farmlet A or C compared to the control, farmlet B. The log-odds ratio is the logarithm (base 10) of the probability of there being a significant difference between treatments. Profile plots of these log-odds ratios and their 95% confidence intervals showed where a botanical species grouping might be significantly different in one farming system relative to the other. While a log-odds ratio of zero was indicative of no difference between the two farmlets, accompanying these profiles of the log-odds are profiles of the species proportions on each farm system which present data in a manner that can be readily interpreted as botanical composition fractions. Nevertheless, statistical inferences were based on the log-odds scale.

Data for intensive paddock investigation were analysed using the General Linear Model (GLM) procedure using the Statistical Analysis Computer Package (SAS Institute Inc. 2003). The mean values were then separated and compared between the farmlets at each sampling time using Minimum Significant Difference (MSD) procedure of the Waller-Duncan t-tests.

Results

Effect of both time and the farmlet on species functional groups

Over the experimental period, a total of 51 species were recorded across the three farmlets comprising 4 fertiliser-responsive perennial grasses, 6 legumes and broadleaf herbs, 4 native cool-season perennial grasses, 15 native warm-season perennial grasses, 4 yearlong green perennial grasses, 4 warm-season annuals, 6 cool-season annuals, 3 weedy grasses and 5

broadleaf weeds (Table 4.1).

Table 4.1 Species were grouped according to their longevity, pattern of growth, nutritive value and drought resilience.

The species codes used in some of the analyses are shown in brackets: Adapted from Lodge and Whalley (1989).

Species groups		Common name	Forage value	Drought resilience	Response to grazing	Response to fertility
I. Fertiliser-responsive perennial grasses						
Festuca arundinacea	(fes)	tall fescue	high	high	Increaser	
Phalaris aquatica	(pha)	phalaris	high	high	Increaser	
Lolium perenne	(lolp)	perennial ryegrass	high		Increaser	
Dactylis glomerata	(dac)	cocksfoot			Increaser	
II All legumes and broadleaf herb						
Trifolium repens	(trir)	white clover	high		Increaser	
Trifolium subterraneum	(tris)	subterranean clover	high		Increaser	
Trifolium dubium	(trid)	yellow suckling clover	high		Increaser	
Trifolium angustifolium	(tria)	narrowleaf clover	high			
Medicago sativa	(meds)	lucerne	high		Decreaser	
Cichorium intybus	(cic)	chicory	high		Decreaser	
III. Native cool-season perennial grasses						
Anthoxanthum odoratum	(ant)	sweet vernal			Increaser	
Dichelachne micrantha	(dic)	plume grass	high	moderate	Increaser	Increaser
Elymus scaber	(ely)	wheat grass			Decreaser	
*Holcus lanatus**	(hol)	Yorkshire fog	low	low	Invader	
IV. Native warm-season perennial grasses						
*Paspalum dilatatum**	(pasd)	paspalum	high	moderate	Increaser	
Bothriochloa macra	(bot)	redgrass	moderate	high	Increaser	Increaser
*Eragrostis curvula**	(era)	African lovegrass	low	moderate	Increaser	Unknown
C_4 warm-season spp	(C_4)					
Sorghum leiocladum	(sor)	wild sorghum	low	moderate	Decreaser	Decreaser
Sporobolus elongatus	(spo)	slender rat's tail	moderate	moderate	Increaser	Increaser
Themeda australis	(the)	kangaroo grass	low	high	Decreaser	Decreaser
*Cynodon dactylon**	(cyn)	couch grass	high	high	Increaser	Increaser
Deyeuxia spp	(dey)	bent grass			?	
Eulalia aurea	(eul)	silky brown top	low	high	Decreaser	
Chloris truncata	(chl)	windmill grass	moderate	moderate	Increaser	Increaser
Paspalidium spp	(pas)	slender panic	moderate	moderate	Increaser	
Aristida ramosa	(ari)	wire grass	low	high	Decreaser	
Panicum gilvum	(pan)	sweet panic	high	moderate	Increaser	Increaser
Pennisetum alopecuroides	(pen)	swamp fox tail	low	moderate	Increaser	
Setaria spp.*	(set)	Pigeon grass				
*Eleusine tristachya**	(ele)	goose grass	low	moderate	Invader	
V. Yearlong green perennial grasses						
Microlaena stipoides	(mic)	weeping grass	high	high	Increaser	Increaser
Austrodanthonia spp	(dan)	wallaby grass	high	high	Increaser	Increaser
Poa sieberiana	(poa)	tussock grass	low	high	Increaser	Increaser
Stipa scabra	(sti)	corkscrew grass	moderate	high	Increaser	Decreaser

VI. Warm-season annual grasses						
*Digitaria sanguinalis**	(dig)	summer grass	low	low		
Cyperus spp	(cyp)	sedge			Invader	
Lolium multiflorum	(lol)	annual ryegrass			Decreaser	
VII. Cool-season annual grasses						
Agrostis avenacea	(agr)	blown grass	moderate	moderate	Invader	Increaser
*Avena fatua**	(ave)	wild oats	moderate	low		
Bromus spp*	(bro)	prairie grass	high	low	Decreaser	Increaser
*Briza minor**	(bri)	shivery grass	low	moderate	Decreaser	
*Hordeum leporinum**	(hor)	barley grass	high	low	Invader	Increaser
Vulpia spp	(vul)	vulpia	low	moderate	Invader	Increaser
VIII. Broadleaf weeds and others						
Juncus spp	(jun)	pin rushes			Invader	
Carthamus lanatus	(car)	saffron thistle			Invader	
Cirsium vulgare	(cir)	spear thistle			Invader	

*Naturalised

Whole farmlet investigations

When categorised into five major classes of pasture species (sown grasses, legumes and chicory, introduced [not sown] grasses, native grasses and weedy species), the high input system (farmlet A) was found to have maintained a relatively stable population of sown perennial grasses and introduced grasses compared to the moderate input system (farmlet B). Under the high input system, the proportion of native grasses gradually increased over time whereas on farmlet B, the native grasses showed a marked increase over time.

The intensive rotational grazing farmlet (C) showed a lower but relatively stable proportion of sown grasses with a stable proportion of introduced grasses compared to the typical farmlet (B). Under this system, the increase in native grasses was intermediate between farmlets A and B. Over a period of five years, the content of weedy species, which mostly comprised broadleaf weeds, remained relatively low across all three farmlets (Figure 4.1).

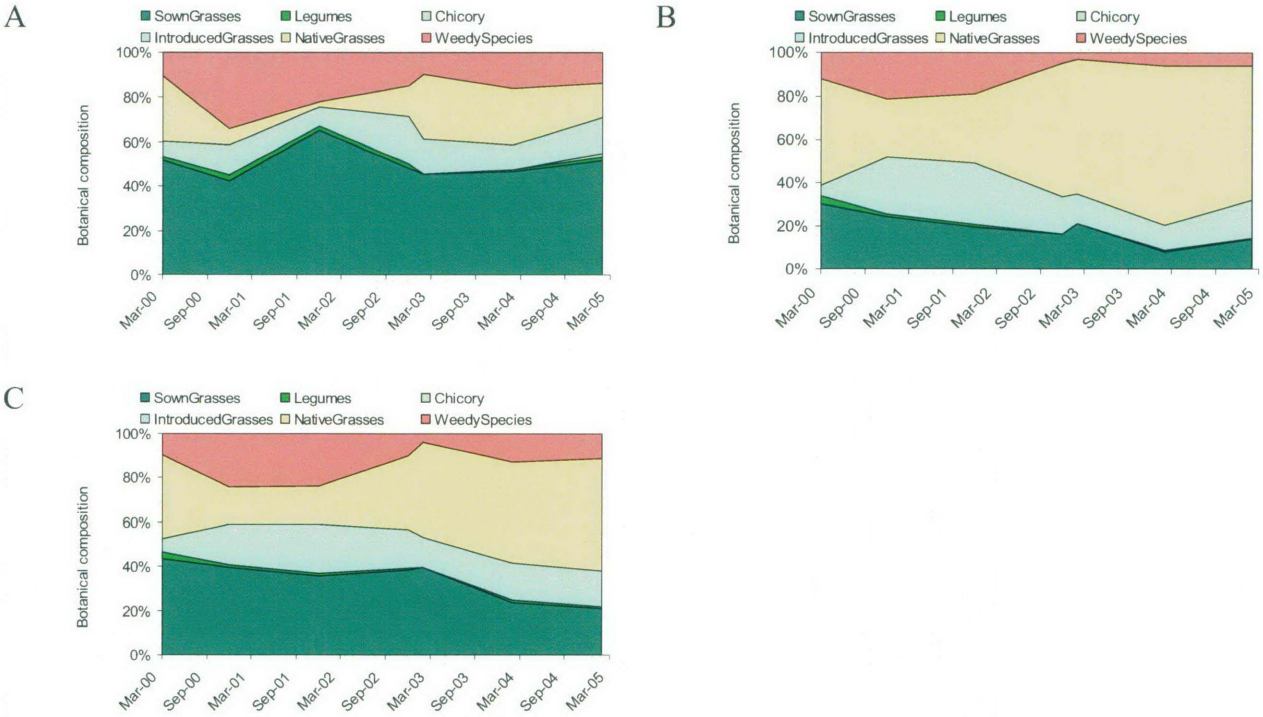


Figure 4.1 Average botanical composition, expressed as aggregations of five species groupings, of all paddocks of farmlets A, B and C over five years from March 2000.

Figure 4.2 shows the data measured from all paddocks of farmlets A, B and C. It is important to note that the data for the A paddocks is only presented since the latest date that each paddock had been resown. The starting sampling time for the farmlet B and C paddocks was the same as no resowing was done on these two farmlets until 2004 when approximately 8% of the area of each farmlet was resown.

The longest established paddocks (A7 and A8) of the high-input system (farmlet A), which have not been resown since the commencement of the farmlets, indicate consistent loss of sown fertiliser-responsive perennial grasses over the years 2000-2005. Paddock A2 also shows a declining trend of these perennial grasses from December 2002 to February 2005. A similar trend was observed in paddocks A3 and A4 even though the proportion of these perennial grasses on these two paddocks apparently increased briefly during summer periods (December 2001, December 2002 and February 2003).

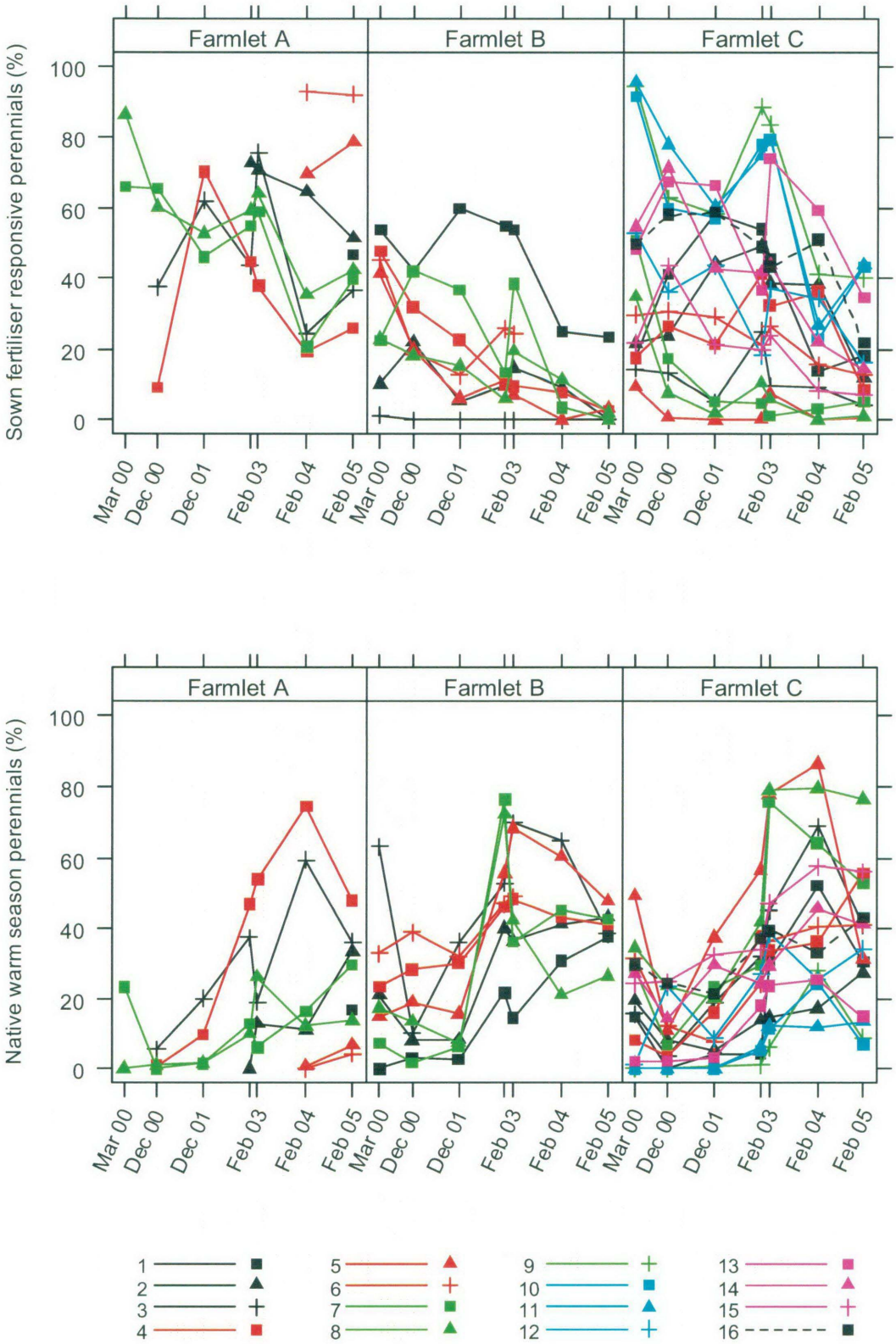
In all the paddocks of the typical district grazing farmlet (B), the content of sown perennial grasses declined consistently during the study period, but less so on the largest paddock, B1. At the other extreme, in all the years of the study, the proportion of these perennial grasses in paddock B3 was less than 5%.

There was a high variation in the proportion of sown perennial grasses among the paddocks of intensive rotational system (farmlet C) with the majority of paddocks (such as C9, C10, C11,

C12, C13, C14, C15 and C16) retaining a relatively high percentage (>50%) of these perennial grasses, while two paddocks of this system (C5 and C7) retained less than 10% of sown perennial grasses.

Over this period of five years, the native warm-season perennial grasses persisted and increased across most paddocks of all three farmlets. This increase was strongly marked in late summer (February 2003 and February 2004) compared to other sampling times such as early summer (December 2000-2002) (Figure 4.2).

(a)



(b)

Figure 4.2. Botanical composition (%) of (a) sown fertiliser-responsive and (b) native warm-season perennial grasses in paddocks of farmlets A (paddocks 1-8), B (paddocks 1-8) and C (paddocks 1-16) over the years 2000 to 2005.

The fitted B-spline curves in Figure 4.3 were developed from the same data presented in

Figure 4.2. The mean values and standard errors fitted in B-spline indicate the decline in botanical composition of fertiliser-responsive perennial grasses over time across the three farmlets (notably B and C). In contrast, the fitted B-spline curves representing the botanical composition (%) of native warm-season perennial grasses show a progressive increase in this species group over time across the farmlets; the increase was most strongly marked on farmlets B and C (Figure 4.3).

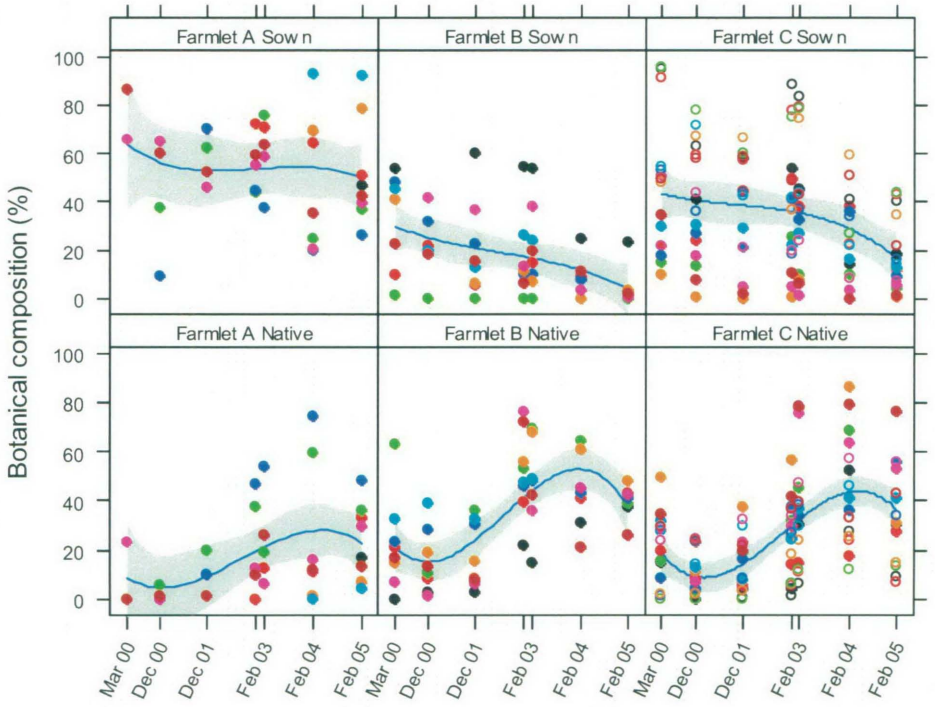


Figure 4.3 Percentage botanical composition of fertiliser-responsive and native warm-season perennial grasses for the three farmlets from 2000 to 2005.

The solid lines represent the fitted B-spline regression curves and the shaded polygon shows 95% fitted confidence intervals. The circles represent data points for all paddocks on each farmlet. Data for the A paddocks have different starting times due to resowing events in six of the eight farmlet A paddocks.

While the percentage of legumes was low and non-significant across the three farmlet systems, this was most marked under the two moderate input systems (farmlets B and C) compared to the high input system (farmlet A). There is an indication from Figure 4.4 that the high input system allowed some increase in the legume content of these pastures. While the trend in fitted B-spline regression curves and the confidence intervals was similar (below 5%) between farmlets B and C, there were several C paddocks which registered above 5% legumes (Figure 4.4). Nevertheless, legumes were excluded from further analyses due to their generally low proportions.

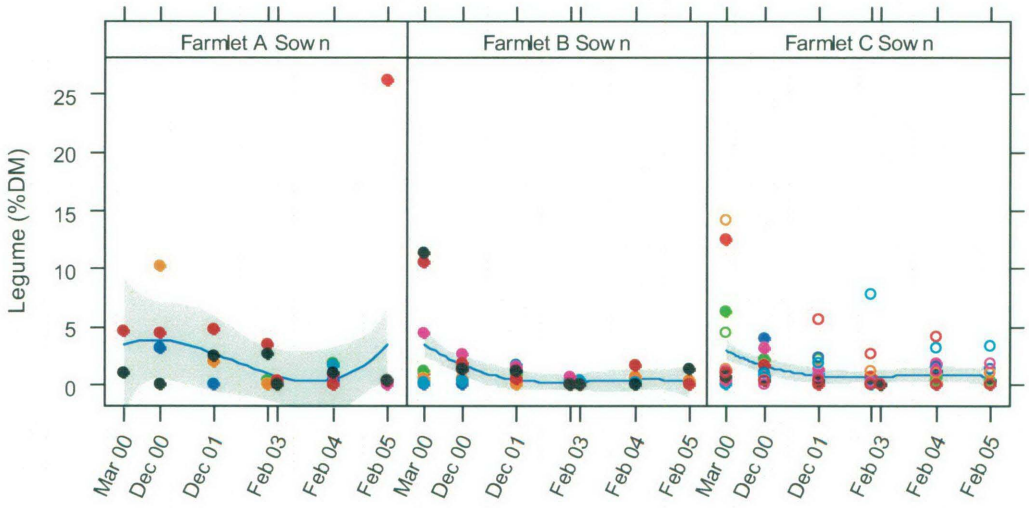


Figure 4.4 The effect of management systems (A, B and C) on changes in the proportion of legumes (%) over a five-year period.

The solid lines represent the fitted B-spline regression curves and the dashed lines show the 95% fitted confidence intervals.

Investigations of paddocks not resown

Both the normality plots and the statistical tests suggested that even though all were significantly positively skewed, 6 out of 8 species groups were not normally distributed (Figure 2.1 of Appendix 2).

The null hypothesis that species functional groups were homogenous was rejected by the results of this study, as the covariance matrices between these groups were significantly ($P<0.001$) different. The multivariate tests of the transformed data confirmed that the farmlet management, time and their interaction had a significant ($P<0.005$) effect on species groups (Table 4.2). Among the range of multivariate tests available to examine multiple response variables, Pillai's Trace was used in this analysis as it has been reported to be more robust compared to other tests (Field 2003).

Table 4.2 The statistical significance of multivariate tests of the transformed data for the effects of farmlet, time and their interaction on species functional groups.

Effect	Multivariate test	Value	F	Hypothesis df	Error df	Sig. level
Farmlet	Pillai's Trace	0.48	5.80	16	296	0.00
Time	Pillai's Trace	1.07	4.14	48	912	0.00
Farmlet* Time	Pillai's Trace	0.81	1.44	96	1232	0.05

Effect of time (seasonal variations)

The frequencies in botanical composition of species groups shown in Figure 4.5 confirm the significant decline in fertiliser-responsive perennial grasses whilst native warm-season perennial grasses increased progressively over time especially on farmlets B and C. Compared to fertiliser-responsive perennial grasses, these native warm-season perennial grasses increased especially over summer (February) (notably on farmlets B and C). The content of native cool-season perennial grasses and yearlong green perennial grasses also varied significantly ($p<0.001$) with time. While the content of native cool-season perennial grasses markedly increased in December 2000 and December 2001, soon after the treatments commenced, the yearlong green perennial grasses showed a slight, but progressive increase, especially on farmlets B and C (Figure 4.5).

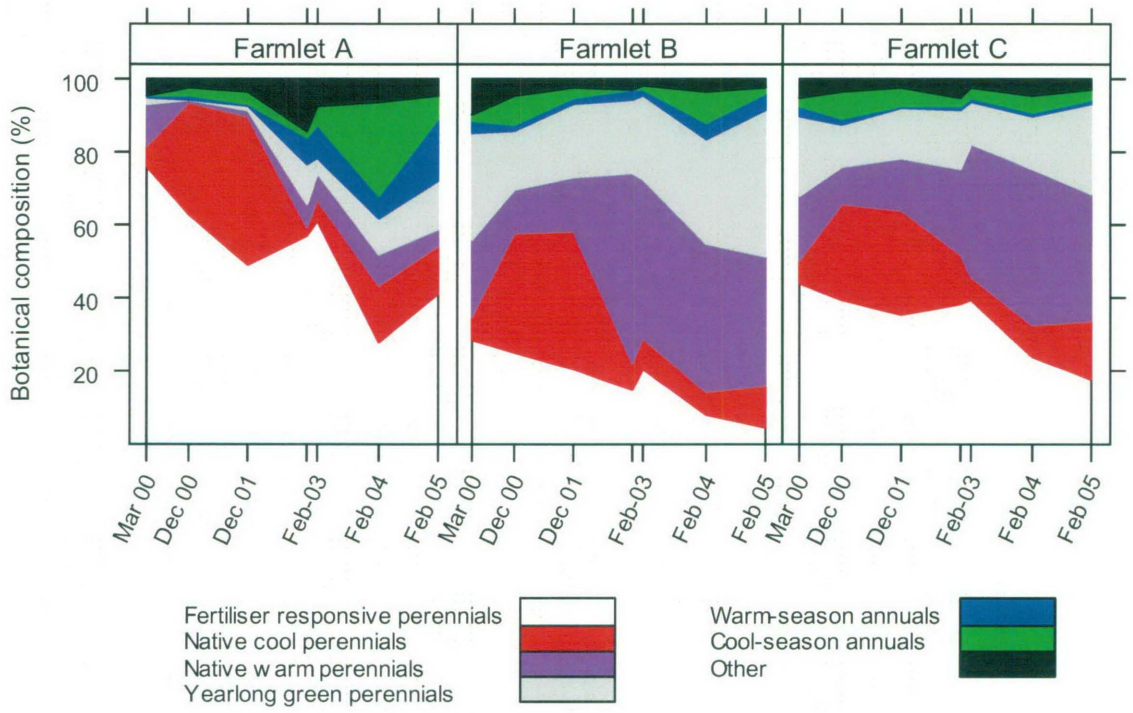


Figure 4.5 Changes in botanical composition of grass species groups from March 2000 to February 2005 in response to the effects of farmlet treatments (A, B and C).

Data measured from the paddocks of each farmlet which had not been sown (2 A paddocks, 7 B paddocks and 16 C paddocks).

Effect of the farmlet systems over time

Using the log odds comparisons, fertiliser-responsive perennial grasses were found to be significantly ($p<0.001$) higher on farmlet A relative to B throughout the seasons. The differences between farmlet C and B were not significant during the early periods of the

experiment (March 2000 to December 2001) when the stocking rate was relatively low across the farmlets. However, following increases in stocking rates from December 2002, farmlet C relative to B maintained a relatively stable content of this species group compared to farmlet B, even though the difference in February 2003 was not significant.

In order to incorporate the time factor with the overall farmlet effect, the estimated log odds of the untransformed data were fitted using generalized estimating equations (GEEs) to combine both correlation structures between the multivariate nature of the species groups and the repeated measures from the same farmlet paddocks over time. For comparisons of the farmlets for changes in species composition over time, farmlet B was taken as a reference point as it represents the 'typical' management (the control) and differed from farmlet A by input levels and from farmlet C by grazing management.

The native warm-season and yearlong green perennial grasses were significantly higher on farmlet B compared to A throughout the seasons. However, the difference between farmlets B and C was only significant ($p<0.01$) in December 2002 for native warm-season perennial grasses and between February 2003 and February 2005 for yearlong green perennial grasses.

During the establishment of the farmlets, warm-season annual grasses were significantly higher on farmlet B relative to A, but between February 2003 and 2005, these warm annuals significantly ($p<0.02$) increased on farmlet A. This species group was also notably higher on farmlet C than on B between February 2003 and February 2005. The cool season annual grasses were significantly higher on farmlet B than on A, but significantly higher on farmlet C relative to B only in December 2002 (Figure 4.6 and Table 2.1 of Appendix 2).

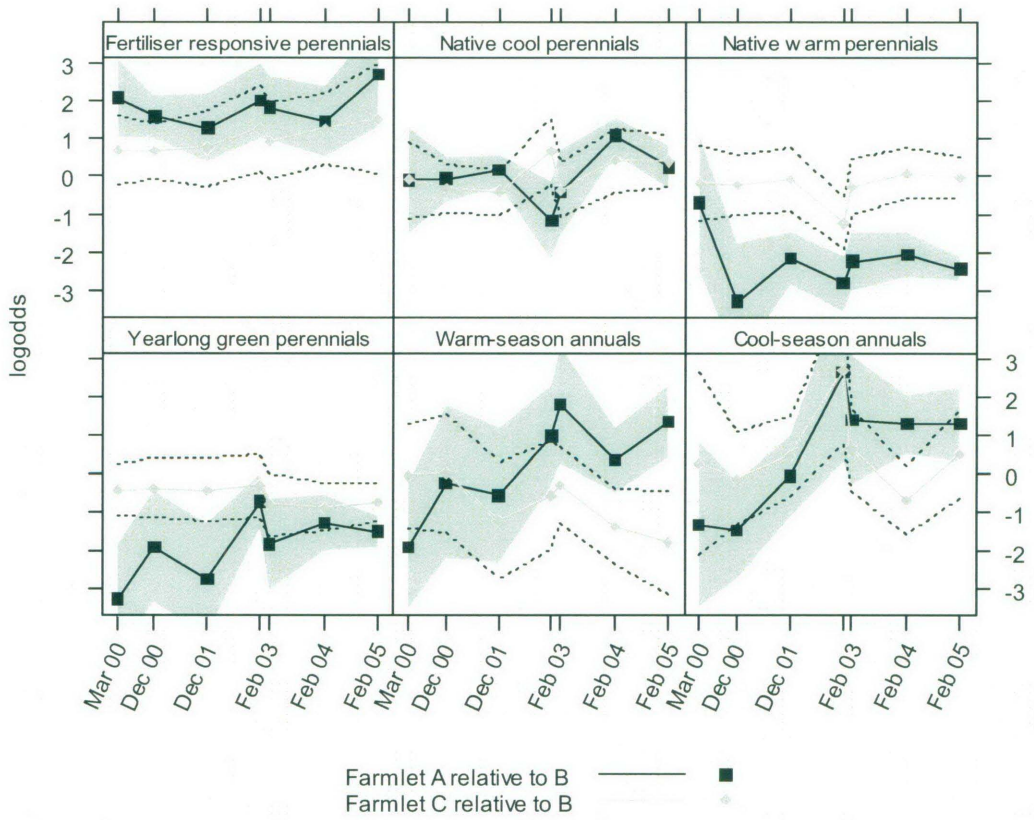


Figure 4.6 The log odds of the grass species groups from March 2000 to February 2005. The solid lines represent the mean log odds for farmlets A and C relative to B. The confidence limits for A relative to B are shown by the shaded polygon area while that for C relative to B are shown by the upper and lower dashed lines.

Effect of both time and the farmlet on individual species

The MANOVA and GEE tests provided insights into which species functional groups responded significantly to the effects of farmlet treatment and time. These species groups were fertiliser-responsive perennial grasses, native warm-season perennial grasses, yearlong green perennial grasses, and warm-season annuals. However, these analyses (MANOVA and GEE) were not able to identify which individual species within these functional groups were most strongly influenced by the management of each farmlet system as some species could have occurred due to chance.

It was therefore necessary to conduct further analyses, following the finding of significant MANOVA and generalised estimating equations of the odds ratios. Thus, a discriminant analysis was chosen to investigate the nature of the relationship between the indicator species and to further separate the three farmlets between two discriminant functions as they influenced the response of these species. A detailed analysis of MANOVA for between-subject effects revealed 10 individual species affected by the farmlet treatment and 11 species

affected by time (Table 2.2 of Appendix 2).

Eleusine tristachya and unclassified warm-season C_4 species (i.e. those which could not be identified) were highly influenced ($p<0.001$) by both farmlet management and time. While the highest content of C_4 species (7.4%) was registered in summer 2002, *Eleusine tristachya* progressively increased over time with the highest content (7.3%) recorded in late summer 2005. When excluding the effects of farmlet management, time also had a highly significant ($p<0.001$) effect on the percentage of *Bothriochloa macra*, *Microlaena stipoides*, *Austrodanthonia* spp, *Phalaris aquatica* and *Lolium perenne*. Both *Bothriochloa macra* and *Microlaena stipoides* tended to increase over time with the highest content of *Bothriochloa macra* (10.3%) recorded in late summer 2003 and the highest percentage of *Microlaena stipoides* (11.4%) in late summer 2005. *Phalaris aquatica* on the other hand consistently decreased over time with the highest percentage (41.4%) registered in autumn 2000 whilst the lowest percentage (5.4%) was recorded in late summer 2004. While the proportion of *Lolium perenne* was generally low at all sampling times, there was a tendency for the content of this species to increase in the summers of 2002 and 2004. The proportions of other species such as *Themeda australis*, *Festuca arundinacea* and *Poa sieberiana* were more influenced by the farmlet management ($p<0.001$) than sampling time.

With fertiliser-responsive perennial grasses, *Festuca arundinacea* was dominant and significant ($p<0.001$) on farmlet A and also on farmlet C compared to farmlet B. This was the case throughout the sampling times except in early autumn (March 2000). Similarly, during early periods of the study, *Phalaris aquatica* was also dominant on farmlets A and C relative to farmlet B, but in later years (February 2004-2005), the content of phalaris slightly increased on farmlet B even though it was not significantly different from the other farmlets. The proportion of two unsown fertiliser-responsive perennial grasses (*Lolium perenne* and *Dactylis glomerata*) was low and insignificant across the farmlets in all the sampling periods.

The proportion of the introduced warm-season grass, *Paspalum dilatatum*, was significantly ($P<0.01$) higher under the intensive rotational system (farmlet C) than under flexible grazing (farmlets A and B). The proportion of other native warm-season perennial grasses such as *Themeda australis*, *Bothriochloa macra*, *Sorghum leiocladum* and some unidentified C_4 species were significantly ($P<0.05$) higher under the moderate-input systems (farmlets B and C) than under the high-input system (farmlet A). Similarly, the proportion of yearlong green native perennial grasses such as *Microlaena stipoides* and *Poa sieberiana* was significantly ($P<0.001$) higher on farmlets B and C than on farmlet A; in fact the percentage of *Poa*

sieberiana on farmlet B remained relatively high throughout all sampling times. Short-lived warm-season perennial grasses such as *Eleusine tristachya* increased significantly more ($P<0.001$) on farmlet A than on farmlets B and C (Table 4.3).

Table 4.3 The comparisons among the means of individual species which responded significantly to effect of the farmlet treatment over time. (Waller-Duncan k-ratio t test of Minimum Significant Difference (MSD) at p = 0.05). Species codes are defined in Table 4.1.

	Farmlet	Fes	Pha	Lolp	Dac	Pasd	Bot	Era	C_4	Sor	Spo	The	Cyn	Dey	Eul	Chl	Pas	Ari	Pan	Pen	Set	Mic	Dan	Poa	Sti	Dig	Cyp	Ele	Lolm
Mar-00	A	12.0	64.5	0.0	0.0	6.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.5	0.5	0.0	0.5	0.0	0.0
	B	7.0	20.7	0.7	0.0	2.7	5.1	0.0	0.0	0.9	0.9	11.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	0.4	26.6	0.0	0.0	3.3	0.0	0.0
	C	4.4	39.4	0.2	0.0	5.6	6.2	0.4	0.0	0.8	1.1	3.2	0.1	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.2	0.0	21.1	0.2	0.0	3.1	0.0	0.0
	MSD	***11.0***	***34.7***	***2.2***	***0.0***	***6.4***	***10.9***	***4.4***	***0.0***	***4.8***	***2.9***	***28.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.6***	***0.0***	***5.4***	***1.0***	***19.0***	***0.4***	***0.0***	***3.4***	***0.0***	***0.0***
Dec-00	A	46.0	17.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0
	B	7.4	16.0	1.6	0.0	4.4	0.1	0.0	0.0	0.1	0.0	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.4	0.0	15.6	0.0	0.0	2.0	0.0	0.0
	C	16.9	21.9	1.2	0.0	6.4	1.0	0.0	0.0	0.6	0.2	0.8	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.1	0.0	11.5	0.0	0.0	1.9	0.0	0.0
	MSD	***12.8***	***11.5***	***3.4***	***0.0***	***3.3***	***1.2***	***0.0***	***0.0***	***1.7***	***0.0***	***10.4***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.5***	***0.0***	***0.0***	***1.6***	***0.0***	***14.1***	***0.0***	***0.0***	***3.5***	***0.0***	***0.0***
Dec-01	A	37.0	12.0	0.5	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	1.0	0.0	0.0
	B	11.0	8.7	1.1	0.0	4.0	0.0	0.0	0.0	4.9	0.0	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	19.6	0.0	0.0	1.7	0.0	0.0
	C	15.4	18.1	2.2	0.2	11.6	0.1	0.0	0.0	0.6	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.1	0.0	13.9	0.0	0.0	0.6	0.0	0.0
	MSD	***22.2***	***12.3***	***5.6***	***1.3***	***13.4***	***0.9***	***0.0***	***0.0***	***6.4***	***0.0***	***14.1***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***2.3***	***0.0***	***0.0***	***1.0***	***0.0***	***28.1***	***0.0***	***0.0***	***1.6***	***0.0***	***0.0***
Dec-02	A	22.0	22.0	13.0	0.0	1.5	3.0	0.5	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.5	0.0	0.0	2.0	0.0	2.0	5.0	0.0
	B	5.6	7.1	2.3	0.0	10.7	1.7	0.4	18.7	1.0	1.1	17.7	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	18.4	0.0	0.0	2.4	0.3	0.0
	C	11.1	22.1	5.1	0.0	10.4	4.3	0.4	2.0	0.7	1.5	3.7	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	1.1	11.2	1.2	0.0	0.8	0.8	0.0
	MSD	***15.7***	***7.2***	***14.9***	***0.0***	***8.3***	***10.0***	***0.8***	***27.9***	***5.0***	***7.3***	***22.8***	***3.3***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***7.7***	***4.6***	***25.2***	***1.5***	***0.0***	***4.0***	***4.8***	***0.0***
Feb-03	A	33.0	27.0	1.0	0.0	2.0	3.5	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	9.0	0.0
	B	6.4	13.3	0.7	0.0	6.7	12.7	2.1	0.0	1.1	1.6	19.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1	19.6	0.1	0.0	0.3	1.4	0.0
	C	14.6	23.8	1.1	0.0	10.1	14.9	1.0	0.0	1.3	5.4	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.1	0.0	0.0	0.9	10.9	0.0	0.0	0.3	0.9	0.0
	MSD	***16.1***	***20.7***	***3.4***	***0.0***	***9.5***	***9.4***	***6.7***	***0.0***	***5.4***	***13.0***	***27.4***	***1.1***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.5***	***0.0***	***0.0***	***4.2***	***20.7***	***0.4***	***0.0***	***0.5***	***7.3***	***0.0***
Feb-04	A	18.5	2.5	7.0	0.0	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	0.0	0.0	10.0	0.0	0.0	0.0	0.0	0.0	6.0	0.0
	B	3.3	2.9	2.0	0.0	8.4	8.1	0.6	0.0	1.1	7.0	14.4	0.0	0.0	0.6	0.0	0.0	0.0	0.1	0.4	0.0	13.4	0.3	14.1	1.0	0.0	1.7	2.9	0.0
	C	9.3	11.2	3.3	0.1	16.1	10.4	0.9	0.0	0.4	9.9	2.5	0.2	0.1	0.0	0.1	0.1	0.0	2.1	0.0	0.0	4.6	0.1	9.8	0.0	0.0	0.4	0.8	0.0
	MSD	***19.5***	***4.8***	***5.7***	***0.5***	***8.4***	***9.3***	***3.1***	***0.0***	***5.4***	***25.8***	***25.0***	***1.4***	***0.5***	***1.8***	***0.0***	***0.9***	***0.0***	***0.8***	***1.4***	***0.0***	***20.4***	***0.9***	***13.3***	***2.5***	***0.0***	***2.0***	***7.6***	***0.0***
Feb-05	A	22.5	17.0	2.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.0	0.0	0.0	0.0	0.0	0.0	17.0	0.0
	B	2.4	11.6	0.3	0.0	7.6	6.1	0.4	0.0	2.0	3.7	14.9	0.4	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	14.1	0.6	25.4	0.0	0.0	0.7	4.1	0.0
	C	5.8	1.9	0.4	0.1	11.1	8.9	1.3	0.0	0.3	8.2	4.9	0.2	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1	6.8	1.3	16.4	0.1	0.1	0.1	0.8	0.0
	MSD	***7.5***	***14.2***	***1.6***	***0.5***	***8.0***	***10.3***	***9.1***	***0.0***	***5.5***	***21.2***	***24.2***	***1.5***	***0.0***	***0.0***	***0.0***	***0.0***	***0.5***	***0.5***	***0.5***	***0.0***	***24.6***	***3.1***	***23.2***	***0.0***	***0.0***	***1.8***	***6.1***	***0.0***

The observations of the Waller-Duncan k-ratio t tests and canonical discriminant functions of the farmlet effect on some species functional groups and individual species among these groups provided evidence of the species which were significantly affected by time and management of each farmlet system.

Canonical discriminant functions of the individual species among the significant groups (Table 4.4 and Table 2.3 of Appendix 2) also revealed that the fertiliser-responsive species such as *Festuca arundinacea* had greater contributions to both variates. *Phalaris aquatica* on the other hand contributed more to the second variate. Variate function one significantly ($p<0.001$) separated farmlet A from farmlet B, but the difference between A and C was not significant. This indicates the dominance of *Festuca arundinacea* on farmlets A and C. Even though not significant, the second variate separated farmlet C from the other two farmlets, indicating the dominance of *Phalaris aquatica* on farmlet C relative to farmlets A and B.

For the native warm-season perennial grasses, variate function one significantly ($p<0.001$) discriminated farmlet B from the other two farmlets indicating a higher contribution of *Themeda australis* on farmlet B. Although not significant, variate function two suggested discrimination of farmlets B and C from farmlet A due to a greater contribution of *Paspalum dilatatum* on farmlet C and a greater contribution of *Bothriochloa macra* on farmlets B and C than on farmlet A.

For the yearlong green perennial grasses variate function one significantly ($p<0.001$) distinguished farmlet B from farmlets A and C, indicating a greater dominance of *Poa sieberiana* on farmlet B than on other farmlets. The second variate separated farmlets A and B from farmlet C, confirming the greater contribution of *Microlaena stipoides* on farmlets A and B than on farmlet C.

For native warm-season annual grasses and short-lived perennial grasses, canonical function one significantly ($p<0.001$) discriminated farmlet A from the other farmlets and this is indicated by a higher contribution of *Eleusine tristachya* on farmlet A. Canonical function two separated farmlet B from A and C which provides evidence of an increasing content of less productive species such as *Cyperus* spp on farmlet B (Table 4.4 and Table 2.3 of Appendix 2).

Table 4.4. The Wilks' Lambda test showing Chi-square and significant levels of the variate functions one and two on species groups.

Group I: fertiliser-responsive perennial grasses; Group IV: native warm season perennial grasses; Group V: yearlong green perennial grasses; Group VI: warm season annuals.

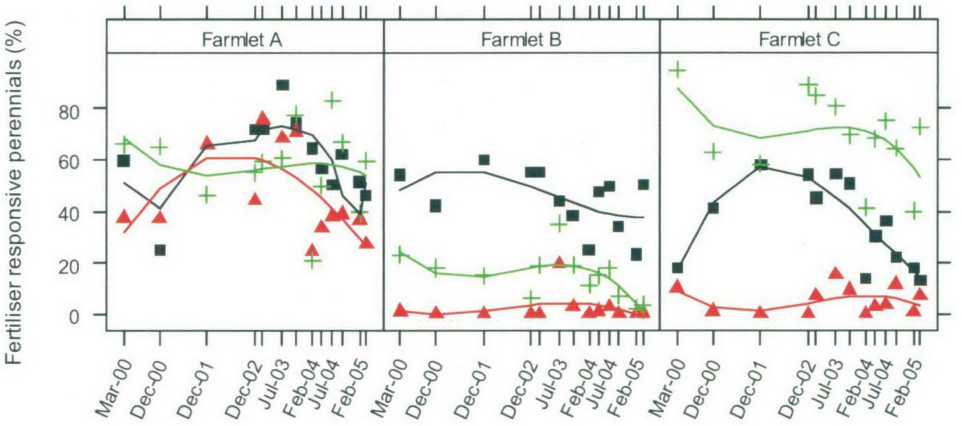
	df	Wilks' Lambda	Chi-square	Sig. Level
Group I				
Function 1	3	0.8	40.3	0.000
Function 2	3	1.0	5.9	0.117
Group IV				
Function 1	14	0.6	81.6	0.000
Function 2	14	0.9	21.6	0.087
Group V				
Function 1	3	0.8	40.8	0.000
Function 2	3	1.0	4.5	0.212
Group VI				
Function 1	2	0.8	31.8	0.000
Function 2	2	1.0	5.0	0.081

Seasonal investigations of representative paddocks

Figure 4.7 shows the seasonal trend in botanical composition of fertiliser-responsive and native perennial grasses between the three selected paddocks of each farmlet over years 2000-2005. The percentage of fertiliser-responsive grasses did not differ significantly across the three paddocks of farmlet A; a similar observation was made with the native grasses. However, the three paddocks of farmlets B and C recorded significantly different proportions of these species groups ($P<0.001$). For instance, since the commencement of the experiment, paddock C9 in particular, maintained a relatively higher proportion (>60%) of fertiliser-responsive perennial grasses than paddocks C1 and C5 (notably C5). The content of native grasses in paddock C9 was relatively low, whilst paddock C5 had a significantly higher percentage (>50%) of native species over the five-year period.

The proportion of fertiliser-responsive perennial grasses recorded on paddock B1 increased significantly from March 2000 to December 2001, but from 2002 to April 2005, there was a consistent decline in the percentage of these perennial grasses. Paddock B3 on the other hand had a markedly lower proportion of fertiliser-responsive perennial grasses from the commencement of the treatments (Figure 4.7).

(a)



(b)

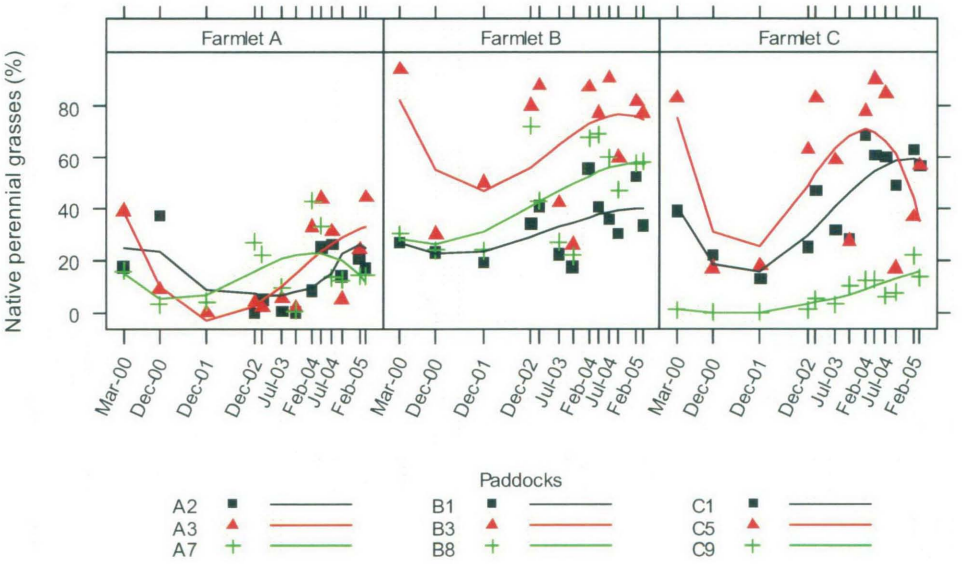


Figure 4.7 The variation in botanical composition (%) of (a) fertiliser-responsive and (b) native perennial grasses for three paddocks of each farmlet over years 2000-2005.

The legend numbers 1, 2 and 3 represent paddocks A2, A3 and A7; paddocks B1, B3 and B8; paddocks C1, C5 and C9, respectively. The lines are locally weighted loess curves fitted to data from each of the three paddocks on each of the three farmlets.

Figure 4.8 shows the changes in botanical composition of individual nutrient-responsive perennial species in the three selected paddocks of each farmlet over time. The variation between paddocks within each farmlet was considerable, reflecting the process whereby the three representative paddocks were deliberately chosen to represent the range of various attributes among all paddocks within each farmlet.

The decline in deep-rooted perennial grasses on paddock A2 in 2001 was due to re-sowing. Generally, paddocks A2 and A7 had a significantly higher percentage of tall fescue between December 2002 and July 2004. There was however an apparent decline in the content of

these species as they were replaced by native warm-season species in February 2004 across the paddocks (markedly on paddock A7 due to high grazing pressure).

The proportion of tall fescue was relatively stable in paddock B1 compared to B3 and B8. These two paddocks (B3 and B8) showed relatively low levels of fertiliser-responsive perennial grasses over the entire period.

The proportion of phalaris in Paddock C9 remained relatively high throughout the study period. Paddock C1 maintained a relatively stable content of tall fescue. The proportions of perennial ryegrass and cocksfoot were low across the paddocks throughout the seasons. Paddock C5 on the other hand had a low proportion of fertiliser-responsive perennial grasses throughout (Figure 4.8).

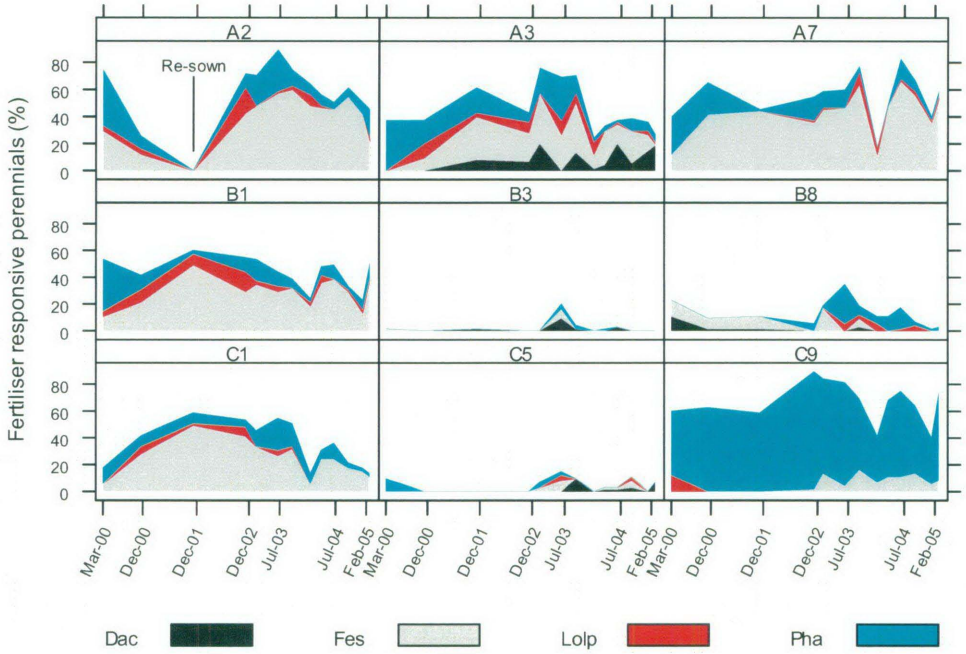


Figure 4.8 Changes in the seasonal botanical composition (%) of nutrient-responsive perennial grasses in response to different input and grazing regimes over years 2000-2005.

Discussion

While different grass species occurring in mixed plant communities could be indicators of some habitat and ecological conditions, the changes in the abundance of some species are strongly correlated with the pattern of grazing (Gibson and Bosch 1996; Hurt *et al.* 1993; Mpiti-Shakhane *et al.* 2002b) and can possibly be used as indicators of particular ecological conditions.

The reason for determining the botanical composition of the pasture species for a period of at

least five years was to monitor the changes and persistence of different pasture species over time. Based on insights from the review of literature, the decline in species composition, particularly the desirable fertiliser-responsive perennial grasses being replaced by less productive species is thought to be associated with pasture degradation in grazing areas of Australia and elsewhere.

The results of this study support the hypothesis that different management systems varying in levels of inputs and grazing management produced significant changes in botanical composition of pasture species over time. The species functional groups that showed significant response to farmlet management system included deep-rooted perennial grasses, native warm-season perennial grasses, yearlong green perennial grasses and warm-season annuals. This supports the concept of Gibson and Bosch (1996) that such changes in the content of pasture species, particularly the nutrient-responsive perennial grasses, could be considered as a useful indicator of potentially negative changes in the management system.

The results of this study support the hypothesis that, through the sowing of new pastures and application of fertiliser, the high-input system (farmlet A) would better maintain stability and persistence of nutrient-responsive perennial grasses than would the moderate-input system (farmlet B). Of course, this does not take into account the cost of resowing these pastures.

The significantly higher percentage of deep-rooted fertiliser-responsive perennial grasses (notably *Festuca arundinacea* and *Phalaris aquatica*) on farmlet A was expected; at the commencement of the farmlet treatments in March 2000, 2 paddocks of farmlet A used in the analysis had a substantially higher proportion (76%) of this class of species compared to the average for all paddocks of farmlet B (28%) and farmlet C (44%). This is likely to be associated also with the changes in soil fertility which occurred due to the higher levels of soil fertility maintained on farmlet A. Despite the substantially higher fertiliser applications on farmlet A to meet the soil P and S targets, the decline in fertiliser-responsive perennial grasses from 76% to 41% over a period of five years is perhaps associated with the much higher stocking rate on this farmlet (Figure 6.7).

The second hypothesis tested, that the intensive rotational grazing system (farmlet C) would result in the retention of a higher proportion of deep-rooted nutrient-responsive perennial grasses compared to the typical district grazing system (farmlet B), was supported by the results of this study. The difference can be attributed to the differences in grazing management between the two systems. Nevertheless, the overall percentage of these

fertiliser-responsive perennial grasses declined from an average of 44% to 18% on farmlet C. Although Farmlet B commenced with a lower content of fertiliser-responsive perennial grasses (28%), it demonstrated poor persistence by declining to an average of just 5% within 5 years.

The persistence of *Festuca arundinacea* and *Phalaris aquatica* on the high input system (farmlet A) even during dry summer periods and under intense grazing reflects not only improved soil fertility, but also the grazing tolerance and deep-rooting habit of these two species. These so called deep-rooted fertiliser-responsive perennial grasses are considered to be longer lived, more competitive and able to increase with grazing pressure. They can also become dormant under stresses of low soil moisture and high temperature (Kemp and Culvenor 1994; Watson *et al.* 2001), while *Phalaris aquatica* becomes productive throughout winter (Hill 1991), the good summer growth of *Festuca arundinacea* allows it to compete with warm-season C_4 grasses (Oram and Lodge 2003).

Other more shallow-rooted fertiliser-responsive perennial grasses (*Lolium perenne* and *Dactylis glomerata*) were not affected by the farmlet treatments. The change in botanical composition of *Lolium perenne* was however significantly ($P<0.0001$) affected by time. The content of *Lolium perenne* increased significantly in dry summer periods of December 2002 and February 2004 which suggests the drought tolerance of this perennial.

The findings of Ridley *et al.* (2003) in north-east Victoria however, revealed a significant effect of grazing management on the persistence of *Lolium perenne* and *Dactylis glomerata*. In that study, these two grasses demonstrated poor persistence under the pressure of continuous grazing when the herbage mass dropped below a threshold of 800 kg DM ha^{-1} (Ridley *et al.* 2003). This finding is in agreement with the study of Waller *et al.* (2001b) in south western Victoria where these two species were again reported as being less persistent under high stocking rates than *Festuca arundinacea* and *Phalaris aquatica*.

The marked drop in the proportion of deep-rooted perennial grasses across the three farmlets in February 2004 and their replacement by warm-season native and naturalised pastures creates some concern about the relative sustainability of the farmlet systems under the existing Cicerone management system which, at times, did not adhere to the stated farmlet guidelines. In particular, the decline in the proportion of fertiliser-responsive perennial grasses in paddocks A7 and A8 was presumably related to the high grazing pressure applied for an extended period in these paddocks (Figure 4.2) during periods when other A paddocks

were being resown.

There is increasing evidence that the botanical composition and productivity of many pastures in New South Wales are now far from optimum and pastures are now almost certainly no longer as resilient as previously. These notions are evidenced by increases in the content of less productive native grasses (Chen 1998; Corbett 2001; Lang and McCaffrey 1984). These results also support the findings of Lodge (2002) on the North-West Slopes of NSW where the production and persistence of sown temperate perennial grasses under continuous grazing declined despite the good establishment of all species, fertiliser application (P at 66 kg/ha and S at 82.5 kg/ha over five years) and the presence of subterranean clover. According to Scott *et al.* (2004) the native warm-season grasses provide low quality feed especially during winter when the nutritional requirements of pregnant ewes are high.

Another important pasture component which contributes to sustainability is legume content (Scott *et al.* 2000c). The content of legumes was relatively low and insignificant across the farmlets. This may have been due in part to the timing of the measurements of botanical composition, being generally in late summer. The investments in sown pasture and higher fertiliser applications on farmlet A were expected to result in a satisfactory composition of legumes. There is no doubt that the dry seasons experienced throughout the experimental period had a great impact on legume survival. The increasing stocking rates particularly under the high input system over the years have meant a higher energy demand from different classes of animals (Figure 7.3) and hence more intense selective grazing pressure on available legumes. Sheep are selective grazers and, given the opportunity, they normally prefer legumes to grass because of their high digestibility (Colebrook *et al.* 1990). This observation is further supported by several investigators who have indicated that, in the absence of nitrogen fertiliser, the decline in legume content is attributable to selective grazing (Curll *et al.* 1985; Schulte and Neuteboom 2002). The lack of legumes on farmlet A could also be attributed to the relatively high content of perennial grasses which commonly exceeded the recommended upper threshold of 70% of the total herbage mass; beyond this threshold, the contribution of companion legumes has been recorded as restricted (Kemp and Dowling 2000; Michalk *et al.* 2003).

The declining proportion of legumes under both moderate-input systems (farmlets B and C) is thought to be not only related to dry seasons, but also to the strong dominance of native grasses and possibly to lower levels of available phosphorus. A reduction in the nitrogen-fixing ability of legume root nodules when the available water to the host plant is diminished

is well documented (Morley 1994; Turner and Begg 1978). According to Scott *et al.* (2004) this not only restricts the nitrogen availability for nutrient-responsive grasses, but may affect below-ground root activity as the plants cannot extract water from deep in the profile. This further increases the chances of plants suffering from the dual stresses of recurring drought and grazing pressure (Boschma and Scott 2000). The decrease in legume content on farmlet C could also be attributed to the greater competition for light by the high herbage mass accumulated (typically 2300 kg DM ha^{-1}) during the long rest periods on this farmlet.

Generally, the proportion of annual weedy grasses such as *Vulpia* species was low across the farmlets. It is well known that perennial grasses commence growth earlier than annuals and thus can monopolise available water, nutrients and light. Perennials are also known to occupy and control more space as they grow, thus reducing gap size for occupation by annuals (Michalk *et al.* 2003). It was however interesting to observe that farmlet A registered a significantly higher proportion of the short-lived warm-season perennial (*Eleusine tristachya*) than the other two farmlets. *Eleusine tristachya* is regarded as a non-palatable invader which dominates heavily grazed areas (Sisay and Baars 2002). The higher content of *Cyperus* spp on farmlet B compared to the other farmlets also suggests selective under-utilisation of the pastures under this grazing system. Whilst the B paddocks carried low stocking rates, the grazing periods were relatively long. This suggests that sheep grazing on farmlet B paddocks had a greater chance to repeatedly select species of their preference while avoiding other species. Such selectivity can result in higher livestock performance per head but can also result in gradual increases in undesirable species. This further suggests 'patch' grazing due to some paddocks of this farmlet being continuously grazed for at least 180 days with a relatively low stocking rate. Although not measured, it appeared that patch grazing was more a feature of farmlet B than either of the other farmlets.

The significant increase in the warm-season introduced *Paspalum dilatatum* under the intensive rotational grazing of farmlet C supports the study of Bowman *et al.* (1998) in the 400-600 mm rainfall zone of northern NSW, which revealed that this species occurred more frequently in rotationally grazed paddocks.

The increased occurrence of native species such as *Themeda australis*, *Bothriochloa macra*, *Sorghum leiocladum*, *Microlaena stipoides and Poa sieberiana* on B and C paddocks and especially the B paddocks, could be an indication of the impact of both soil fertility status and grazing management. Of these native grasses, by far the most dominant on farmlet B were *Themeda australis* and *Poa sieberiana*. The dominance of *Themeda australis* and *Poa*

sieberiana could be an indication of selective avoidance, although these two species are palatable when young they are less so when mature. They are reported to have moderate nutritive value with crude protein ranging from 2.8% to 12.4% (Lodge and Whalley 1989). Greater increases of these less productive grasses were strongly marked during warm seasons as these species respond well to high temperature and summer rainfall. During periods of high temperature, the sub-tropical C_4 species (such as *Bothriochloa macra*) are known to have the potential for reducing transpiration while conserving water for photosynthesis because of the narrower leaf surface area and lower respiration rates compared to temperate C_3 species. The increase in these undesirable species could be related to lack of fertiliser input but also the impact of extended grazing periods.

It is acknowledged that the decision to undertake botanical composition assessments of all farmlet paddocks in late summer is likely to have led to overestimates (in terms of the average composition over the entire year) of the proportion of summer active species (especially C4 grasses) and underestimates of the contribution of temperate species. Nevertheless, this time was chosen to facilitate species recognition and hence to increase the efficiency of gathering information from transects across all paddocks on a regular basis. The important findings in relation to botanical composition are the relative differences between farmlets and the changes over time.

The results from the three representative paddocks of each farmlet system provided additional information on changes in botanical composition to provide some indication of seasonal trends in botanical composition change. A similar pattern of the seasonal fluctuation of the fertiliser-responsive perennial grasses (*Festuca arundinacea*, *Phalaris aquatica*, *Lolium perenne* and *Dactylis glomerata*) was observed across all the three representative paddocks of the farmlet systems. For instance, there was a clear trend of significant increase in the content of these grasses in winter through spring, then a marked decline during summer through autumn. These seasonal fluctuations were obvious during the three years (winter 2003 to autumn 2005) of intensive assessment of the changes in species composition in these representative paddocks. The findings of three representative paddocks of each farmlet further provided more information on the variation in species composition between the three paddocks within each farmlet system. There was a high variation in botanical composition among the B paddocks (e.g. B1 *versus* B3) and C paddocks (C5 *versus* C9), but less variation was observed among A paddocks (due largely to re-sowing).

Lambert *et al.* (1996) and Scott *et al.* (2000c) have argued that biophysical sustainability is

best achieved in pastures where a balance is maintained between fertiliser-responsive, deep-rooted perennial grasses combined with persistent legumes; hence it is important that a balance between these two components be maintained in spite of the selective utilisation of some species by livestock in preference to others. The results of this study have confirmed that botanical composition varies with management and this is potentially driven not just by fertiliser application and sowing of improved species but by opportunities for selective grazing. This concept of preferential selection will be further addressed in the next section.

Experiment II: Dietary selection of species

Introduction

The diet selected by grazing animals is an important determinant of nutrient intake and overall animal productivity. Both herbage intake and diet selection by grazing animals are influenced by a number of factors but species composition is probably one of the most critical and preferences can determine long-term survival of particular plant species and therefore subsequent growth and nutritive value and botanical composition of the pasture (Freer and Jones 1984; Gibb and Teacher 1983).

In order to understand the potential impact of grazing animals on species composition of pastures, the diet composition of animals can be estimated as can the variation in selectivity between individuals (Frame *et al.* 1992; Hameleers and Mayes 1998).

There are many difficulties and inaccuracies in identifying representative samples of the ingested nutrients when using methods such as hand plucking, harvesting plant material pre- and post-grazing, or direct collection of ingested material from the rumen or oesophageal fistulae (Bohman and Lesperance 1967; Cook 1964; Hamilton 1976). Indirect methods such as chemical markers (Forwood *et al.* 1987) and near infrared spectroscopy (Coleman *et al.* 1985) have also been reported to be unsatisfactory for routine quantification of the species of ingested pasture (Dove and Mayes 1991; Hameleers and Mayes 1998) because of limitations such as the difficulty in the physical separation of chewed material (Dove 1992)

The use of the *n*-alkane method (Hameleers and Mayes 1998; Mayes *et al.* 1986) offers the potential for measuring both forage intake and the proportion of different pasture species in the diet. It is based on the wax profile detected in plants and the faeces. The principle of using *n*-alkanes to estimate diet composition is based on establishing the best match between the pattern of alkane concentrations in the components of the diet and the concentrations in the faeces (Hameleers and Mayes 1998).

For the purpose of the present study, a pilot experiment using the *n*-alkane technique was carried out to estimate the faecal output, herbage intake, digestible intake and particularly diet selection by merino ewes grazing a diverse array of pastures species in one paddock within each of the three different farmlet management systems. It is acknowledged that one paddock is an inadequate representation of each farmlet; however, it was considered useful to explore the issue of diet selection. Only the results of the diet selection are reported in this section as this component is the most important factor influencing changes in species composition.

Materials and methods

Pasture sampling

Herbage samples for *n*-alkane analysis were collected at the same time as pasture sampling for botanical composition using the BOTANAL procedure (Tothill *et al.* 1978) and assessing the available herbage mass using the median quadrat technique (Bell 2003). Due to limited financial and human resources, the measurements of diet intake and selection were carried out in only one of the three representative farmlet paddocks chosen for more intensive measurements (A7, B1 and C1). Because of the limited number of animals and paddocks studied, it is acknowledged that the findings will only provide an indication of the differences in dietary intake of species between the farmlets and reflect selection as at the end of the experimental period.

The detailed description of the statistical methodologies used to select representative paddocks is presented in Chapter 3. Sampling was carried out at three times within one year (late-summer, mid-autumn and mid-spring 2005). Although sampling was also done in mid-autumn, there was less available green herbage mass and hence few species were identified during this season. Sampling was not carried out in winter as the green herbage mass across the farmlets was well below the critical PROGRAZE benchmark of 500 kg DM/ha (Bell 2003) and the animals were being fed a grain supplement.

At sampling, pasture samples were harvested once between the 8th and 11th day after inserting capsules into the rumen of 5 sheep grazing in each of 3 experimental paddocks (A7, B1 and C1). These experimental paddocks were characterized by different types of pasture species ranging from (i) fertiliser-responsive perennial grasses (*Festuca elatior*, *Lolium perenne* and *Phalaris aquatica*), (ii) legumes (*Trifolium repens*) (iii) native and naturalised perennial grasses (*Eleusine tristachya*, *Paspalum dilatatum*, *Bothriochloa macra*, *Anthoxanthum odoratum*, *Microlaena stipoides*, *Avena fatua*, *Themeda australis*, *Holcus lanatus*,

Austrodanthonia spp, and *Poa sieberiana*), and (iv) broadleaf weeds (*Plantago lanceolata*, *Taraxacum officinale*, *Rumex brownii*, and *Hypochaeris radicata*). About 50-100 g (depending on availability of green herbage) of leaf samples from these different species were collected across each paddock, oven dried at 65 °C for 48 h and then ground to pass through a 1 mm sieve prior to *n*-alkane analysis.

Alkane dosing and faecal sampling

Five merino ewe weaners (weighing between 35-40 kg) were randomly chosen from each treatment and were administered with capsules releasing 50 mg/day of dotriacontane (C_{32}) and hexatriacontane (C_{36}) (Dove and Mayes 1991). Individual animals within treatments were considered to be replicates for the design based on the observations that selectivity of animals within groups is commonly independent (Broom and Arnold 1986). Faecal samples from each weaner were collected twice, on the 8th and 11th days after the capsules were administered. By this time the dosed n-alkanes in the faeces should have reached plateau concentrations (Mayes *et al.* 1986). Faecal samples were oven dried at 65°C for 48h and then ground to pass through a 1-mm sieve prior to *n*-alkane extraction and analysis.

Alkane extraction and analysis using gas chromatography (GC)

Prior to analysis of both pasture and faecal samples, a preliminary analysis was done to determine the most appropriate time for digestion. In this preliminary analysis, a sample of white clover was analysed after: (1) one hour heating, two extractions and three washes with heptane, (2) one hour heating, three extractions and three washes with heptane, (3) three hours heating, two extractions and three washes with heptane, (4) three hours heating, three extractions and three washes with heptane. The variation in these repeats of preliminary analyses was low and it was therefore decided to use the first method (Figure 3.1 of Appendix 3).

About 500 mg of ground herbage and 300 mg of faecal samples were placed in digest tubes together with magnetic stirrers; 4 ml of absolute ethanol, 200 µl of 7.5 M KOH and 50 µl of tetratriacontane (C_{34}) (50.37 mg/50 ml in undecane) as an internal standard were added. The bottles were sealed with screw top lids and the contents were mixed well on a vortex mixer and then heated in a digester block at 90 °C for 1 hour. After cooling the sample mixture to room temperature, 3 ml n-heptane and 2 ml of distilled water were added then mixed well before putting in a digester block at 37 °C for 5-10 minutes to separate the phases. The upper phase of the mixture was separated using a clean Pasteur pipette and filtered through pipette

tips containing glass wool and silica gel to 8 ml vials. Extraction was repeated with a further 2 ml heptane and the phase was again added to the filter. The filter was then rinsed with three 1 ml washes of heptane and collected in the same 8 ml vials. The vials were evaporated to dryness in a fume cupboard under nitrogen at 90 °C. Using two 0.5 ml heptane washes, the alkanes were transferred into 1.8 ml GC vials via a Gilson pipette and analysed by Gas Liquid Chromatography (GLC) (Dove 1993).

The GLC analysis was performed using a Varian 3400 equipped with a 48-position (8200) auto sampler using the following operating parameters (D. Alter, pers. comm.):

- Column: AT35: 30 metre x 0.25 mm i.d. 0.25 micron film thickness. Alltech Cat # 13642.
- Injector: 280 °C.
- Flame Ionisation Detector: 300 °C.
- Oven: 180 °C for 1 minute then ramp @ 10 °C/minute to 275 °C and hold for 11.5 minutes.
- Helium gas flow @ 3.5 ml/minute.

A mixed alkane standard containing approximately equal amounts of C_{24} and C_{36} was run at the start and after each set of 12 samples. The average of these runs was used to quantify individual alkanes and these results were corrected for recovery using the internal standard C_{34}.

Calculations

As the recovery of alkane markers is not 100%, a small proportion of each alkane is digested during transit through the gut (Dove 1996; Dove *et al.* 1999). Thus, recoveries of these alkanes were corrected for losses prior to the estimation of diet composition. The mean values (Table 3.2 of Appendix 3) from 8 published papers contained in an appendix of a PhD thesis of Lee (2000) were used to calculate the correction factors. These mean values were compared with the data of Herd *et al.* (2003) which showed a similar trend line to that shown in Figure 4.9.

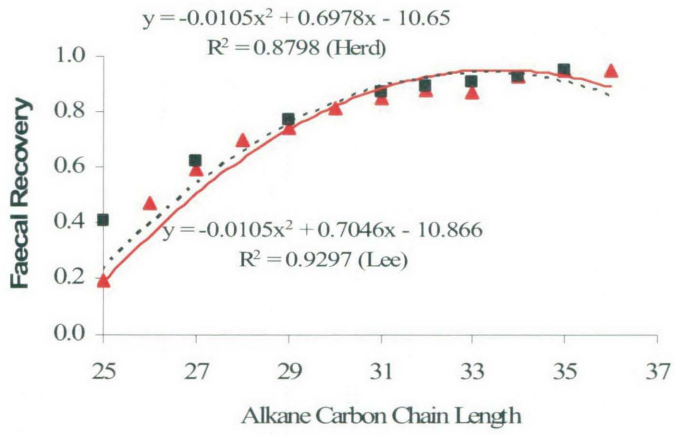


Figure 4.9 Relationship between alkane carbon chain lengths (C_{25}- C_{36}) and their recoveries in faeces.

The red solid line and triangles represent data sourced from Lee (2000) while the black squares and dashed line represent data sourced from Herd *et al.* (2003).

Diet composition of the herbage mixture was then estimated from the simultaneous equations of the least square optimisation procedure using the 'Eatwhat' software package (Dove 1996). The estimation was based on the establishment of the best match between the pattern of alkane concentrations in the diet components and those corrected for their recoveries in the faeces (Dove *et al.* 1999; Hameleers and Mayes 1998). Computations were done for the best 4 or 5 solutions and the 'best' option accepted. The large diversity of species meant that the robustness of this choice could be questioned in some cases.

The approach of using the Least Square optimisation procedure has been confirmed by the study of Dove and Moore (1995) to allow the application of non-negativity constraints to solutions involving many species in the diet, as was the case in this present study. Dove and Moore (1995) emphasised that this procedure overcomes the earlier criticisms raised by Newman *et al.* (1995) concerning the simultaneous equations approach.

Using the data collected for species and alkane concentrations of potential diet and faeces, the intake of the various species was estimated using the following equation:

$$e_{i-j} = a_{i-j}W + b_{i-j}X + c_{i-j}Y + d_{i-j}Z \qquad (3)$$

where W, X, Y, Z are the proportions of each pasture species in the diet; a-d are the concentrations of the *n*-alkanes i-j in each pasture species; and e_{i-j} is the concentration of the *n*-alkanes in the faeces after the correction of faecal recovery.

Statistical analysis

Principal component analyses were conducted to separate pasture species based on the similarities of their alkane signatures at each sampling time. Graphical presentations of the two-dimensional principal components of the alkane signatures for pasture species accounted for by the first and second components were plotted. The mean values for the first three principal components were then separated and compared among the odd-numbered alkanes at each sampling time using the Minimum Significant Difference procedure of the Waller-Duncan t-tests (SAS Institute Inc. 2003).

The Linear Model (LM) procedure of the analysis of variance was also followed to examine differences in the alkane concentrations of different pasture species in response to the effect of different farmlet treatments, time and the interaction terms (R Development Core Team 2005):

$$Model = farmlet, time, species, farmlet \times time, farmlet \times species, species \times time \quad (4)$$

Relative preference for pasture species was estimated from a selection index using the formula:

$$Selection\ index = \frac{proportion\ \ in\ diet}{proportion\ \ on\ offer} \quad (5)$$

Results

Species detection

The results presented are of the data collected from one representative paddock (A7, B1 and C1) from each farmlet. The odd-numbered alkanes were present in greater concentrations than the even-numbered alkanes and varied between the sampling periods. The concentration of C_{35} was low in all the species throughout the sampling periods, while the concentrations of C_{24}, C_{25}, C_{26}, C_{27}, C_{28}, C_{30} and C_{32} were small in most species compared to the concentrations of C_{29}, C_{31} and C_{33}.

Of the fertiliser-responsive perennial grasses, *Festuca arundinacea* and *Lolium perenne* registered significantly higher concentrations of C_{29}, C_{31} and C_{33} than other species while *Phalaris aquatica* had lower concentrations of these alkanes.

Among the native and naturalised perennial grasses, *Eleusine tristachya*, *Paspalum dilatatum*, *Bothriochloa macra*, *Anthoxanthum odoratum*, *Microlaena stipoides*, *Avena fatua* and *Themeda australis* had relatively higher concentrations of either C_{29} or C_{31} or C_{33} or all three alkanes than *Holcus lanatus*, *Austrodanthonia* spp and *Poa sieberiana*.

Of the broadleaf weeds, *Plantago lanceolata* registered significantly higher concentrations of C_{29}, C_{31} and C_{33} than *Taraxacum officinale*, *Rumex brownii* and *Hypochaeris radicata*. While for the purpose of this study, and in the literature (Chen *et al.* 1998), *Hypochaeris radicata* is classified as a weed, this species is known to be an edible forb because of its high nutritive value and, at times, is highly preferred by sheep; as such, some publications indicate that *Hypochaeris radicata* should be encouraged in pastures (D. Kemp pers. comm.).

The alkane concentrations occurring in different species in each selected paddock of the farmlet systems differed significantly between sampling times and these results are shown in Appendix 3. As indicated earlier, the technique used to identify the species is one that has some limitations and consequently it is possible that the wrong species ranking could have been made where 'Eatwhat' solutions were very similar. A much larger number of animals would have had to be sampled in order to overcome this limitation.

Diet selection

A clear selective grazing pattern was exhibited by the five sheep grazing in each representative paddock of all three farmlets at each sampling time (Figure 4.10). In late summer 2005, there was a high preference for *Festuca arundinacea* and some preference for *Phalaris aquatica* and *Lolium perenne* by sheep grazing in A7. In B1, the preference was for *Plantago lanceolata* and *Microlaena stipoides*, with a lower proportion of *Hypochaeris radicata* (1%) in the diet. Sheep grazing in C1 showed a high preference for *Themeda australis* while about 8% of *Paspalum dilatatum* was eaten by some sheep. In autumn, sheep grazing in A7 showed a distinct preference for *Festuca arundinacea* while sheep grazing in B1 and C1 tended to favour *Paspalum dilatatum*. It is important to note that during the dry summer/autumn of 2005, there were low levels of herbage mass available on the farmlets and hence more supplementation (lupins) was provided during autumn sampling which contributed to greater selectivity by grazing sheep, notably in paddocks C1 and B1. Thus, the alkane analysis allowed separation of the supplement component of the diet as well as the pasture species (Figure 4.10).

In spring, *Rumex brownii* was the dominant species mostly selected by sheep grazing in A7 with *Hypochaeris radicata* and *Phalaris aquatica* being the next most preferred. In B1, greatest preference was for *Festuca arundinacea* and *Phalaris aquatica* while in C1 higher preference was for *Hypochaeris radicata* with a small proportion of *Phalaris aquatica* eaten by some sheep (Figure 4.10).

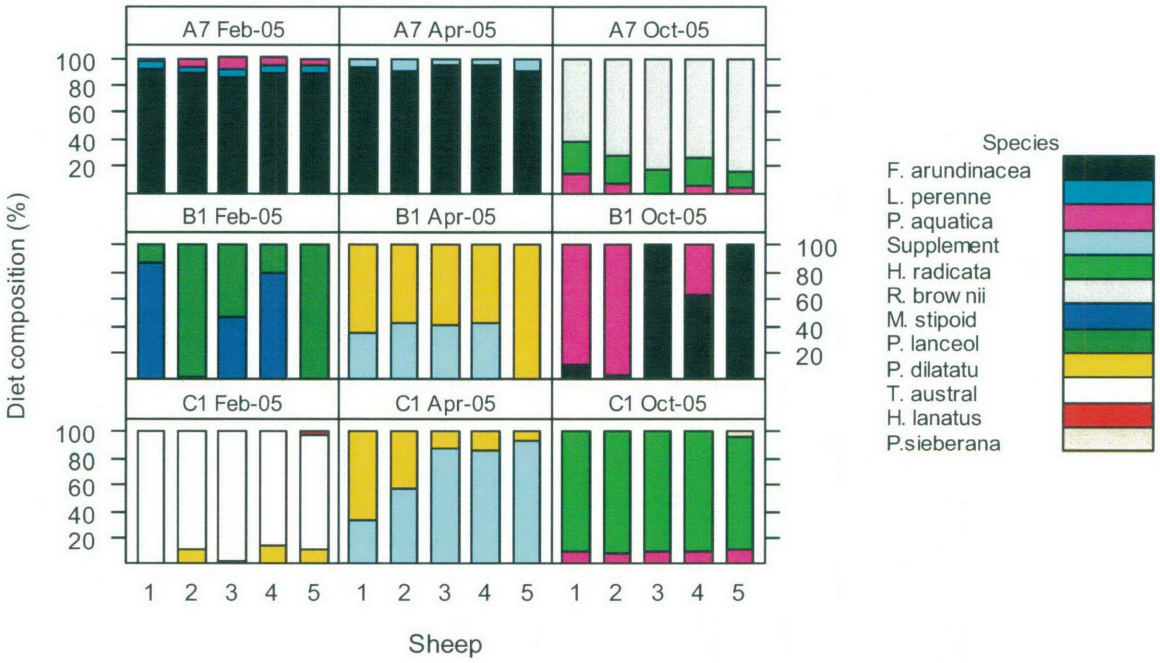


Figure 4.10 The diet composition (%) of the sheep grazing in paddocks A7, B1 and C1 in Summer (Feb), Autumn (Apr) and Spring (Oct) 2005.

Figure 4.11 shows the selection preference for pasture species by grazing sheep at the three sampling times in paddock A7. There was a higher proportion of *Festuca arundinacea*, *Eleusine tristachya*, *Holcus lanatus* and *Microlaena stipoides* recorded in A7 in late summer; other species contributed less than 5%. The content of *Festuca arundinacea* in the sheep diet was approximately double the proportion of the composition on offer.

There was also a relatively small proportion (6%) of *Phalaris aquatica* and *Lolium perenne* in the diet. Because the proportion of *Lolium perenne* on offer was low, the selection index of this species was higher than those for *Festuca arundinacea* and *Phalaris aquatica* (Figure 3.2 of Appendix 3). While the content of *Festuca arundinacea* estimated in the pasture on offer and in the diet in this paddock was higher in autumn, weeds (*Hypochaeris radicata*) contributed 11% of the diet.

During this period there was also supplementation (lupins) provided across the three farmlets which contributed 7% of the sheep diet in paddock A7. Even though the species composition of *Festuca arundinacea* recorded in spring was still high (56%), the diet of the sheep shifted to broadleaf weeds (94%) and *Phalaris aquatica* (6%) (Figure 4.11).

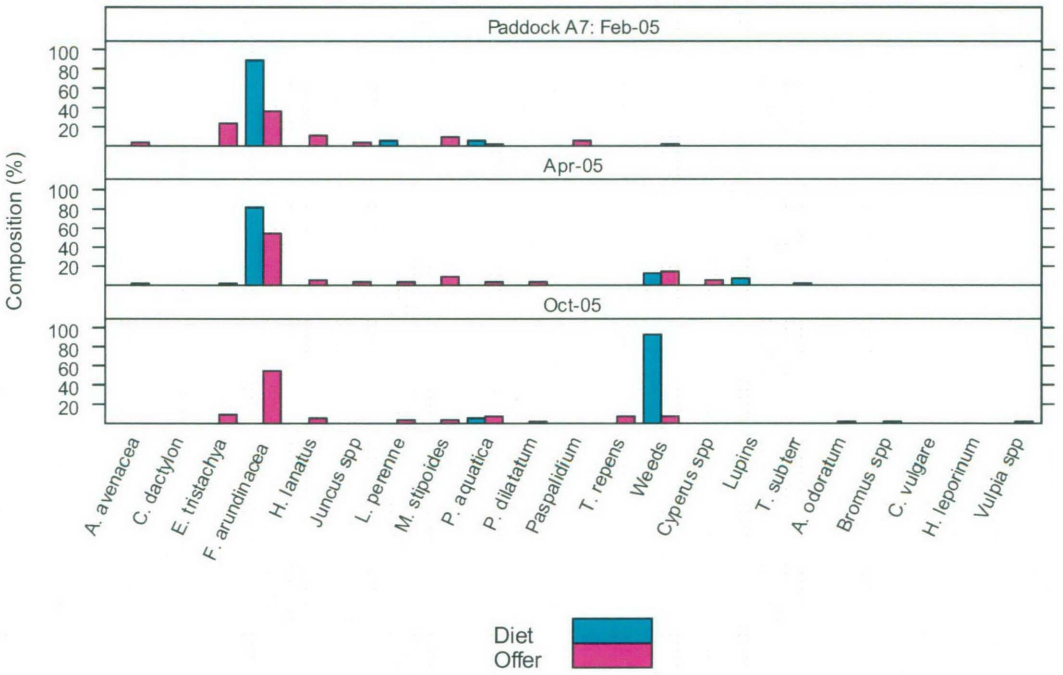


Figure 4.11 Botanical composition (%) of the pasture on offer and in the diet of sheep grazing in paddock A7, in summer, autumn and spring.

In paddock B1, while weeds contributed the highest proportion (57%), of the diet in late summer, there was also a higher proportion of *Microlaena stipoides* in the pasture on offer (51%) as well as in the diet (43%). *Paspalum dilatatum* contributed 14% of the pasture composition on offer. The proportion of some grasses such as *Anthoxanthum odoratum*, *Bothriochloa macra*, *Eleusine tristachya* and *Holcus lanatus* was about 6%. In autumn, *Festuca arundinacea* and *Poa sieberiana* registered 39% and 22%, respectively of the composition on offer, but there was a higher preference for *Paspalum dilatatum* (67%) by sheep grazing in this paddock. There was also supplementation given to sheep during this dry autumn period which contributed 33% of the diet. In spring, species which contributed a high proportion of the pasture on offer included *Festuca arundinacea* (29%), *Poa sieberiana* (26%) and *Bromus* (24%). The content of *Festuca arundinacea* was high (56%) in the diet as was *Phalaris aquatica* which also contributed a high proportion (44%) of the diet (Figure 4.12).

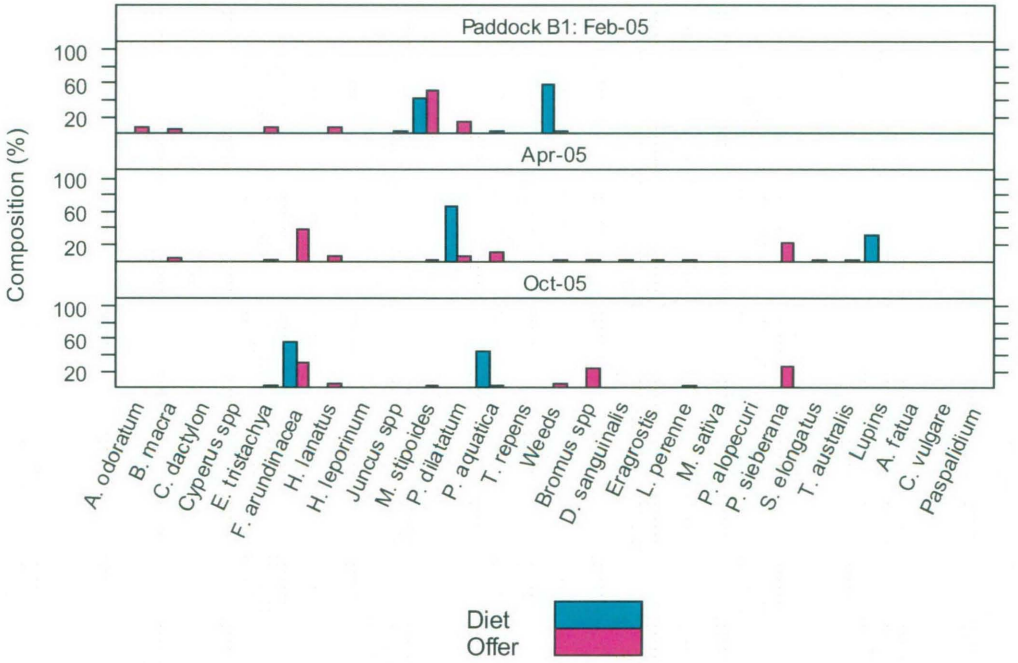


Figure 4.12 Botanical composition (%) of the pasture on offer and in the diet of sheep grazing in paddock B1, in summer, autumn and spring.

Throughout the sampling periods in paddock C1, *Poa sieberiana* registered the highest proportion of the pasture on offer whilst *Festuca arundinacea* and *Themeda australis* also contributed a relatively high proportion of the pasture on offer in summer. In late summer (February), a similar content (8%) of *Paspalum dilatatum* was observed in the pasture on offer as well as in the diet. While a similar content (8%) of *Holcus lanatus* was also noted in the pasture on offer, this species contributed less than 1% of the diet. Similarly to paddock B1, sheep grazing in C1 demonstrated a higher preference for *Paspalum dilatatum* (28%) shown by a higher selection index (Figure 3.2). There was also 72% of the supplement (lupins) in the diet of sheep grazing in paddock C1 during this sampling period. In spring there was a similar pattern of the main species contributing to the pasture on offer as was the case in autumn. However, the diet of sheep during this time was 90% broadleaf weeds, 10% *Phalaris aquatica* and less than 1% *Poa sieberiana* (Figure 4.13).

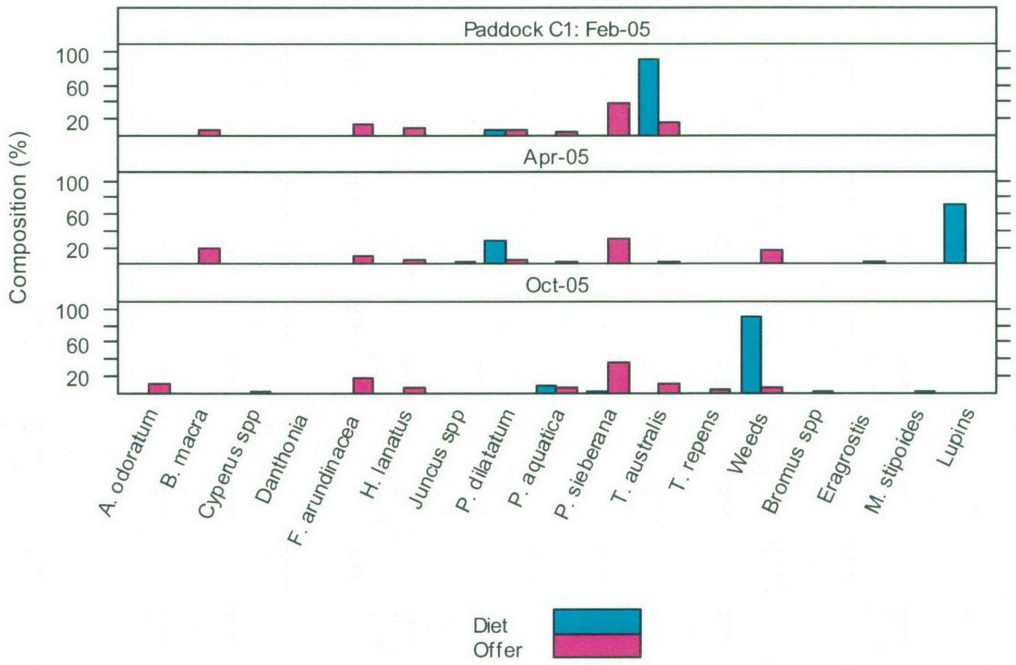


Figure 4.13 Botanical composition (%) of the pasture on offer and in the diet of sheep grazing in paddock C1, in summer, autumn and spring.

Discussion

Species detection

As the alkane profiles of two species can be similar to the extent that they are mathematically indistinguishable, multivariate procedures such as principal component (1 sample/species) and canonical variates analysis (replicate alkane analysis/species) were potential methodologies for analysis (H. Dove pers. comm.). In this study, principal component analysis was employed to compare and discriminate pasture species in terms of the similarities of their pattern of alkane signatures at each sampling time. The results confirm that pasture species can be distinguished and separated based on their alkane profiles as previously reported for pastoral/semi-arid regions (Lee and Nolan 2003) and that the differences in n-alkane signatures between species are sufficiently persistent over time (Chen 1998). Detailed discussion of species detection is in Appendix 3.

Diet selection

Diet selection is commonly expressed as an index representing the proportion of a component in the diet expressed as a fraction of the proportion of the same component in pasture on offer. According to Hodgson (1990) values >1.0 indicate positive selection and values <1.0 indicate avoidance. In this study, of the total number of pasture species (48), a broad range of

selection indices from 0.8 to 22.8 was observed. It is well documented that sown pastures are likely to be uniformly grazed and as such have a low range of selection indices while in mixed communities of native species a higher variation of selection indices has been reported. Hodgson (1990) reported a range of selection indices from 0.6 to 2.0 for sown pastures of perennial ryegrass and white clover and a range of 1.3 to 8.0 in mixed native pastures consisting of 10-12 grasses and 8-10 herbs.

The strong preference for *Festuca arundinacea* by sheep grazing in paddock A7 during both summer and autumn was expected as this species was present in greater proportion compared to other species and also had the highest digestibility. Although *Festuca arundinacea* was also present in the greatest proportion in paddock C1, the lower selection preference by sheep grazing in this paddock could be due to the lower quality of pastures on C paddocks, compared to A paddocks, presumably due to the lower soil nutrient levels on farmlet C. There was also a tendency for sheep grazing in A7 to select *Phalaris aquatica* and *Lolium perenne*. Apart from having a capacity to maintain highly digestible green leaf throughout the growing seasons, *Festuca arundinacea* and *Phalaris aquatica* are reported to be productive even during relatively dry summer periods in this region (Ayres *et al.* 2000b; Harris and Culvenor 2004). These grasses have a deep-rooting habit and the ability to tolerate grazing pressure and can become dormant under dry climatic conditions (Kemp and Culvenor 1994). The higher proportion of *Festuca arundinacea* both in the pasture on offer and in the sheep diet in summer/autumn 2005 could be related to its good summer growth and hence its ability to compete well with the native warm-season C_4 grasses (Oram and Lodge 2003).

There was a shift in preference from *Festuca arundinacea* to broadleaf weeds in spring when these weeds appeared in paddock A7 for the first time after the dry summer/autumn period in 2005. This finding is consistent with the study of Chen *et al.* (2002) who reported that the selection for any pasture species by grazing sheep changes over time with availability of alternative species, especially if they have green leaf. It is also well documented that the proportion of the sheep diet does not always reflect the proportion of the available herbage on offer (Arnold 1981; Hodgson 1990; Kenney *et al.* 1984).

The shallow-rooted *Lolium perenne* was present in small proportions both in the pasture on offer and in the diet throughout the sampling periods. This observation suggests that while the content of *Lolium perenne* could be changing with seasonal variability and soil fertility (Kemp and Culvenor 1994), it may also be a reflection of its poor persistence which has been reported under high grazing pressure (Waller *et al.* 2001b).

In paddock B1, the strong preference for *Microlaena stipoides* and *Plantago lanceolata* by grazing sheep in summer could be related to the higher nutritive value of these species. *Microlaena stipoides* is a yearlong green native perennial capable of providing high grazing value to grazing animals particularly in summer (Lodge and Whalley 1985). Even though there was a tendency for sheep grazing in this paddock to select *Paspalum dilatatum*, there was a shortage of feed in autumn 2005 and hence supplementation provided across the farmlets contributed greater amounts of the sheep diet. In spring, there was a strong preference for *Festuca arundinacea* and *Phalaris aquatica* by sheep grazing in paddock B1 compared to those grazing in C1 which suggests that different grazing managements between farmlets B and C may alter opportunities for expression of diet choices at the same level of inputs.

Despite the markedly lower nutritive value of *Themeda australis* observed in paddock C1 throughout the sampling periods, there was a preferential selection for this species in summer. This could be attributed to its presence and availability in summer as a warm-season C_4 native species. The content of *Paspalum dilatatum* in the diet of sheep grazing in B1 and C1 during the dry autumn period in 2005, suggests that this species is preferred when desirable species such as *Festuca arundinacea* and *Phalaris aquatica* are over-grazed. Its preferential selection could therefore be considered as an alternative for the sheep diet. As occurred in A7, sheep in C1 showed a strong preferential selection for broadleaf weeds when they established in the spring of 2005 after the preceding dry summer/autumn periods.

Even though paddocks A7 and B1 differed in input levels they experienced similar grazing management and diet selection for *Festuca arundinacea* was similar between these two paddocks over time. In contrast even though *Festuca arundinacea* was present in greater amounts in C1, the content of this species in the diet of sheep was lower compared to A7 and B1. This difference could be due to the high stocking density practised on farmlet C, which restricted the animals from selecting their preferred species. While this may protect desirable species from being selectively overgrazed, this practice may also reduce the animal's ability to select highly digestible species with a consequence of lower animal performance. This finding is consistent with the study of Watkin and Clements (1978) which revealed that increasing grazing pressure can reduce the differences in relative acceptability between species; thus, previously neglected species and plant parts can make up an increasing proportion of the diet. A second possible reason could be the differences in the nutrient content of pastures under the three systems which could influence the sheeps' intake and diet

selection.

These data provide evidence that, at least in the limited number of paddocks measured here, selective grazing was greater under flexible grazing systems with their longer grazing periods (farmlets A and B) compared to intensive rotational grazing (farmlet C). Animals grazing on farmlets A and B at relatively low stock densities presumably had a greater capacity to choose species which they preferred compared to those under the high stocking density regime of farmlet C. However, more extensive studies would need to be done to test this finding across all paddocks of each farmlet.