Chapter 1

Review of the literature

1.1 A brief history of grazing and pasture decline

Most present-day grasslands in temperate Australia are anthropogenic, having evolved under Aboriginal burning regimes and/or resulted from a combination of many factors since European settlement, including the clearing of wooded vegetation, grazing and trampling by domestic livestock, cultivation for crops and pastures, fertiliser addition and both intentional and unintentional plant introductions (Moore 1970, 1993; Lodge and Whalley 1989). Over the last 200 years, the grazing of these grasslands has almost always been undertaken on a reactive, set-stocked basis (Doyle *et al.* 1994; Vizard and Foot 1994; Mason and Kay 1995).

Australian pastoralists have traditionally orientated their management to the European style of agriculture, attempting to shape the environment to suit their production requirements. There has been a strong emphasis on livestock production and little consideration of land condition and the soil resource (Noble and Brown 1997). Severe degradation of the landscape was recorded after a relatively short period of settlement, mainly due to ignorance of the different ecology of the land (Tothill 1978). At the end of last century Turner (1895) was emphasising the need to address the problem of severe overgrazing of the most productive native grasses. It is difficult to comprehend that over 100 years later, continuous grazing remains a common practice and that animal production still has priority over sustainable land use (Roberts 1986; Dowling *et al.* 1996).

Efforts to restore grassland productivity through species introduction have been relatively unsuccessful in many areas and have often been accompanied by ecological impairment (Barr and Cary 1992). The legacy of more than a century of overgrazing and the past 50 years of agricultural "development" has been the deterioration of vegetation and soil structure, resulting in landscape dysfunction (Williams and Chartres 1991; Archer *et al.* 1993; Lodge 1995; Nadolny 1995).

The term "grazing", as it is used in most American, African and Australian agricultural publications, invariably refers to the practice of continuous grazing, that is, containing domestic livestock within defined partitions of land for the major part of the year. Even though stock may be moved, so that paddocks contain different stock classes from time to time, most paddocks on a property have stock in them for much of the year. When used in this context the term "grazing management" is somewhat of a contradiction, since continuous grazing represents the zero option (Hutchinson 1993; Beattie 1994). "Management" infers some degree of control over the grazing process, primarily through alternating grazing and rest periods (Booysen 1969). Use of the term management also introduces sociological and cultural factors into the system (Heitschmidt and Walker 1996).

Grazing involves the harvesting of forage by livestock and the associated activities of trampling both plants and the soil surface and the deposition of dung and urine. It is an ecological process in which the grazing animal is only one component, and as such it requires some appreciation of ecosystem function in order to be managed effectively.

1.2 The grazing ecosystem

The highly complex grazing ecosystem has three fundamental components;

- the primary producers - plants
- the consumers (or secondary producers) - livestock
- the decomposers - microorganisms and mesofauna

All components of the ecosystem are interdependent and interact to affect energy flow and nutrient cycling (Harper 1978; Archer and Smeins 1991). Research on grazed grasslands has frequently focused on a single aspect of the ecosystem, the production attained by the either the plants or the livestock. The focus on production neglects basic ecosystem processes and their importance to functioning landscapes (Spedding 1965; Wilson 1986), with livestock in particular often viewed as being external to the ecosystem itself (Peiper 1994).

1.2.1 *The producers*

The transfer of energy through the food chain begins with the capture of solar energy and its conversion to plant product. Net primary production of biomass is either consumed by grazers or returned to the soil as litter. As grazing pressure increases a greater relative proportion of primary production is consumed by livestock and less is incorporated into the soil organic pool (Parsons *et al.* 1983). The proportions consumed or returned in litter are the critical factors in the determination of the ecosystem carbon balance (Larcher 1995). To ensure the sustainability of the ecosystem the carbon balance must be in equilibrium or positive (Williams and Chartres 1991).

Environmental constraints of soil fertility and the reliability of rainfall, place an upper limit on the primary productivity of a community (Huntly 1995; Larcher 1995). Management can have little effect on the inherent constraints of the environment, but by imposing a degree of control over the grazing process it may be possible to manipulate the energy flux through the ecosystem. The conversion of energy through the food chain involves losses at every level (Harper 1978). Briske and Heitschmidt (1991) presented an example of the energy conversion efficiency at a site in Texas (Table 1.1).

Table 1.1 Energy content and conversion efficiencies for primary and secondary production in relation to total and photosynthetically active solar radiation.

SYSTEM COMPONENT	ENERGY CONTENT (MJ/ha/yr)	CONVERSION EFFICIENCY (%)			
Solar energy					
Total	63,000,000				
Photosynthetic radiation	28,000,000	0.10%			
Primary production			0.22%		
Above ground	62,705			0.50%	
Below ground	250,820				0.002%
Total	313,525	2.00%			
Secondary production	1,257				

Source: Briske and Heitschmidt 1991.

The energy content of the system was derived on the basis of 3183 kg/ha/yr of primary (herbaceous) production and 53.5 kg/ha/yr in livestock gain (secondary production) and calculated by multiplying production values by 19.7 and 23.5 MJ/kg respectively (Heitschmidt *et al.* 1987; 1990). The table highlights the low conversion efficiency of solar energy to livestock product.

There are two areas in which improvements may be made in these conversion efficiencies - in the above ground capture of light energy and in the amount of material harvested by consumers (secondary production). Briske and Heitschmidt (1991) suggested that these factors "cannot be maximised simultaneously because of the contribution of leaf area to both processes". While this is true under conditions of continuous grazing there may be possibilities under alternative grazing practices through the following processes:

i) *Improved light interception.*

An improvement in botanical composition which increases the diversity of perennial grasses and/or the distribution of summer and winter active species in the sward may extend the period of light interception. A mixture of species with different photosynthetic pathways may further enhance productivity through a greater distribution of resources both vertically and temporally (Pyke and Archer 1991).

Until the recent growth in the field of conservation biology few studies of the relationship between diversity and productivity were undertaken (Kareiva 1996). Recent research has shown that the productivity of grasslands is greater in more diverse communities and these communities are more resistant to the effects of drought (Tilman and El Haddi 1992; Givinish 1994). The positive effect of species diversity is thought to be associated with increased ground cover and reduced nutrient losses from the soil through leaching, combined with enhanced nitrogen uptake (Tilman *et al.* 1996).

ii) *An increased efficiency of water utilisation.*

Physical parameters such as the level of organic matter, groundcover, aggregate stability and porosity, function to regulate energy transformations and the flux of water through the soil profile (Anderson 1995; Emerson 1995). Improvements in these parameters should improve the infiltration rate and retention of soil moisture, hence extending the active growth period of the pasture.

iii) *An improvement in plant vigour.*

To maximise herbage accumulation, all light incident on the canopy must be intercepted by photosynthetically active leaf material. Three characteristics influence the light interception and regrowth of plants; leaf size, number of tillers per plant and number of leaves per tiller (Chapman and Lemaire 1993). Plants which are in healthy, vigorous condition have a greater capacity for regrowth and rapid restoration of leaf area following defoliation. An optimum leaf area index exists for grazed pastures, and when maintained near this optimum, yield is maximised (McNaughton 1979). Strict control over the grazing process through a regime of intermittent grazing and resting is necessary to maintain pasture in a condition conducive to the production of a high leaf area index (Harris 1978; Simpson and Culvenor 1987; Smetham 1990).

iv) *An improved harvest efficiency of consumers.*

A significant proportion (60 - 90%) of total plant biomass occurs below ground and is unavailable for livestock consumption. Of the above-ground component of primary production, estimates of livestock utilisation vary from 13 - 50% (Painter and Detling 1981; Parsons *et al.* 1983). Using high stock densities and extending the interval between graze periods has been shown to increase the level of harvested forage (Binnie and Chestnutt 1991). A number of other researchers have also used high stock densities to successfully achieve a higher and more even level of pasture utilisation (e.g. Wallace 1990; Mazzanti and Lemaire 1994; Tate *et al.* 1994). Lemaire and Chapman (1996) suggested that a high efficiency of utilisation may be achieved and maintained with the use of high stock density and intermittent grazing for periods of 12-72 hours. Different species and classes of grazing livestock have different preferences for plant species and plant parts, so that the use of multiple species of grazing animals either together or in rotation may also improve the efficiency of pasture utilisation (Nolan *et al.* 1993; Walker 1994).

Although the potential biomass production of an ecosystem has upper limits set by environmental constraints, the level of primary production achieved is often very low in comparison to the potential productivity (Harper 1978). Improved functioning of the ecosystem through increased diversity and vigour of plants may be an achievable target. The distribution of plants, litter and roots are qualitative indicators of the extent of nutrient cycling and energy flow. Small increases in the efficiency of energy flow can result in greater increases in secondary production (Briske and Heitschmidt 1991).

1.2.2 *The consumers*

The environment dictates ecosystem-level constraints which determine the number and type of organisms which may be supported. However, grazing livestock are a primary influence on interactions which operate within the ecosystem and their presence accelerates processes at all levels (McNaughton 1986; McNaughton *et al.* 1989). Herbivores, through feedback effects on ecosystem processes, have the ability to modify the spatial and temporal landscape structure to some extent (Huntly 1995) which ultimately patterns ecosystem processes and function. Landscape variation in combination with climatic conditions provides opportunities for plants species to respond through changes in distribution and abundance (Chesson and Huntly 1989).

Livestock are also the most visual of the ecosystem components and ultimately determine the profitability and economic sustainability of an enterprise (Taylor 1989). They are however, usually poor indicators of ecosystem health. Losses in livestock productivity may not be observed until long after important plant species have been lost from the vegetation or soil structural decline has been recognised.

The direct effect of livestock in structuring the landscape is through differential patterns of defoliation which may be area selective or species selective (Theron and Booysen 1966; Huntly 1995). A common assumption is that animals preferentially select plants which contain high protein levels, although McNaughton (1988; 1990) found a stronger correlation between the distribution of animals across an area and the forage concentration of sodium, magnesium and calcium, than of plant nitrogen.

Preferences for individual species and plant parts affect competitive relationships between plants and plant response to defoliation. Differential defoliation patterns of individual plants may alter their morphology and physiology and the rate of uptake of mineral nutrients and moisture. Changes to the composition and structure of above- and below-ground components of the vegetation in turn affect microbial and invertebrate populations. The effect of selective herbivory on vegetation will be dealt with in greater detail in subsequent sections.

Non-trophic effects of grazing are those which occur in the physicochemical environment (Huntly 1995). The activity of grazing animals may potentially alter soil structure and below-ground processes which in turn affect plant growth and microbial and invertebrate activity. The effect of grazing livestock on ecosystems is usually perceived as being negative (McNaughton 1983; Peiper 1994). However, through their influence on the rate of nutrient cycling their presence is critical to the maintenance of vital ecosystem processes.

The movement of grazing animals affects the rate of return of standing dry matter to the soil where its accessibility to soil organisms is increased (Naeth *et al.* 1991). Ruminants return 60 - 95% of the nutrients they consume to the soil surface in a microbially processed form (Williams and Haynes 1992). Grazing also influences the turnover of root biomass (Richter *et al.* 1990). The impact of consumers is largely dependent on climatic conditions at the time of grazing and may be moderated by management through control of the grazing process (Archer and Smeins 1991).

1.2.3 *The decomposers*

The decomposer organisms, through their role in regulating the flow of nutrients, are the driving force within ecosystems. These organisms are dependent on a supply of carbon from plant material to maintain ecosystem processes (Roper and Gupta 1995). The efficiency of biological breakdown of litter by invertebrates and subsequent decomposition by microbes are important determinants of the period of immobilisation of carbon and other nutrients (Spain and Hutson 1983).

Soil invertebrates play a primary role in the recycling of nutrients from senesced plant material and dung, regulating the carbon (energy), nutrient and water fluxes within the ecosystem (Anderson 1995). Through the process of particulation and communition of organic material and its incorporation into upper soil horizons, the accessibility of material to microflora is increased (Spain and Hutson 1983). Soil fauna communities are dominated by micro-arthropods and nematodes. In temperate Australian soils, the presence of micro-arthropods can reportedly enhance the release of nutrients from the litter by up to 50% (Taylor 1993). While the condition of the soil determines the environment for soil microorganisms and invertebrates, these organisms are also important modifiers of the soil environment. The indirect effects of soil invertebrate activity include their influence on porosity and soil structure, the effects of which are cumulative and continue to operate in the absence of the organisms (Anderson 1995).

Microorganisms are the largest components of biomass in most ecosystems. Jong (1989) estimated that microbes compose one quarter of the earth's biomass. In temperate pastures their contribution has been estimated to be the equivalent of 100 DSE/ha (King 1994; Anon. 1996). Microbial decomposers process up to 90% of the carbon, nitrogen, sulphur and phosphorus contained within plants (Beattie 1994; Parmelee 1995). In addition, microbes provide a labile store of carbon and nutrients in their biomass (Diaz-Ravina *et al.* 1993). The mineral cycle of pastures is dependent on the maintenance of an active microbial community.

The growth rates of the microbial and soil biota communities are positively influenced by increases in root biomass (Srivastava and Singh 1991). Parmelee (1995) found where root biomass was high, levels of ammonium and nitrate ions in the soil solution were lower, indicating a greater degree of efficiency of utilisation of plant-available nitrogen. Root exudates also provide an important source of substrate for microbes, which in turn have a direct effect on the mineral nutrition of plants. Defoliation of plants increases the release of exudates and the rate of turnover of fine root material (Singh *et al.* 1991).

Microbial biomass and activity are influenced by soil moisture and temperature conditions (Diaz-Ravina *et al.* 1993; Nicolardot *et al.* 1994). Maintenance of a high level of soil surface cover by plants may moderate fluctuations in these parameters and enhance the activity of organisms and their function in the soil. Management practices which affect the quality and quantity of surface litter and below-ground organic matter may significantly affect flora and fauna populations and community structure through their effect on below-ground food webs, soil water and nutrient availability (Emerson 1995; Parmelee 1995; Holt *et al.* 1996).

Many plant species have mutualistic mycorrhizal associations. In grasses the association is facultative with little specificity (Allen and Allen 1990). By increasing the volume of soil that may be exploited, mycorrhiza play an important role in improving the ability of associated plants to access and acquire water and nutrients in situations where these factors may be limiting plant growth (Killham 1994). Through hyphal strand connections the transfer of nutrients between infected plants is also possible (Read *et al.* 1986).

The productivity and sustainability of agricultural ecosystems is governed by the timing of inputs to the organic matter pool and the size of the pool. The inputs to the system control the biomass of soil organisms and thereby determine the rate of turnover of carbon and nutrients (Robertson *et al.* 1994; Blair *et al.* 1995). Biological processes are often overridden by anthropogenic activities such as overgrazing, fertiliser addition and cultivation. With the cessation of such practices and the application of ecologically sensitive management, the efficient functioning of the biological processes can be reestablished (Anderson 1995).

Soil physical, chemical and biological properties are intricately linked. Enhancing or degrading one of these properties, affects all other aspects of the soil environment (Lal 1988; NRC 1994; Holt *et al.* 1996). The loss of biological function in a pasture is a critical source of production decline (Taylor 1993).

1.3 The process of vegetation change

1.3.1 *Theories of vegetation change*

Clements (1916) made perhaps the largest contribution to our understanding of the process of vegetation change with the introduction of his successional theory (Peiper 1994). Although many flaws in the proposal that all ecosystems move toward a climax vegetation have been identified, the concept of succession and species position on this arbitrary scale are still in common use.

However, chance in relation to environmental circumstances and the ability of species to reproduce and establish successfully, are critically important in determining the direction of vegetation change (Gleason 1917; Westoby *et al.* 1989; Botkin 1991). This is particularly so in variable environments where rainfall events are episodic and unreliable (Walker 1993; Wilson and Simpson 1994). The State and Transition model proposed by Westoby *et al.* (1989), although it was developed for arid and semi-arid environments, has recently tended to take precedence over successional theory. These authors suggested that episodic environmental events provided the opportunity for land managers to direct vegetation change.

Habitat changes may occur either as a result of disturbance or stress (allogenic factors) such as drought and grazing or through changes initiated by plants in response to environmental conditions (autogenic factors) e.g. soil modifications or light conditions (Burrows 1990). In grasslands the two processes are often closely linked. Changes in the vegetation will differ in style, degree and rate according to the local environment and the dominant plant species, as well as the frequency and extent of events which affect plant death, lifespan and reproduction (Harper 1978; Burrows 1990). Because plant communities are dynamic and in a constant state of flux, the direction of change is not always predictable (Lawton 1994).

When a habitat changes through either allogenic or autogenic factors it may alter the competitive relationships of plants within the community. Changes in microsite temperature and water relations may favour the emergence of new or previously suppressed species, further changing soil-plant and plant-plant relationships (Harris 1978). The changed conditions, while suitable for establishment, may not favour the long-term survival of the species, and the process of compositional change may continue until a relatively stable vegetation is established.

1.3.2 *Competition*

The characteristics of the dominant species in the sward in combination with environmental conditions will have an important influence on the outcome of inter-plant relationships. In the absence of grazing animals plant competition is the dominant mechanism by which grassland communities are structured (Bullock 1996). The relative abilities of species to compete may vary depending on the resource which is most limiting (Tilman 1988).

Competition in grasslands is centred around light, moisture and nutrient resources and suitable sites for germination (Tilman 1990b). Light is not generally a limiting environmental factor in Australia but rather is related to canopy characteristics, the architecture of the dominant species controlling light levels within the lower stratum. In rangeland environments water and nutrients (particularly nitrogen) are the factors most commonly limiting plant growth. Consequently, competition for below-ground resources is most intense (Tilman 1990b). Berendse and Elberse (1990) listed the factors which affect the ability of plants to capture resources and this list is dominated by root characteristics, inferring that competition for below-ground resources is most critical.

Most theories on plant competition are related to the concept that successful species are capable of either

i) more effective exploitation of available resources through rapid acquisition (e.g. Grime 1979) or
ii) tolerating lower levels of the limiting resource better than neighbouring plants (e.g. Tilman 1990b).

The difference between these two popular explanations of plant competition is essentially semantic, each author defines the same concept of competition with a slight change of emphasis (Grace 1990).

Features of successful competitors include a relatively high allocation of resources to shoot growth, high concentration of nitrogen in leaf tissue, high growth rates and generally high palatability. Conversely, stress-tolerant species allocate more biomass to roots, have lower nitrogen levels in leaf tissue, slow growth rates and are relatively less palatable (Grime 1979; Moretto and Distel 1997). Tradeoffs are apparent between the ability of species to grow rapidly and exploit resources and their ability to tolerate environmental stresses (Tilman 1990b).

Plant density may have a significant influence on competitive interactions within a community as resources become limiting. Where plant density is high, the level of inter-plant competition is increased and individuals may tend to have a smaller basal area and lower potential seed production and seed size (Bullock 1996). The combination of these effects increases the likelihood of compositional changes at the community level when stresses are imposed.

1.3.3 *Influence of grazing on plant competition*

Perhaps the greatest influence of grazing livestock on grassland population dynamics is their effect in modifying the competitive balance between co-existing pasture plants through the process of selective grazing (Harper 1978; Louda *et al.* 1990; Brown and Stuth 1993; Moretto and Distel 1997). Grazing induced changes to plant-plant interactions are not dependent on the density of plants in a pasture (Bullock 1996).

The direct effects of grazing on population dynamics include removal of plant tissue which may influence plant mortality or fecundity (Bullock 1996) and the differential allocation of resources within plants. Defoliation may strongly influence competitive relations in pastures (Richards 1984; Belsky 1986; Caldwell and Richards 1986) since the growth rate varies considerably among species. Thus the direct effects of grazing on plant communities will be dependent on the species composition of the pasture.

In grassland species palatability, grazing resistance and competitive ability are continuous variables (Peiper 1994; Briske 1996). Often the most valuable palatable species are those that are tolerant of grazing and more competitive due to their ability to re-establish photosynthetic material rapidly following defoliation. However, under continuous heavy grazing these species are eventually lost from the pasture because they are preferentially selected by grazers and they are relatively intolerant of moisture and nutrient stress (O'Brien 1986; Pyke and Archer 1991). As mentioned previously, successful competitors require conditions of high resource availability and low stress. When soil resources are limiting, below-ground competition will be more intense and the impact of animal selectivity on the desirable pasture components will be amplified.

Herbivory modifies those plant traits which are most critical in the acquisition of resources largely by changing plant morphology (Turkington and Mehrhoff 1990). Above-ground features which are affected by grazing are the reduction in leaf area and alteration of the age structure of tillers. Frequent defoliation may result in a change in the architecture of the canopy. For example, plants may develop prostrate growth and ultimately the dominant life forms may change, grasslands converting from perennial species to be dominated by annual grasses and forbs (Wilson and Simpson 1994). Grazing may also affect the root:shoot ratios of plants, litter accumulation rates and nutrient cycling (Louda *et al.* 1990).

The repeated defoliation of desirable sward components suppresses their ability to compete relative to neighbouring plants which remain ungrazed. As the ability of these ungrazed less palatable species to compete for resources is improved, they may exclude the weakened grazed plants from the pasture (Brown and Stuth 1993).

As species disappear or individuals are weakened, gaps occur in the canopy providing the opportunity for species present in the seed bank to colonise these areas (Bullock *et al.* 1995). Heavy continuous grazing inevitably increases the frequency of gaps (Silvertown and Smith 1988) and many more species may take advantage of the altered conditions. Which species colonise depends on the composition of the seed bank and the specific microclimate within the gap. Management practices influence both canopy cover (gap frequency) and soil organic matter (microclimate in gaps) which ultimately affect nutrient availability and soil structure. By controlling these factors through grazing management, changes in botanical composition may be directed (O'Brien 1986; Pyke and Archer 1991; Bullock *et al.* 1995).

1.4 Plant response to defoliation

1.4.1 *Evolved mutualism?*

Grasses possess a range of adaptations which suggest they have evolved a mutualistic relationship with herbivores (McNaughton 1976; Owen 1980; Owen and Weigert 1981; McNaughton 1983; Gonzalez *et al.* 1989). Adaptive features include the location of basal meristems, the ability to re-establish photosynthetic material, the capacity for vegetative reproduction, low levels of secondary compounds (e.g. tannins) and high palatability relative to other plant species (Owen and Weigert 1981; McNaughton 1983; Becker *et al.* 1997b).

There has been some debate as to whether the features listed represent absolute evidence for the co-evolution of a mutualistic relationship between grasses and grazers (Herrera 1982; Silvertown 1982, Belsky 1986). Silvertown (1982) cited situations where species composition had been altered by grazing and suggested a general hypothesis was not applicable. There have been many other examples of grazing altering botanical composition and vegetation structure (Noy-Meir *et al.* 1989; Westoby *et al.* 1989; Belsky 1992; Wilson and Simpson 1994; Anderson and Briske 1995). Notwithstanding, grasses generally are relatively well adapted to tolerate defoliation, although wide variation exists between species.

1.4.2 *Grazing resistance*

The term "grazing resistance" acknowledges that grass species respond differently to defoliation and environmental conditions (Briske 1986). Although the use of this term is somewhat subjective, having a limited theoretical basis (Scogings 1995), it is a useful concept to explain the relative abilities of grasses to survive and grow in a grazed environment.

Morphological plasticity, polymorphism and physiological variation in response to herbivory are all important mechanisms in grazing resistance (Briske 1986; Burrows 1990; Louda *et al.* 1990; Turkington and Mehrhoff 1990). Other mechanisms such as sharp seeds, high silica content, low leaf:stem ratio and the production of anthocyanins, tend to regulate consumption rather than to act as defences from predation (Burrows 1990). In a comprehensive review of plant survival strategies under grazing Briske (1996) described the various avoidance and tolerance strategies exhibited by plants (Table 1.2).

All grasses exhibit both avoidance and tolerance strategies to varying degrees over time and in response to different grazing methods (Briske 1986). A high degree of grazing tolerance is critical for the stability of grasslands and persistence of a desirable pasture composition (Richards 1993). Strategies of grazing tolerance are of relatively greater importance to the more palatable species of a pasture which are more likely to be preferentially selected by livestock.

Table 1.2 Grazing resistance strategies of perennial grasses.

AVOIDANCE STRATEGIES	TOLERANCE STRATEGIES
Spatial mechanisms	Morphological mechanisms
species associations	number and source of meristems
growth form	number and viability of seed
phenotypic plasticity	
Constitutive mechanisms	Physiological mechanisms
mechanical	compensatory processes
biochemical	compensatory growth
defensive symbiosis	
Temporal mechanisms	
inducible defences	
asynchronous growth and development	
developmental resistance	

Source: Briske 1996

1.4.3 *Physiological response*

The physiological response of grasses to defoliation consists of two phases. The first period lasts from one to a few days and the second phase may last for several weeks (Richards 1993). The duration of these phases of recovery depends on the amount of tissue removed, the plant parts removed, the stage of development of the plant and the environmental conditions at the time of defoliation (Richards 1993).

Short term response

The most immediate effect of defoliation is the removal of leaf area reducing the photosynthetic capacity of plants (Briske and Richards 1994). Immediately after defoliation the allocation of carbon is directed to leaf growth and shoot meristematic regions at the expense of the root system (Ryle and Powell 1975). Within a few days current photosynthesis is the primary source of resources for plant growth (Briske and Richards 1994). The rate of regrowth is dependent on the accumulation of carbon which is directly related to the nitrogen content of the plant (Lemaire and Chapman 1996).

Carbon imported from attached, undefoliated tillers may be an important source of substrate for regrowth. Welker *et al.* (1985) reported an increase in carbon import to defoliated daughter tillers of 36 - 85% within 30 minutes of defoliation and the level increased until the defoliated tillers regained their capacity for carbon gain after 10 - 84 hours. This reallocation between tillers is not necessarily at the expense of assimilate supply to the root system, depending rather on the relative leaf areas of the defoliated and attached undefoliated tillers (Richards 1993).

The leaf sheath region can also be an important source of photosynthate following defoliation since the majority of residual material is often sheath (Wallace *et al.* 1990). The length of leaf sheath may also act to control animal intake as consumption decreases when this level in the sward is reached irrespective of grazing method (Wade *et al.* 1989). The ability of grasses to change the sheath length in response to defoliation may influence their adaptability to different grazing regimes (Lemaire and Chapman 1996).

Removal of 50% of the above-ground tissue has been shown to result in cessation of root elongation within 24 hours (Davidson and Milthorpe 1966; Ryle and Powell 1975). In addition, root respiration and consequently nutrient absorption decrease due to the reduction in carbon assimilation, the effects of which are closely related to the intensity of defoliation (Briske and Richards 1994). The absorption of nitrate does not begin until plants re-establish a positive carbon balance.

Stress-tolerant plants growing under low nutrient conditions generally allocate a greater proportion of nitrogen to their roots than faster growing species, therefore root growth, respiration and nutrient absorption are less affected in these species (Grime 1979; Chapin and Slack 1979). When growing in mixed swards, those grasses which depend on uptake from the roots (competitive species) are at a relative disadvantage when nitrogen becomes limiting, as remobilisation is a more efficient process under these conditions (Thornton *et al.* 1993; Hunt 1983).

The extent of storage, remobilisation and partitioning of nitrogen within plant tissue is species specific and the flexibility of these processes are primary determinants of regrowth potential following defoliation (Richards 1993; Lemaire and Chapman 1996). In *Lolium perenne,* remobilisation of previously absorbed nitrogen was found to be the main source of nitrogen in the first few days following defoliation, thereafter uptake supplied nitrogen for regrowth (Ourry *et al.* 1988).

Longer term response

The ability to rapidly re-establish photosynthetic area is indicative of a greater degree of grazing tolerance and is a distinguishing characteristic between species (Caldwell and Richards 1986; Tilman 1990a). This requires continued preferential allocation of carbon and nutrient resources to growing tissue. The development of these compensatory processes results in the return to normal plant function and is the second phase of recovery from defoliation (Richards 1993).

Residual leaf area and the number and location of active shoot meristems are primary determinants of regrowth following defoliation (Briske 1986; Richards 1986; Briske and Richards 1994). The timing of grazing in relation to the development of tillers will influence regrowth potential. New tillers are initiated within 2 - 3 weeks following defoliation and the length of time remaining in the growing season will determine the extent of tiller recruitment and the total potential tiller production in defoliated plants (Butler and Briske 1988; Olson and Richards 1988a; 1988b). The ability to recruit new tillers is the basis of perenniality of grasses and it is this feature which confers grazing resistance (Brown and Stuth 1993).

Grasses with elevated apical meristems within vegetative tillers are the most susceptible to frequent defoliation. These species are more productive and persistent when grazed intermittently (Hyder 1972; Briske 1986). The pattern of elevation of shoot apices varies between seasons and ecotypes (Rethmann 1971) and the removal of shoot apices can be a major cause of tiller death, particularly when grasses are in the reproductive phase (Lemaire and Chapman 1996). Extension of basal internodes may increase the risk of defoliation of shoot apices and C_4 species are particularly vulnerable in this respect (Davies 1988). Species such as *Themeda triandra* which synchronise tiller development are at a further disadvantage under continuous grazing (Mott *et al.* 1992). If the apical meristems are lost to defoliation tiller replacement is limited. Other grasses (e.g. *Heteropogon contortus*) with less synchronous tiller development or which are less susceptible to removal of apical meristems are able to maintain more stable tiller populations (Mott *et al.* 1992).

Following defoliation the photosynthetic capacity of the remaining tissue increases, but this often does not result in increased growth (McNaughton 1979; Richards 1986; Wallace 1990). No linear relationship has been shown to exist between the rate of photosynthesis and plant growth rate, presumably due to the different allocation patterns of assimilate to remaining shoots and roots among species (McNaughton 1979; Wallace *et al.* 1984).

1.4.4 *Morphological response*

Morphological changes may be induced by frequent, intensive defoliation. Under such conditions plant structure may tend towards more prostrate or decumbent growth to maintain growth and limit the accessibility of foliage to livestock (Simpson and Culvenor 1987; Turkington and Merhoff 1990). The relative ability of species to display phenotypic plasticity may influence their grazing tolerance (Owen 1980; McNaughton 1983; Wallace *et al.* 1984). Intermittent grazing with long rest periods tends to favour more erect genotypes due to increased competition for light. These conditions may also reduce the capacity for lateral growth. McNaughton (1983) suggested that when grazed intermittently, grasses which are relatively grazing tolerant are unlikely to suffer mortality due to the effects of defoliation.

1.4.5 *Timing of defoliation*

Regrowth potential is influenced by the timing of defoliation events and the phenological stage of the plants (McNaughton 1983). Late season defoliation has been shown to induce bud inhibition in some species (Olson and Richards 1988a; 1988b; Busso *et al.* 1989; Becker *et al.* 1997b). Barnes (1972) also indicated cutting late in the season may be more detrimental than cutting earlier because of bud inhibition and the limited time available in the growing season to produce adequate regrowth. The seasonal production of some species may also be influenced by the timing of the initial defoliation event of the growing season, depending on their regrowth ability following defoliation.

The desirable rest period should be of sufficient length to allow recovery from the previous defoliation. This time period is likely to vary considerably between seasons and years depending on the prevailing climatic conditions. In arid zones, Caldwell and Richards (1986) suggested that the necessary recovery period may be in excess of 5 years if dry conditions persist, while in Victoria, 9 months was considered an adequate recovery period following grazing of native pastures (Zallar 1986). Decisions on the timing of defoliation and recovery periods should include consideration of prevailing environmental conditions and not simply be undertaken on a calendar basis, because of the unreliability of pasture growth and rainfall (Wilson and Simpson 1994).

Management of the defoliation process is a balance between the intensity and frequency of grazing, in concert with seasonal and climatic variation and understanding the basis of plant physiological processes, vegetation dynamics and animal nutritional requirements. Therefore, grazing management in rangeland environments must be highly flexible (Zallar 1986).

1.5 Selective grazing

1.5.1 *Factors associated with diet selection*

The control of livestock movement across the landscape will influence the degree of selection pressure applied to individual plant species. Selective grazing influences community structure through the alteration of plant-plant interactions (Brown and Stuth 1993). As a result of changes in species composition or plant density selective grazing may also indirectly affect the efficiency of energy capture.

Herbivore selectivity occurs at two levels; species and site selective (Theron and Booysen 1966). A range of palatabilities, nutritive values, grazing tolerances, growth rates, rooting patterns and flowering phenologies exist in any mixed grass sward (Jefferies 1988; Tainton and Walker 1993; NRC 1994). Under a continuous grazing regime, even when stocking rates are low in relation to carrying capacity, the most palatable, nutritious and actively growing species or plant parts will be subjected to higher grazing pressure than species or plant parts which are less palatable or in a dormant phase (Wilson and Harrington 1984).

When the spatial heterogeneity and topographical variation within paddocks are superimposed upon this within- and between-plant variation, it is obvious that grazing pressure cannot possibly be uniform in large paddocks (Hormay 1970; Wilson and Harrington 1984; Friedel 1994). Johnson and Parsons (1985) estimated that in a ryegrass paddock continuously stocked at 15 DSE/ha, the variation in stocking rate due to patch grazing would range from 0-45 DSE/ha on different areas. This effect would probably be magnified in a more heterogeneous pasture.

Overgrazing, except in extremes, is rarely a uniform phenomenon, but takes place plant by plant, species by species, in paddocks which are lightly stocked and appear to be well managed to the unobservant eye (Parsons 1995). Under a continuous grazing regime, heavy stocking leads to a rapid deterioration in botanical composition, while light stocking leads at best to a slow deterioration (Hughes 1993). The use of stocking rate as an indicator of the grazing pressure on the most palatable components of the pasture becomes less reliable as botanical composition deteriorates, because the grazing pressure exerted on palatable species increases as their representation in the sward declines (Hormay 1970; Tainton and Walker 1993).

1.5.2 *Grazing systems: attempting to control the grazing process*

Management of the grazing process aims to regulate forage utilisation by animals by controlling their spatial distribution and therefore the time, frequency and intensity of defoliation of plants (Beattie 1994). Grazing pressure, that is, the number of animals (forage demand) per unit weight of herbage (forage available) at any instant (Hodgson 1979), is regulated by rainfall and its effect on forage supply (Noble and Brown 1997). However, simply adjusting the stocking rate in response to reduced forage availability has little effect on the grazing pressure applied to the most palatable species in the sward.

Booysen (1969) maintained that in terms of management of vegetation there were only two critical components - rest period and graze period. The design and promotion of grazing systems, that is, "specialised forms of grazing management that include a series of scheduled periods of grazing and rest" (Heitschmidt and Walker 1996) in order to exert greater control over the grazing process, have been the subject of much research and debate.

There has been some argument against the use of grazing management if pastures are stable and resilient (Wilson 1986; Lodge 1995). The existence of such pastures is likely to be rare - the very nature of grassland ecosystems is highly complex and dynamic (Walker 1993). If the other option of continuous stocking is used (i.e. no management), stocking rate must be maintained at very low levels and be sub-optimal in terms of productivity. One would expect that in such environments productivity could be increased greatly by implementing some form of control over the grazing process.

A number of grazing systems have been advocated with the aim of improving range condition. The Merrill system (Taylor *et al.* 1980) consists of a four-paddock three-herd rotation where one paddock receives a seasonal rest. Non-selective grazing (Acocks 1966) or high utilisation grazing (HUG) aims at heavy grazing of all species in the sward to a uniform level (Booysen and Tainton 1978). Controlled selective grazing was advocated by Pienaar in 1968 and is similar in practice to the high production and high performance grazing system (HPG) proposed by Booysen (1969) (Booysen and Tainton 1978). These systems emphasise moderate levels of pressure on the desirable components of the sward and complete non-utilisation of undesirable components. Short duration grazing (SDG) is characterised by graze periods less than 14 days and rest periods up to 60 days. High intensity low frequency (HILF) grazing is distinguished from SDG in that grazing periods are greater than 2 weeks and rest periods are greater than 60 days (Kothmann 1984). Both SDG and HILF grazing systems are variations on the HUG and HPG systems and all use high stock densities.

Results from experiments analysing the effects of grazing systems have been variable and it appears generally accepted that grazing systems are not successful in realising desirable changes in vegetation, soil properties and animal production simultaneously (McKown *et al.* 1991; Brown and Stuth 1993). Some grazing management strategies based on species phenology have been shown to be effective in changing botanical composition (Suijdendorp 1969; Lodge and Whalley 1985; Grice 1994; Kemp *et al.* 1995) although graziers frequently report difficulties with their implementation and have observed that pastures quickly revert to their previous composition once the strategy is relaxed. Furthermore, very few such strategies based on species phenology are available for application at the whole-farm level (Hacker 1993; Hutchinson 1993; Lodge 1995).

A temperate pasture may contain over 100 different species, but is usually dominated by up to 12 species, often with different growth habits and rates, physiologies, palatabilities and responses to grazing (Lodge 1995). There are two major problems inherent in the application of "strategic rest" (e.g. Kemp *et al.* 1995) designed to favour one species in the sward. The first is that the chosen rest period will have unknown effects on other pasture components, all of which interact in either competitive or mutualistic ways with the target species (Jefferies 1988; Hutchinson 1993; Beattie 1994). The second is that when paddocks are not being "strategically rested" they are being continuously grazed (Dowling *et al.* 1996). In effect this means they are being selectively grazed for most of the time. As with pasture replacement, the "strategic rest" approach is anthropocentric in that it underestimates the complexity of nature and assumes that we can manipulate outcomes with single factor, mechanistic models (Lefroy 1995).

Michalk and Kemp (1994) in a comprehensive review of pasture management concluded that: "Despite decades of pasture research the potential for manipulating pasture composition, with the aim of restoring pasture balance and productivity to a level considered desirable for livestock, has not been defined for most Australian pastures." If it is not possible to define precise strategies for manipulating pastures, then perhaps we need to take a more intuitive view as suggested by Lefroy (1995). That is, to use an approach based on our current knowledge of the attributes of the ecosystem we are interested in, rather than attempting to understand all the functional processes in detail before taking action. Guidelines can then be refined as more information becomes available (Lefroy *et al.* 1992).

1.6 Cell grazing

1.6.1 *Origins*

The concept of grazing animals at high stock density for short periods of time to achieve desirable results in pasture composition has a long history. In Australia more than 100 years ago Turner (1895) advocated the use of small paddocks and extended rest periods to allow recovery of overgrazed areas of pasture. More formal approaches to high intensity grazing were developed during the 1960s.

Non-selective grazing was developed by South African botanist John Acocks in collaboration with a number of landholders in the early 1960s (Acocks 1966). It was developed with the aim of reclamation of degraded rangeland (veld). The principles of non-selective grazing included:

- stocking intensity must be sufficient to graze an area within two weeks to increase the grazing pressure on unpalatable species
- graze periods must be short enough to avoid repeated defoliation of palatable species
- minimum rest periods must be long enough to allow regrowth - at least six weeks
- at least twelve paddocks were required, the size of which was determined by herd or flock size in relation to average rainfall
- dry stock which have relatively constant nutritional requirements should be used for reclamation (Acocks 1966).

This concept gained momentum in South Africa and was the subject of a large research effort during the 1960s. The results of a number of years of experimentation on multi-camp grazing systems were reviewed by Roberts (1969), who identified the advantages and disadvantages associated with the application of such grazing regimes.

At about the same time as Acocks was developing non-selective grazing, Frenchman André Voison was advocating rational grazing (Voison 1959). The basis of this form of grazing was that rest periods and graze periods were adjusted in accordance with the growth rate of the plants. When plant growth rate was high, rest and graze periods were relatively shorter than when the growth of plants was slowed. Much of Voison's work was undertaken on single species pastures in high rainfall regions where the issue of selective grazing and its effect on botanical composition was not such an important consideration.

Cell grazing evolved from the observations of a South African ecologist Allan Savory who incorporated principles from both Acocks and Voison into a whole-farm management program. In its earliest form it was referred to as short duration grazing but the name was "loosely used to describe various forms of rotational grazing which did not comply with the principles" and the term The Savory Grazing Method was adopted (Savory and Parsons 1980). Those paddocks which were used for a particular rotation collectively formed the grazing cell.

With the formation of two divergent consultancy groups, cell grazing has developed into Planned Grazing (Ward 1996) and Time Control Grazing (McCosker 1993; Martyn 1995). The principles are taught as part of Holistic Management and Grazing For Profit school respectively. Many graziers have attended both courses. For simplicity and to avoid bias, reference to cell grazing throughout this thesis encompasses both of the grazing methods referred to above.

1.6.2 *Theory*

The principles of cell grazing form one component of a whole farm business management package which incorporates human, financial, livestock and property planning aspects. The influence of these factors are difficult to quantify experimentally (Hart *et al.* 1986; Taylor 1989)

Both the Holistic Management and Grazing For Profit ecosystem models incorporate four foundation building blocks; community dynamics, the water cycle, mineral cycle and energy flow, and identify a range of tools available to manipulate ecosystem processes. The tools that may be implemented are rest, fire, grazing, animal impact, living organisms and technology (Savory 1988). Any or all may be utilised to achieve the most effective use of available financial and labour resources.

The grazing component of the Grazing For Profit package identifies five critical principles; rest, stocking rate, number of paddocks, stock density and herd effect (Parsons 1995).

- adequate *rest* periods must be maintained to allow plants to recover from defoliation events. The rest period is adjusted such that during periods of rapid pasture growth rest periods are shorter and in periods of slow growth rest periods are longer.
- *stocking rate* should be matched to the carrying capacity of the property. Overstocking harms the animal, the property and economics.

- increasing *paddock numbers* enables shorter graze periods. With shorter graze periods the probability of repeated defoliation of the most palatable species declines.
- *stock density* is dependent on stocking rate and the number of paddocks. More paddocks result in increased stock density and more even utilisation of the pasture.
- *herd effect* may be used where the physical influence of high concentrations of livestock is required for a specific purpose e.g. to trample old standing vegetation or to control the flowering of undesirable species.

The grazing principles used in cell grazing cannot be viewed in isolation from the ecological, economic, people and livestock factors and it is this holistic approach which sets cell grazing apart from systems based on a single factor or reductionist approach (Parsons 1995).

Holistic Management is a decision-making process. All decisions regarding all aspects of the business are tested against the operator's personal, production and landscape goals. The response to a series of seven testing questions relating to the ecosystem, financial and social aspects are evaluated to decide which option will best fulfil the criteria to attain the stated desired goal. There is a strong emphasis on the need to plan, monitor and re-plan activities. The principles associated with Holistic Management only have relevance in relationship to the defined goal (Savory 1988).

It has been suggested that the highly integrated nature of cell grazing renders comparisons between cell and conventional grazing management invalid (Lodge 1995). There is no doubt that a grazing method such a continuous grazing is very rigid in comparison, providing land managers with little control over selective grazing, little flexibility and little opportunity to respond to seasonal conditions.

1.6.3 *Practice*

Grazing cells on the Northern Tablelands usually comprise 20 to 40 paddocks, with stock densities normally above 200 DSE/ha. For most of the growing season, graze periods range from 1 - 3 days and rest periods from 40 - 90 days. Each paddock in the cell is rested for 95 to 98% of the year. The stocking rate and the length of the graze and rest periods are adjusted according to the feed on offer and the anticipated seasonal growth rates. The planned rotation is continuously monitored and re-planned as necessary. Nothing is fixed, and stock may move through the paddocks in any order.

With respect to the development of rationed grazing in New Zealand, Clark (1994) noted that "researchers made surprisingly little contribution", however the principles were "intuitively grasped and applied with outstanding success" by livestock producers. There appears to be a similar dichotomy between landholders and researchers with respect to cell grazing in the high rainfall zone of Australia (McCosker 1994b). More than 300 landholders in the Northern Tablelands region have undertaken at least one of the cell grazing schools to date (McCosker and Ward personal communication) and many are successfully implementing the grazing principles.

Prior to the commencement of this research, no scientific comparison of cell grazing and continuous grazing had been undertaken in Australia. Various forms of high - intensity short duration grazing have been evaluated on research stations often using rigid "systems". Stock have been moved through the same paddocks in the same order with each rotation and the most important "tools" for the management of the grazing process, such as the length of the graze and rest periods and the stocking rate, have been maintained at pre-determined, fixed levels throughout the experimental period. As the methodology used in these types of experiments bears no resemblance to the basic principles of cell grazing as currently taught in Australia, they have not been dealt with here.

1.7 Conclusions from the literature

The level of landscape degradation evident across many regions of Australia would suggest our current management practices have failed to adequately consider the function of ecological processes in sustainable agricultural production.

Livestock and their patterns of grazing are a significant influence on the composition and structure of grassland vegetation. In the absence of catastrophic events, vegetation change is usually a subtle process often not observed until desirable species are lost or undesirable species become dominant components of pastures. Some understanding of the physiological response of grass species to defoliation and subsequent changes to inter-plant relationships through competitive interactions is necessary to attempt to manage the pasture ecosystem.

Relative to other plant species, many grasses are well adapted to tolerate defoliation by herbivores and have the capacity to rapidly replace leaf material. The more desirable species in terms of animal production are generally better adapted to regenerate quickly.

However, frequent defoliation by livestock particularly during critical growth periods may push some species beyond their tolerance limits. Allowing these species adequate periods of rest to recover from defoliation events through regeneration of lost or damaged tissue is necessary to maintain their presence in a pasture.

Many past and current practices have been undertaken with the aim of achieving short term gains in production. However, this has often been at the long-term expense of the landscape. All three of the principle components of the grazing ecosystem must be managed for and management of the grazing process is fundamental to achieving directional change in botanical composition, landscape function and productivity.

The practice of cell grazing has recently been adopted by many graziers on the Northern Tablelands of NSW. This form of management offers landholders an integrated approach to the management of livestock enterprises and natural resources, the effects of which have not been evaluated experimentally prior to the research reported in this thesis.

Chapter 2

Introduction

2.1 Background to the study

Grazing land is one of Australia's greatest natural resources, occupying approximately 468 million hectares (61%) of the continent (Ockwell 1990; Hutchinson 1992). Produce from sheep and cattle from this area contributes more than half of the nation's agricultural production (Ockwell 1990). Native vegetation comprises 94% of the area and the remaining 6% has been sown to introduced perennial species (Hutchinson 1992). Sown perennial pasture species are largely restricted to the high rainfall zone of eastern Australia and there is recent evidence to suggest that the sown species are minor contributors to pasture biomass in many areas (eg. Kemp and Dowling 1991; Schroder *et al.* 1992). In an assessment of the extent of pasture decline Archer *et al.* (1993) concluded "The evidence strongly supports the case that pastures have declined to the extent that botanical composition and production of many pastures is now far from a desirable optimum...".

The Meat Research Corporation acknowledged the extent of pasture decline with the introduction of the Temperate Pastures Sustainability Key Program (TPSKP). The first phase was aimed at identifying the most effective form of grazing management for the persistence of perennial grasses. A primary objective of the program was to identify "procedures for manipulating pastures to restore desirable composition (Goal 1a) and to maintain recently established pastures in a desirable composition (Goal 1b)" (PDP 1992). A portion of the research reported here formed Component 4 of the TPSKP program.

Most animal and pasture production research in the high rainfall zone of NSW has been undertaken on research sites which have been well fertilised and dominated by introduced species - atypical of pasture conditions which prevail in the region (Mason and Kay 1995). These authors proposed that the disparity between research sites and typical pastures was a primary cause of the low rate of adoption of research outcomes. Research has provided the principles of sound grazing practices to sustain or improve the pasture resource base but the technology developed by scientists on research stations is often rejected by graziers because it cannot be adequately adapted to fit their needs (Pretty 1995). Stuart-Hill (1989) stated that worldwide, research had been unable to produce a practical or effective management procedure suitable for application in pastoral regions. Prescription based management packages are not considered applicable to pastoral management in variable environments (Watson *et al.* 1996).

The grazing principles associated with cell grazing do not differ markedly from those currently advocated by pasture scientists and agencies. The difference is that the process offers a realistic method of achieving the objective of improving the pasture resource on a whole farm basis. Cell grazing is a flexible, adaptive method of moving livestock across the landscape at a rate compatible with the growth rate of pastures. High stock densities are used to improve the evenness of pasture utilisation and to enable adequate rest periods for grazed plants between defoliation events.

Cell grazing is a single component of a highly integrated whole-farm management package which incorporates ecological, economic, livestock and human factors. All factors are considered in the decision-making process which is orientated towards achievement of an individual's defined personal, production and landscape goals. It is this integrated approach to enterprise management that differs markedly from the traditional reductionist approach commonly implemented in livestock production systems.

The long-term advantages expected to accrue to cell grazing were listed by Hutchinson (1993) as including "better weed control, improved pasture utilisation, increased root development and soil biological activity, breaking sheep camping behaviour and improving nutrient redistribution, easier stock handling and earlier recognition of stock health problems".

Management packages incorporating cell grazing are introduced to graziers by way of intensive training schools and these are currently marketed under two names in Australia; Grazing For Profit$^{\text{TM}}$ (McCosker 1993; Martyn 1995) and Holistic Management$^{\text{TM}}$ (Ward 1996). The grazing components of these schools are referred to as Time Control Grazing and Planned Grazing respectively. The schools provide a totally integrated farm management package which includes financial, farm, stock, drought and human resource planning, improved decision-making, and the monitoring of animal performance, animal nutrition, reproductive efficiency, biological recycling of nutrients, soil surface condition, biodiversity and the effectiveness of rainfall (Hacker 1993; Lodge 1995; Martyn 1995; Parsons 1995). It is difficult to separate a single aspect of these programs for scientific evaluation in isolation from other factors.

The promotion of cell grazing has generated considerable debate in scientific circles. A panel of researchers and grazing industry representatives who attended a forum in Queensland in 1992 to "critically examine" the basic principles of cell grazing, found them "to be either contradictory or not achievable" (Roberts 1993). Jones (1993) was "not enthusiastic about the value of commencing full-scale formal comparisons of TCG (Time Control Grazing) with other forms of grazing in Queensland".

At the time this project was commenced cell grazing was being rapidly adopted by many graziers on the Northern Tablelands of New South Wales (McCosker and Ward personal communication), and as such warranted enquiry, since no scientific evaluation of this form of grazing management had been undertaken in Australia. That cell grazing was being trialled and implemented by graziers on such a wide scale prior to scientific investigation was an unusual occurrence. New methods are traditionally evaluated on research stations before being implemented by graziers. This may be part of the reason for the initial dismissal of the concept by many scientists without adequate knowledge of the process.

2.2 Approach

This thesis is an analysis of grassland ecosystems at sites located on three properties on the Northern Tablelands of NSW. The availability of sites on commercial properties which were in the process of converting to a cell grazing regime provided an opportunity to monitor the components of ground cover in paired cell grazed/continuously grazed paddocks which had been single management units prior to subdivision. The choice of continuous grazing as the only comparison treatment was a reflection of economic constraints and did not imply that other forms of set-stocking were not worthy of consideration.

An ecological approach was taken to compare the effects of these two different forms of grazing management on ecosystem function in grasslands. The monitoring of field experiments within the pasture communities utilised a Before After Control Impact (BACI) design (Green 1979). Measurements were taken at the time of initiation of cell grazing at each site and repeated at various times over the period of study. The continuously grazed treatment represented the control and cell grazing the impact treatment.

The greatest advantage associated with field experiments under natural conditions over controlled laboratory experiments lies in the potential of such studies to detect temporal and spatial variation (Diamond 1986). The higher levels of natural variation experienced among sites may extend the generality of application of results over a wider range of environments. However, this natural variation may also increase the susceptibility to artefacts in sampling. Such effects can be minimised by comparing paired sites, selected on the basis of similarity prior to the imposition of the treatments (Peters 1991).

2.3 Aim of the study

The aim of the study was to compare the effects of cell grazing and continuous grazing on botanical composition and soil properties at three sites. Emphasis was placed on the perennial grass component of the pastures. Given the relatively short time frame for a grazing management experiment, it was proposed that the use of multiple criteria would give an improved understanding of the processes which operate to affect vegetation change and provide a more robust basis for the evaluation of the effects of the two grazing regimes on the three grasslands studied.

Cell grazing and continuous grazing represent the two extremes in a continuum of possibilities in the grazing process. High stock density grazing for short periods of time in combination with extended rest periods are features of the cell grazing regime, while constant low density stocking is associated with continuous grazing. To evaluate the comparative effects of each form of grazing on botanical composition the following questions were addressed experimentally.

1. What was the potential for change in botanical composition with respect to the recruitment of species from the seed bank?

2. What was the effect of the contrasting grazing regimes on the persistence of the dominant perennial grass components of the pastures at each of the sites? Specifically what was the effect on
   - i) plant basal cover
   - ii) species diversity
   - iii) pasture biomass?

3. Under the two grazing regimes, individual plants may experience different time intervals between defoliation events. What was the effect of different defoliation intervals on the productivity of the dominant perennial grasses?

4. Was there a difference in the effect of high stock densities imposed infrequently and continual low stock density on soil physical properties?