Rangel. J. 18(2) 1996, 327-50

THE NEED FOR A NEW APPROACH TO GRAZING MANAGEMENT - IS CELL GRAZING THE ANSWER?

J.M. Earl and C.E. Jones

Department of Botany, University of New England, Armidale, NSW 2351

Abstract

With any grazing method, the grazing pressure applied to an individual plant is a site, stock density and time dependent variable and the diet selection hierarchy of grazing animals is to the disadvantage of the most palatable and actively growing pasture components. The greater the differences in palatability and abundance among the components of a sward, and the lower the stock density, the greater the variation in the grazing pressure exerted. These effects are heightened when animals are set-stocked under adverse environmental conditions.

This paper reports the comparative effects of cell grazing and continuous grazing on pasture composition on three properties on the Northern Tablelands of New South Wales. The basal diameters, relative frequency and contribution to dry weight of the most desirable/palatable species at each site were found to remain constant or to increase under cell grazing, while declining significantly under continuous stocking. The converse was true for the least palatable components of the pasture, which declined significantly under cell grazing but changed little under continuous grazing. Percentage ground cover was significantly higher after two years of cell grazing than under continuous grazing. These changes in pasture composition may have long-term benefits with respect to erosion control, nutrient cycling, hydrological function and the stability of animal production at the cell grazed sites.

Introduction

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). Set-stocking, which constitutes more-or-less continuous grazing, represents the zero option for grazing management (Hutchinson 1993, Beattie 1994).

The term 'grazing', as it is used in most North American, south and east African and Australian agricultural publications, invariably refers to this practice of continuous grazing, that is, containing domestic livestock within defined partitions of land for the major part of the year. The term is normally applied in an absolute sense, land being classified as either grazed (e.g. pastoral areas), infrequently grazed (e.g. roadside reserves) or ungrazed (e.g. cemeteries and railway lines). Adjectives such as 'light', 'moderate', or 'heavy' may be included for clarification, or a 'stocking rate' may be provided.

Specific information relating to the timing, intensity or frequency of defoliation of the individual pasture components is difficult to find, as these factors cannot be controlled under continuous grazing. Even the 'stocking rate' provides little indication of the grazing pressure applied to the most palatable components of a mixed sward at the critical feed times of the year (Hormay 1970, Tainton and Walker 1993, Beattie 1994, Lodge 1995, Parsons 1995).

The accelerating deterioration in Australia's vegetation and soils over the last century (Williams and Chartres 1991, Archer *et al.* 1993, Lodge 1995, Nadolny 1995) closely resembles that recorded on the African and North American continents, although those continents had already been grazed by cloven-hoofed animals for thousands of years prior to white settlement. The common theme for all three continents was that European-style agriculture brought with it fenced land parcels which were continuously grazed by domestic livestock, a reduced fire frequency, the introduction of drought feeding practices and a rapid degeneration in vegetative cover, botanical composition, and soil structure and function (Herlocker *et al.* 1993, Tainton and Walker 1993, NRC 1994).

Selective grazing and grazing management

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).

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).

Efforts to restore grassland productivity through species introduction have been relatively unsuccessful in many areas and have often been accompanied by ecological impairment and a deterioration in ecosystem function (Williams and Chartres 1991, Rychnovská 1993, Tainton and Walker 1993, Nadolny 1995). The continual replacement of degraded pastures should not be utilised as a compensatory mechanism for inappropriate grazing practices. Unless the grazing method is changed, newly sown pastures will be subjected 'to the same abuse as the old' and will also deteriorate (Voisin 1961).

The complexities of controlling the grazing process however, are a little more difficult to come to terms with than the relatively simple, if short-lived, solution of pasture replacement. It is easy to blame the fertiliser or the grass cultivar for not living up to expectations, but to accept that pasture deterioration and land degradation are mismanagement issues requires a considerable change in attitude. A recent survey found that although 80% of livestock producers expected sown pastures to weaken or disappear within 10 years of sowing, the majority of them did not regard inappropriate grazing management as an important factor contributing to this decline (Mason and Kay 1995).

This may be partly attributable to uncertainty on the graziers' part as to what 'grazing management' can actually achieve. The term as it is used in the literature, usually refers to pro-active set stocking, involving periods of rest or deferment, and/or variations in grazing intensity, designed to coincide with the phenologies of selected species within the sward (Lodge 1995). Some grazing management strategies 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 effective grazing management strategies based on species phenology are available for application at the whole-farm level (Hacker 1993, Hutchinson 1993, Lodge 1995).

A 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. 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).

Cell grazing

Cell grazing is not a form of grazing management in the strict sense, as it does not have a precise species composition goal, although one objective is the improvement of the pasture resource (Lodge 1995). The use of 'cells' for grazing is only one aspect of 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).

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 other systems based on a single factor or reductionist approach (Parsons 1995). 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.

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".

Cell grazing packages are introduced to graziers by way of intensive training schools and these are currently marketed under two names in Australia; Time Control Grazing (McCosker 1993, Martyn 1995) and Planned Grazing (Ward 1996). 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) in reviewing cell grazing, stated that there was "little evidence to substantiate the major benefits which have been claimed for rapid rotational grazing, time controlled or otherwise, in terms of animals, pastures or soil". Similarly, Lodge (1995) concluded: "Application of any discriminatory management strategy that has no relationship to achieving a desirable species composition is likely to lead, at best to little improvement in botanical composition, or at worst, to undirected change".

The extent to which cell grazing is evaluated scientifically in Australia will be of interest. 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" and he has not been alone in that view. 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.

The concept of cell grazing was recently introduced to the Northern Tablelands of New South Wales and has been rapidly adopted in comparison with other grazing management strategies. Over 200 graziers in the Armidale region have now attended the 7-day 'Grazing For Profit' course run by Resource Consulting Services.

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 one to three days and rest periods from 40 to 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 livestock may move through the paddocks in any order.

Prior to the commencement of the research reported here, no published 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 using extremely 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 contravenes most of the basic principles of cell grazing as currently taught in Australia (Parsons 1995), they will not be dealt with here.

Aim of this study

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.

While ecosystem health is not a physical characteristic that can be easily measured, multiple criteria of vegetation assessment give an indication of the health of grazed land (NRC 1994).

The persistence of perennial grasses, basal diameters of indicator species, percentage groundcover and the components of cover, diversity of species and the contribution of these species to the biomass available for livestock consumption, are all parameters which can be used to assess the condition of pastures. The aim of this study was to compare cell grazing and continuous grazing at three sites on the Northern Tablelands of New South Wales, using these parameters to evaluate changes in the components of the extant vegetation.

Methods

Site descriptions

Three predominantly native pasture sites on which a cell had recently been established were selected on commercial properties situated within the Northern Tablelands region of New South Wales. A summary of site descriptions is presented in Table 1. At each site an area was separately fenced and set stocked with the same class of livestock as that rotating in the cell. The continuously grazed and cell grazed paddocks had in each instance previously belonged to a single larger paddock. Stocking rates varied with season but were always maintained at the same level in both the cell grazed and continuously grazed paddocks, with the exception of one site as detailed below.

Table 1. Site descriptions of the three properties at which the study was conducted.

	Strathroy	Lana	Green Hills
Lat/Long	30°23'S 151°16'E	30°37'S 151°15'E	30°15'S 151°48'E
Height ASL (m)	760	850	1380
Av. rainfall (mm)	730	780	870
Soil type	fine granite	coarse granite	basalt
Soil pH (H_20)	5.1	5.3	5.6
Bray P (mg/kg)	2.6	4	8

Strathroy

A 730 ha cell comprising 28 paddocks was established at Strathroy, 50 km west of Armidale, in September 1993. Baseline data were collected in April 1994 within a newly established 28 ha cell paddock and an adjacent 15 ha paddock, continuously stocked with sheep and cattle of the same type and class as was rotating in the cell. The average stocking rate from April 1994 to June 1996 was 6.2 DSE/ha in the both the cell grazed and continuously grazed paddocks.

Lana

Cell grazing on the site which was monitored at Lana, 50 km south-west of Armidale, was initiated in June 1993. This cell comprised 35 paddocks. Monitoring of the effects of cell grazing on *Aristida ramosa* and *Stipa scabra* began in June 1993 and the collection of additional data began in December 1994 in a 15 ha paddock within the cell. The adjacent 60 ha control paddock was set stocked in accordance with the type of grazing management which operated prior to the introduction of cell grazing on this property. The stocking rate from January 1994 to June 1996 averaged 6.0 and 3.1 DSE/ha in the cell grazed and continuously grazed paddocks respectively. At this site the grazier felt it was not possible to maintain the same stocking rate under continuous grazing as in the cell.

Green Hills

At Green Hills, 30 km east of Guyra, a 243 ha cell comprising 26 paddocks was established in September 1994. Baseline measurements were made at the same time as the fences were constructed. Monitoring was conducted on an 8.7 ha cell paddock and an adjacent continuously grazed paddock of 3.5 ha. As for Strathroy the control paddock was stocked with the same class and type of stock as the cell. The average stocking rate from September 1994 to June 1996 was 6.9 DSE/ha in both the cell grazed and continuously grazed paddocks.

Grazing pressure over time on each of the monitored paddocks is shown in Fig. 1. Rainfall for the experimental period at each site and long-term averages are shown in Fig. 2.

Vegetation monitoring

To evaluate the effects of cell grazing and continuous grazing on various aspects of the vegetation, three paired replicate measurement areas were established along a stratified topographical gradient at each site. The paired measurement areas were carefully chosen to ensure similarity in aspect, soil type and chemical and botanical composition. In each of these paired measurement areas permanent fixed point transects were established and four different non-destructive sampling methods were used to assess changes in the vegetation.
These were:

i) Basal diameter of the four dominant perennial grasses at each site
ii) Plant basal cover
iii) Relative frequency of species recorded in the pasture
iv) Percentage contribution of species to total dry weight

An outline of each sampling method follows.

Basal diameter

Four dominant perennial grass species were selected at each site as indicators of the response of individual species to grazing method. Indicator species were selected on the basis of the following criteria; they covered a range of desirability/palatability in terms of animal preference, the populations of each species in each of the paired replicate measurement areas were sufficiently high to be representative and the communities in which they occurred were similar in both treatments. The species monitored at Strathroy and Lana, in order of conventional rankings of desirability for animal production were *Eragrostis leptostachya*, *Sporobolus creber*, *Stipa scabra* and *Aristida ramosa*. The species at Green Hills, in order of desirability/palatability were *Phalaris aquatica*, *Bothriochloa macra*, *Sporobolus creber* and *Poa sieberiana*.

The line intercept method was used to determine changes in the basal diameter of the indicator species. A 2 m length of rod marked with 1 cm gradations was passed through the centres of three permanently marked rows of plants of each species in each of the six measurement areas at each site. The exact location and diameter of each individual plant lying along the transect was recorded to the nearest centimetre and the sum of the total distance was calculated. Only the rooted plant material that was present beneath the measurement rod was recorded and species other than the species of interest were ignored.

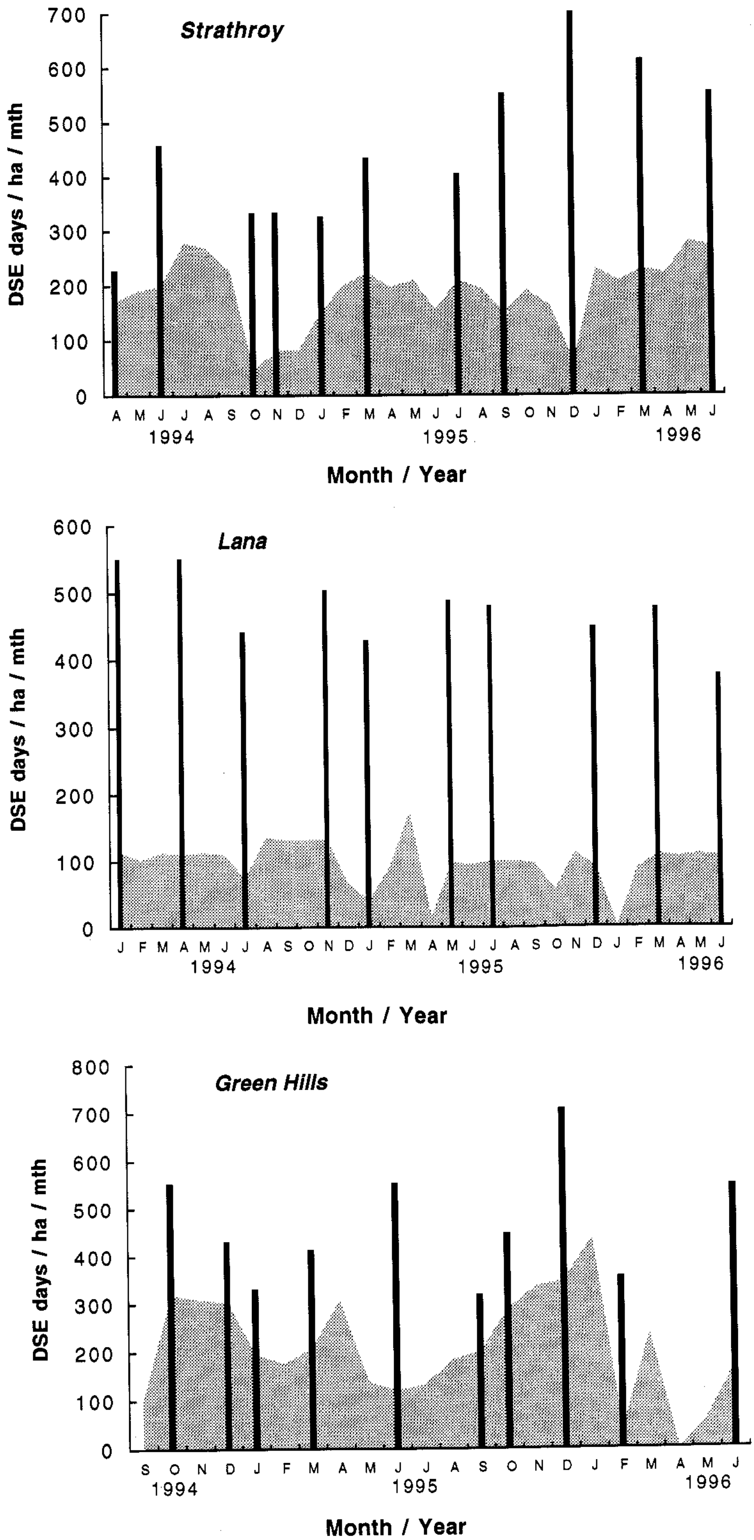

Fig. 1. Grazing pressure imposed on a monthly basis in cell grazed (solid bars) and continuously grazed (shaded area) paddocks from the initiation of monitoring at each site to the end of June 1996.

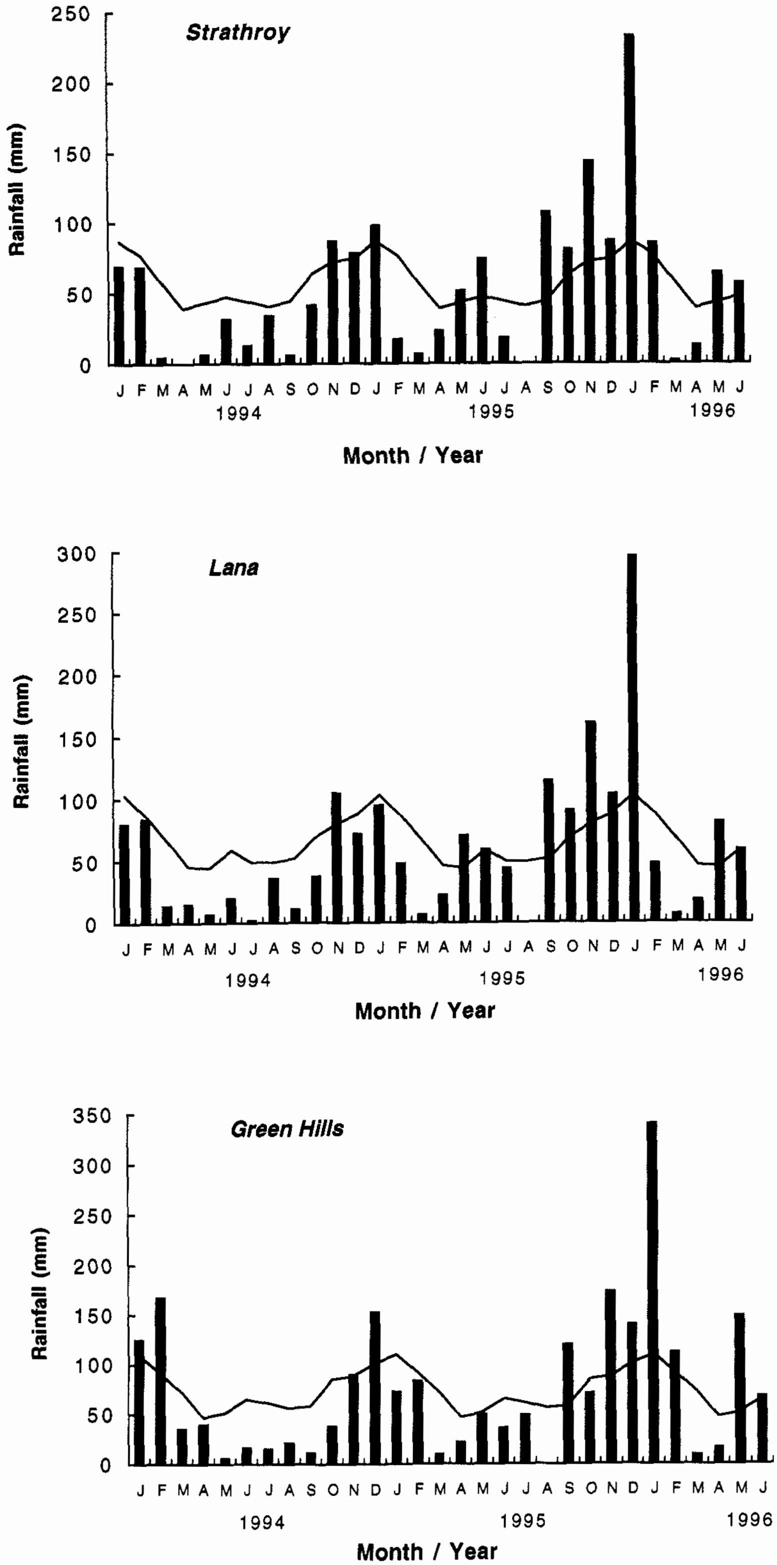

Fig. 2. Total monthly rainfall recorded at each site (solid bars) and long term average district monthly rainfall (line).

Percentage plant basal cover

The measurement of plant basal cover is considered to be a more accurate measure of pasture condition than the more commonly used measure of canopy cover (e.g. Munnich *et al.* 1991), since the amount of foliar cover present at any time will be affected by time since grazing, stage of growth of individual species and the timing and amount of rainfall.

A 100 point quadrat with pins located 10 cm apart in a square grid formation was used to estimate percentage plant basal cover. Within each treatment 1600 fixed points were measured at each site. A 'hit' was recorded when the point of the pin contacted a rooted portion of a living plant. The species of plant occurring under the pin was recorded, or if no plant base was present the presence of litter, bare ground, dung or stone under a point was recorded. Strikes occurring on dead tillers which persisted on a plant were classified as part of the litter fraction. All 100 point quadrat data were collected by the same operator to avoid observer differences.

Relative species frequency

The determination of relative species frequency by the presence/absence method enables the importance of different species within a pasture to be evaluated and gives an indication of the total number of species present and their distribution over a site (Walker 1970). Relative species frequency measures are a function of the size of the quadrat (Brummer *et al.* 1993). Baseline measurements were made using 20x20, 40x40 and 100x100 cm square quadrats and the variance estimate was calculated for each quadrat size. The lowest variance on each of the properties was recorded from the 40x40 cm quadrat and this size was used for all subsequent measurements.

The relative frequency of species which occurred in twenty 40x40 cm permanent quadrats placed within each of the three measurement areas in both the cell grazed and continuously grazed treatments was determined at regular intervals over the period of the study.

Species contribution to dry weight

Each spring and autumn, species contribution to pasture dry weight was measured at each site using the dry-weight-rank (Botanal) technique (Haydock and Shaw 1975). The contribution of species to biomass was measured in thirty 50x50 cm permanent quadrats within each treatment at each site. The quadrats were placed 2 m apart along three 25 m transects. Initial sampling of sixty 40x40 cm quadrats indicated no significant difference in the results obtained from the two data sets and subsequent measurements were taken from the former sample sites.

Botanical nomenclature

Botanical nomenclature follows Harden (1993).

Statistical analyses

The experiment took the form of a BACI design as described by Green (1979, 1993). The environmental 'impact' of cell grazing on several aspects of the vegetation was compared to a continuously grazed 'control'. The 'before' samples were collected prior to cell grazing being undertaken on each of the properties and the 'after' samples were collected at regular intervals after cell grazing had been initiated. In this type of environmental impact study, sampling is replicated in time (Stewart-Oaten *et al.* 1986, Green 1993). Repeated measurements of representative sub-samples of larger populations within the Control and Impact sites form the basis of the statistical analysis.

Analysis of the baseline data for each site showed no significant difference between the Control (continuously grazed) and Impact (cell grazed) treatment paddocks in any parameter measured at the commencement of the experiment. At each property the paired replicate measurement areas were situated sufficiently far from the fences to avoid fenceline effects but in close enough proximity to each other to be exposed to the same range of environmental/edaphic/climatic influences. During each sampling period, data for each of the parameters measured were collected from the paired Control and Impact measurement areas on the same day.

The basal diameter of indicator species, percentage plant basal cover, pasture dry weight and species contribution to dry weight data were analysed using the general linear model procedure (SAS 1990) for repeated measures analysis of variance. The raw data for basal diameter and plant basal cover measurements satisfied the assumptions for analysis of variance (ANOVA). Pasture biomass and species contribution to biomass were transformed (ln + 1) to achieve normality and homogeneity of variance. Presence/absence data were analysed using the CATMOD procedure in SAS (1990). This program is specifically designed for analysis of repeated measures of categorical data (Crowder and Hand 1990). Linear models were fitted to the data using weighted least squares.

The univariate repeated measures was the most appropriate test for analysis of the data, since it is valid for any number of times (Green 1993). The test of interest was the time by treatment interaction, since variation over time is expected in biological systems. Degrees of freedom were adjusted using the Huynh and Feldt (1976) estimator. Decomposition into pairwise contrasts of consecutive time periods were performed to identify significant time trends.

Results

Basal diameter

At all sites the basal diameters of the most desirable/palatable species were significantly higher ($P<0.05$) after two years of cell grazing than under continuous grazing. The basal diameter of *E. leptostachya* at Strathroy increased by 20% under cell grazing compared to a 65% reduction under continuous grazing (Fig. 3a). At Lana *E. leptostachya* decreased 7% under cell grazing whereas under continuous grazing the basal diameter was 65% less than that originally recorded (Fig. 4a). The most significant change ($P<0.05$) in basal diameter of *E. leptostachya* at both sites was recorded during the first 12 months of measurement. During this period the annual rainfall recorded at each property was only 60% of the long-term average (Fig. 2).

At Green Hills the basal diameter of the introduced species *P. aquatica* was significantly higher ($P<0.05$) after almost two years of cell grazing than under continuous grazing. The basal diameter of *P. aquatica* increased by 47% under cell grazing compared to a 70% decrease under continuous grazing (Fig. 5a). Again the most significant changes ($P<0.05$) occurred within the first twelve months of the treatments being imposed.

Sporobolus creber was the only indicator species of intermediate palatability to occur at all sites. At Strathroy and Lana grazing treatment had no significant effect on the basal diameter of this species. At Strathroy it declined under both treatments (Fig. 3b) and at Lana little relative change in basal diameter was recorded (Fig. 4b). However, at Green Hills the basal diameter of *S. creber* increased under both grazing regimes (Fig. 5c). The 100% increase under continuous grazing was significantly greater ($P<0.05$) than the 28% increase recorded under cell grazing.

The basal diameter of *S. scabra*, another species of intermediate palatability, was reduced to a greater extent under continuous than cell grazing during the initial 12 month period of the experiment at Strathroy, although final treatment differences were not significant (Fig. 3c).

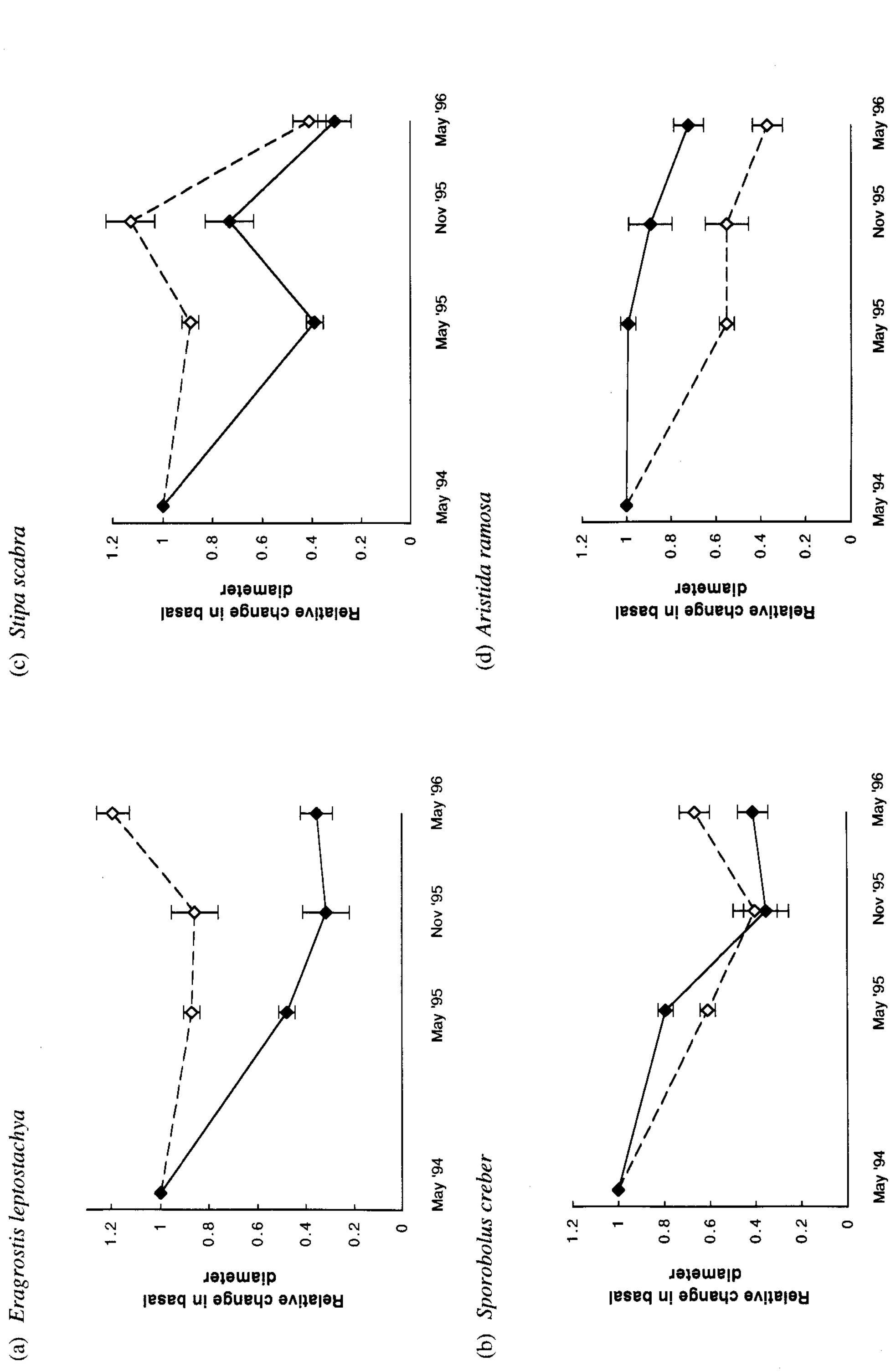

Fig. 3. Strathroy. Relative change in basal diameter in (a) *Eragrostis leptostachya* (b) *Sporobolus creber* (c) *Stipa scabra* and (d) *Aristida ramosa* under cell grazing (- - -) and continuous grazing (——). Error bars indicate one standard error.

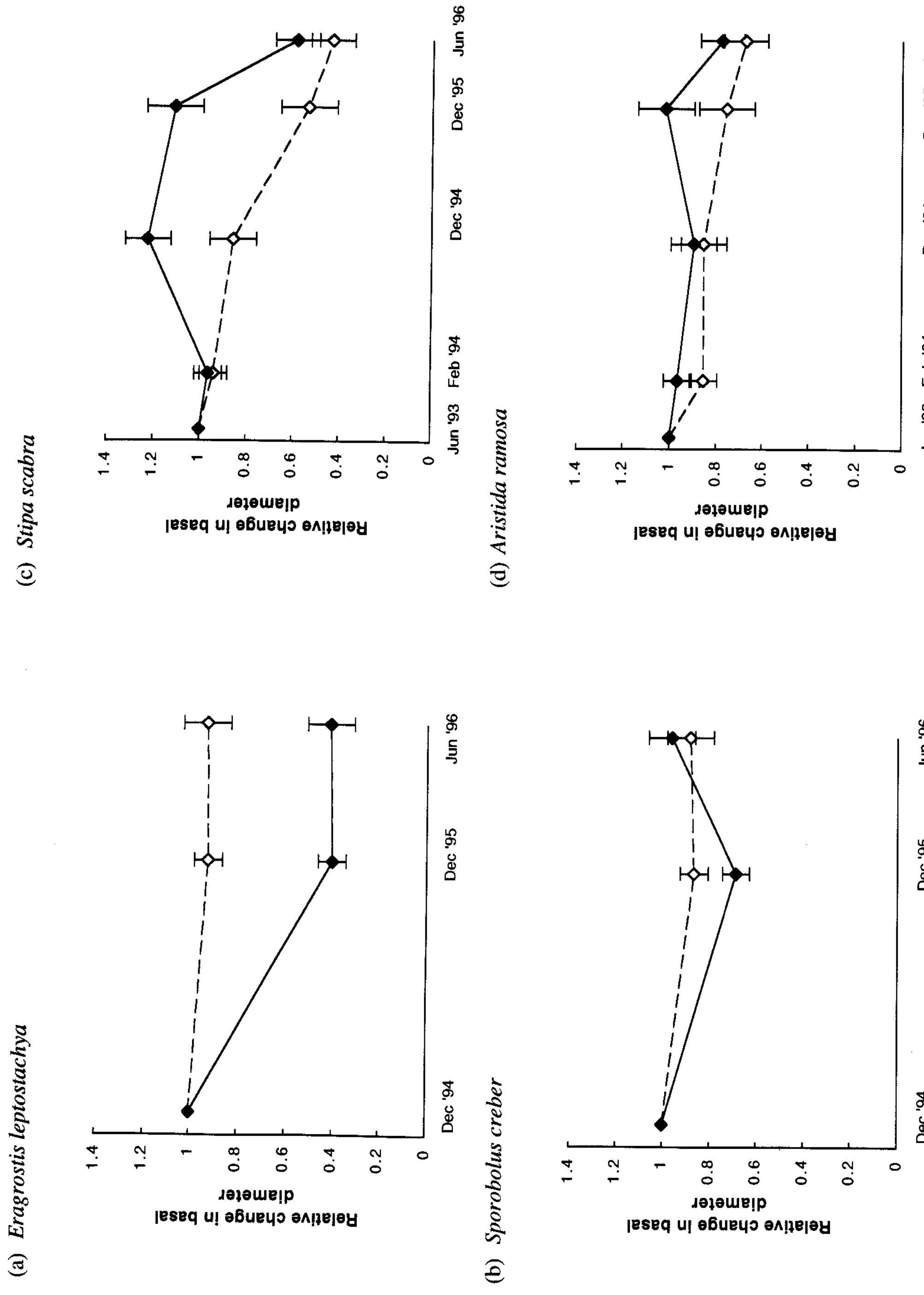

Fig. 4. Lana. Relative change in basal diameter in (a) *Eragrostis leptostachya* (b) *Sporobolus creber* (c) *Stipa scabra* and (d) *Aristida ramosa* under cell grazing (- - -) and continuous grazing (——). Error bars indicate one standard error.

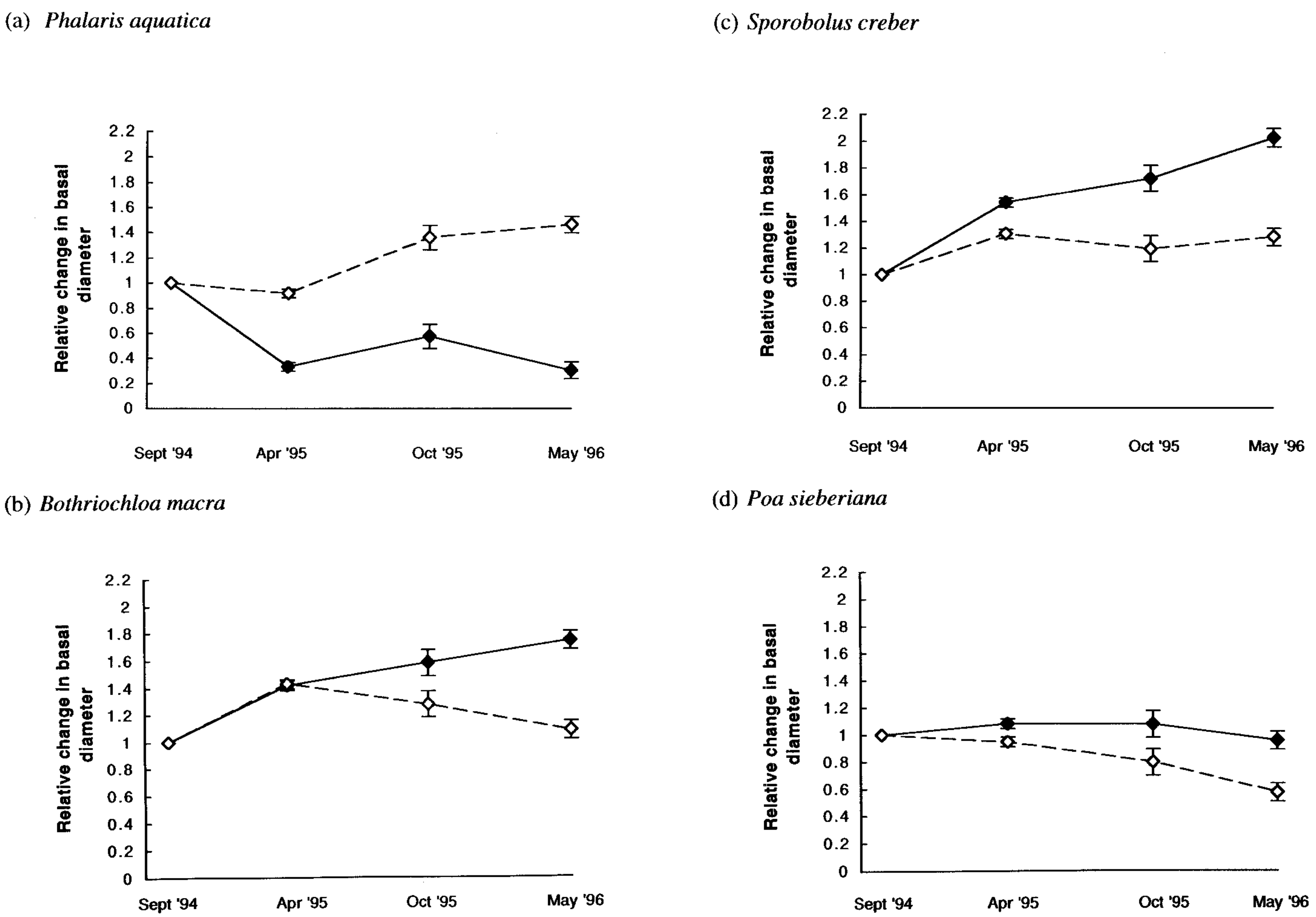

Fig. 5. Green Hills. Relative change in basal diameter in (a) *Phalaris aquatica* (b) *Bothriochloa macra* (c) *Sporobolus creber* and (d) *Poa seiberiana* under cell grazing (- - - -) and continuous grazing (——). Error bars indicate one standard error.

At Lana however, there was a significant (P<0.05) time by treatment interaction, the basal diameter of *S. scabra* increasing initially and then decreasing, under continuous grazing. By the final measurement, it had decreased by 56% under cell grazing compared to a 42% reduction under continuous grazing (Fig. 4c).

The basal diameter of *B. macra* was initially unaffected by grazing method at Green Hills. However, as the experiment proceeded the basal diameter of *B. macra* became significantly higher (P<0.05) under continuous grazing than under cell grazing (Fig. 5b).

The least desirable species in terms of animal preference at Strathroy and Lana was *A. ramosa*. During the first 12 months of monitoring at Strathroy the basal diameter of *A. ramosa* decreased significantly (P<0.05) under cell grazing, the reduction being 45% as compared to a 1% reduction under continuous grazing (Fig 3d). No significant changes were recorded subsequently under either grazing regime. At the Lana site grazing treatment had no effect on the basal diameter of *A. ramosa* at any measurement date (Fig. 4d).

At Green Hills *P. sieberiana* was the least palatable of the indicator species. A 43% reduction in the basal diameter of *P. sieberiana* was recorded under cell grazing; this was significantly different (P<0.05) from the 6% decrease recorded under continuous grazing (Fig. 5d).

Percentage plant basal cover

At all sites the level of plant basal cover was significantly higher (P<0.05) after two years of cell grazing than under continuous grazing (Table 2). At Strathroy under both grazing regimes, cover was significantly (P<0.05) reduced to 7 and 6% in the cell grazed and continuously grazed treatments respectively, during the drought period to May 1995. Following substantial rainfall in spring 1995 plant basal cover increased markedly in both treatments due to the germination and establishment of annual species. By the final measurement in June 1996, the perennial component had reasserted dominance and the 16.4% plant basal cover recorded in the cell grazed treatment was significantly higher (P<0.001) than the 9% cover in the continuously grazed paddock (Table 2).

Table 2. Percentage plant basal cover at each site

Site	Grazing method	Plant basal cover (%)			
		May 1994	**May 1995**	**Nov 1995**	**June 1996**
Strathroy	Cell	11.6	7.1	21.0*	16.4***
	Continuous	12.1	6.1	16.3	9.0
			Dec 1994	**Dec 1995**	**June 1996**
Lana	Cell		17.8	17.5**	16.7*
	Continuous		16.2	12.2	12.9
		Sept 1994	**Apr 1995**	**Oct 1995**	**May 1996**
Green Hills	Cell	19.0	21.6	23.7***	25.0**
	Continuous	19.8	19.5	18.0	19.7

Note: Asterisks indicate significant differences between the values for cell and continuous grazing at a given measurement time:- * (P<0.05), ** (P<0.01), *** (P<0.001)

Percentage plant basal cover remained relatively stable under cell grazing at Lana while slowly decreasing over time under continuous grazing (Table 2). The difference between the treatments was significant over time ($P<0.05$). At Green Hills plant basal cover increased significantly ($P<0.01$) over time under cell grazing while decreasing at a similar rate under continuous grazing (Table 2).

The contribution of the indicator species to percentage basal cover reflected changes similar to those recorded in their basal diameter measurements. The contributions to basal cover of the desirable species *E. leptostachya* at Strathroy and Lana and *P. aquatica* at Green Hills, were significantly greater ($P<0.05$) under cell grazing than under continuous grazing (Table 3).

Relative species frequency

At Strathroy the relative frequency of the highly palatable *E. leptostachya* increased significantly ($P<0.05$) under cell grazing while decreasing under continuous grazing. Conversely, the frequency of the relatively unpalatable *A. ramosa* declined significantly ($P<0.05$) under cell grazing and increased under continuous grazing (Table 3).

At both Lana and Green Hills no significant changes in the relative frequency of species were able to be detected using the presence/absence technique. At Green Hills, *P. aquatica* was recorded in 92% of the quadrats in both treatments at the first sampling, and over the experimental period this increased to 98% of quadrats in the cell grazed paddock and decreased to 80% of the quadrats in the continuously grazed paddock. Similar trends were observed for *T. repens* which increased to a greater extent under cell grazing. However, neither of these differences were statistically significant.

Percentage contribution to dry weight

The first Botanal measurement made at Strathroy in September 1994, indicated that *A. ramosa* and *S. creber* dominated both the cell grazed and continuously grazed paddocks in terms of dry-weight-rank (Table 3). *Eragrostis leptostachya* and *S. scabra* were sub-dominant. Over time, the relative contribution of *E. leptostachya* to dry weight in the cell grazed paddock increased relative to the contribution of other species, and it had become one of the dominant species by the final measurement (Table 3). Conversely, the relative contribution of *E. leptostachya* to dry weight declined significantly ($P<0.05$) in the continuously grazed paddock and the pasture remained dominated by *A. ramosa* and *S. creber* (Table 3).

The botanical measurements recorded in October 1995 at Strathroy were markedly different from those recorded on other dates. Until June of that year the effects of drought had been particularly severe, and percentage basal cover had been significantly reduced ($P<0.05$) (Table 2). Following substantial spring rainfall in 1995 many annual species germinated and dominated the vegetation. Annual species contributed 89.6% to the dry weight of the herbage in the cell grazed paddock and 97.2% in the continuously grazed paddock in October 1995. This measurement reflected the annual species' capacity for rapid growth rather than the absence of perennial grasses from the pasture. By May 1996 the perennial species were again dominant in terms of herbage mass.

Changes in pasture composition at Lana tended to be related more to season than to grazing method. The only significant change recorded in percentage contribution to dry weight was the significant increase ($P<0.05$) in the highly palatable winter active native species *Elymus scaber* under cell grazing (Table 3).

The baseline measurement of the vegetation biomass at Green Hills revealed that there was on average 27% *P. aquatica* and 50% *B. macra* at the site in 1994. After 20 months of contrasting grazing regimes the contribution of *P. aquatica* to total dry weight remained at a similar level

Table 3. Changes in the botanical composition of the main species components of pastures at three properties determined by different methods of monitoring.

Property	Species	Plant basal cover (%)								Relative species frequency (%)								Dry weight rank (%)									
		cell				continuous				cell				continuous				cell					continuous				
		# 5.94	5.95	11.95	6.96	5.94	5.95	11.95	6.96	5.94	5.95	11.95	6.96	5.94	5.95	11.95	6.96	9.94	11.94	4.95	11.95	6.96	9.94	11.94	4.95	10.95	6.96
Strathroy	*Eragrostis leptostachya* *	2.3	1.3	1.8	2.2	4.2	1.7	0.7	1.0	55	63	63	63	65	63	47	55	9.7	15.9	20.3	1.1	13.9	14.9	11.7	7	0	2.2
	Sporobolus creber *	2.0	1.5	0.6	1.3	1.5	1.5	0.9	1.0	72	70	43	50	52	52	22	33	24.3	24.1	23.3	0	18.9	18.9	25.8	38.1	0	19.2
	Stipa scabra *	1.1	0.8	2.4	1.0	1.8	0.8	1.4	0.7	40	53	57	45	35	42	50	52	7.2	2.6	6.2	0.8	14.4	2.9	3.8	2	0	11.9
	*Aristida ramosa**	1.5	0.7	0.5	0.3	2	0.8	1.1	0.7	27	28	23	20	23	42	35	35	21.1	20.8	26.2	0.9	7.3	35.6	32.1	37.6	1.5	20.7
	Microlaena stipoides	0.8	0.7	2.3	3.1	0.1	0.2	0.3	0.6	37	53	53	55	25	38	32	40	8.4	8.8	3.4	2.2	8.7	5.6	2.8	0	0.4	10.1
	Trifolium subterraneum	0.2	0.3	1.2	0.5	0.2	0.3	1.0	0	77	85	87	70	68	63	63	58	0	0	0	20.3	2.4	0	0	0	9.1	0.6
	Dry weight (kg/ha)																	3136	2326	874	2159	2525	3123	2662	1119	2028	3257
		#	12.94	12.95	6.96		12.94	12.95	6.96	12.93	12.94	12.95	6.96	12.93	12.94	12.95	6.96		12.94	6.95	12.95	6.96		12.94	6.95	12.95	6.96
Lana	*Eragrostis leptostachya* *		7.2	6.9	8.4		5.9	3.9	3.3	87	93	97	98	90	97	100	83		76.0	18.9	42.0	32.8		37.7	12.1	22.1	15.7
	Sporobolus creber *		2.5	1.3	1.5		3.4	2.5	3.3	37	73	80	85	50	67	77	93		7.6	20.8	12.0	31.9		23.6	44.5	27.1	60.8
	Stipa scabra *		0.6	0.5	0.5		0.8	0.5	0.4	27	17	23	22	37	33	33	20		3.5	3.7	3.3	1.5		1.0	3.3	0.7	1.8
	*Aristida ramosa**		1.3	0.5	0.5		1.0	0.3	0.6	10	10	7	3	17	17	20	13		1.2	0.8	0	0.9		1.6	2.0	1.7	1.9
	Microlaena stipoides		2.0	1.6	0.9		0.8	0.8	0.4	26	27	23	35	43	50	73	60		1.5	5.5	4.7	4.2		14.2	7.4	11.3	4.3
	Elymus scaber		0.4	0.8	0.5		0.3	0.3	0.1	60	43	63	77	83	43	97	65		0.3	12.9	2.7	11.2		0.0	4.3	1.1	1.8
	Dry weight (kg/ha)																		1513	1588	2372	2880		1290	1600	2062	2787
		# 9.94	4.95	10.95	5.96	9.94	4.95	10.95	5.96	9.94	4.95	10.95	5.96	9.94	4.95	10.95	5.96	9.94	11.94	3.95	11.95	5.96	9.94	11.94	4.95	11.95	5.96
Green Hills	*Phalaris aquatica* *	3.5	2.0	3.8	5.2	2.5	0.6	0.8	0.6	92	90	97	98	92	80	78	80	29.1	26.8	15.7	31.0	26.7	25.1	12.4	0.3	9.7	3.2
	Bothriochloa macra *	7.3	10.1	7.2	8.9	10.2	10.1	6	7.7	98	100	100	100	98	100	100	100	45.7	44.6	61.8	32.9	29.9	53.3	61.2	84.7	51.6	54.4
	Sporobolus creber *	2.1	2.4	1.6	2.2	4.1	5.6	4.3	5.4	28	33	33	42	60	68	65	75	3.6	3.9	3.9	0	1.8	6.2	7.7	6.2	0.7	7.4
	Poa seiberiana *	2.1	1.2	1.3	1.1	1.0	0.6	0.8	0.7	5	5	5	5	15	15	15	15	0.7	0.9	0.2	0	0	0	0	0.2	0.1	1.9
	Trifolium repens	0	0.3	0.9	1.3	0	0	0	0.1	28	52	72	93	15	42	53	72	0	0.9	2.0	3.9	10.6	0	0	0.5	3.1	3.3
	Dry weight (kg/ha)																	2742	2234	3443	3001	4102	2478	2162	2404	2493	4267

* Indicator species at each site

\# Date of collection

of 27% in the cell grazed paddock and had declined to 3% under continuous grazing ($P<0.05$) (Table 3). Conversely, the contribution of *B. macra* to dry weight decreased ($P<0.05$) from 46% to 30% under cell grazing, while under continuous grazing it remained the dominant species contributing 54% to the available biomass.

Trifolium repens was not recorded in either treatment at the initial measurement at Green Hills. In May 1996, *T. repens* contributed 11% to the pasture biomass under cell grazing, which was significantly ($P<0.05$) different to the 3% contribution in the continuously grazed paddock (Table 3). The contribution to dry weight of *S. creber* was significantly less ($P<0.05$) under cell grazing than under continuous grazing (Table 3).

Discussion

Vegetation change is a dynamic process, usually manifested through changes in the relative vigour and abundance of the component parts, and occasionally influenced by species extinctions or the ingress of species not previously recorded. All vegetation change is due to one or several causal mechanisms, although the exact nature of these may not be readily apparent.

Two possible causal mechanisms for undesirable change, which are inherent in continuous grazing are i) the ongoing process of selective grazing of the most palatable species or plant parts in the sward and ii) the lack of rest for the pasture ecosystem as a whole.

Selective grazing

While it is accepted that under continuous grazing individual plants are rotationally grazed (Hodgson 1966, Beattie 1994), the rate of rotational grazing of different species is likely to be distinctly different and in a mixed sward some species will be largely avoided. The degree of selective grazing exerted on individual species is dependent on a complex of site related interacting factors, including floristic diversity, grazing intensity, species of grazer, age of pasture, pasture height, moisture content, season of grazing and the growth cycle of each species (Hodgson 1966, Theron 1966, Roberts 1967, Hormay 1970, Wilson and Harrington 1984).

The selective grazing pressure placed on an individual plant will influence its survival more than the grazing pressure placed on the pasture as a whole. One of the most important determinants of whether or not an individual plant will be grazed at a particular time, will be the relative palatability of the other plant species on offer and their relative proportions in the pasture (Harper 1977, Gammon and Roberts 1978, Anderson and Roberts 1987). In multispecies communities selective removal of plants or plant parts alters competitive relationships, initiates population turnover and ultimately results in changes in species composition, as the growth of some species is stimulated while others are inhibited (Belsky 1986). A grazing method which enables the degree of selective grazing to be controlled, may enable significant improvements in the vigour of the more palatable pasture components to be achieved.

Pasture rest

It is generally accepted that a plant's ability to recover from a defoliation event, as indicated by the rate of regrowth, is dependent on the amount of carbohydrate reserve stored in the roots and crown (Davidson and Milthorpe 1965). The ability of plants to recover from defoliation increases as the defoliation interval is extended (Hill 1989). Lengthening the interval between defoliations also increases the yield of herbage, as frequency of defoliation and production are inversely related (Binnie and Chestnutt 1991).

Following severe defoliation initial regrowth is slow and root extension virtually stops (Davidson and Milthorpe 1965), roots become thinner and shorter and the rate of initiation of new roots is slowed (Davidson 1968, Harper 1977). Continuous or frequent defoliation results in root pruning, or grazing of the root system, the effects of which are cumulative (Voisin 1961). A reduction in root mass reduces the efficiency of plants to aquire nutrients and water (Davidson and Milthorpe 1965) and reduces the ability of plants to withstand periods of moisture stress or insect damage (Davidson 1968).

The degree to which the available root zone is occupied by plant roots and the diversity of plants with different rooting depths will influence the cycling and utilisation of nutrients, soil aeration, soil structure and levels of microbial activity (NRC 1994). The longer a grassland ecosystem can be left undisturbed to enable the component parts to engage in core functions such as primary and secondary production, energy flow, reproduction and nutrient cycling (Jefferies 1988), within the economic constraints imposed by the need for animal production, and the physiological requirements of grasses to be intermittently grazed (McNaughton 1979, 1983) the better. Herbivores are essential components of grassland ecosystems (Jefferies 1988) but it is difficult to mimic natural plant-herbivore interactions when animals are confined within one paddock for long periods.

Attempts to combine pasture rest with continuous grazing

The growing body of evidence that mixed species swards, whether sown or natural, require periodic rest from grazing to maintain or improve composition, function and stability, has prompted attempts to combine pasture rest with the practice of continuous grazing. For example, Robinson (1993) reported the effects of four seasonal closures (spring, summer, autumn and winter), or no closure, on continuously grazed phalaris and fescue pastures over the 7 year period 1975 to 1983, under two stocking rates.

The phalaris and fescue both declined in abundance over the experimental period, irrespective of the season of closure, and none of the 'rested' paddocks had a significantly different pasture composition to the continuously grazed control. The rate of deterioration was faster under the highest stocking rate (Robinson 1993).

An important point to arise from this and similar studies is that although three months is a long closure period by conventional standards, each of the rested paddocks was selectively grazed for the remaining 75% of the year - and that was far too long. Furthermore, graziers encounter practical difficulties when attempting to combine systems of deferred grazing with conventional stock management.

The combination of pasture rest and non-continuous grazing: an integrated approach

Data obtained from three sites on the Northern Tablelands of New South Wales, using a range of measurement methods, clearly demonstrated that continuous grazing predisposed vegetation to undesirable change and that cell grazing could prevent or reverse that process. The three cells monitored on Strathroy, Lana and Green Hills comprised 28, 35 and 26 paddocks respectively, so that each paddock in these cells was rested for more than 95% of the year. The grazing disturbances imposed during the other 5% of the time were intermittent and of short duration.

The effect of grazing method on the indicator species at each site was found to be dependent on both their relative palatability and relative abundance. In general, the protection afforded to the most palatable species under cell grazing resulted in improved vigour and abundance, and this effect was more pronounced if their initial representation in the sward had been relatively low.

Conversely, the grazing pressure applied to the least palatable species under cell grazing resulted in a decline in vigour and abundance, and this effect was more pronounced if their initial representation in the sward had been relatively high.

Eragrostis leptostachya is a high quality, leafy summer-active native perennial grass which has been observed to be one of the first species selected by livestock at Strathroy and Lana (Earl, unpublished). Under continuous grazing, the basal diameter of *E. leptostachya* declined by 65% on both of these properties in the low rainfall years of 1994 and 1995 (Figs 3a and 4a). The dry-weight-rank (Table 3) of this species was also significantly reduced by continuous grazing at both sites. Similarly, the basal diameter of the palatable introduced species, *P. aquatica*, declined 70% under continuous grazing at the Green Hills site (Fig. 5a).

An increase in the basal diameter of *E. leptostachya* under cell grazing was recorded at Strathroy under the more favourable rainfall conditions of 1996, whereas little change was recorded under cell grazing at Lana. This difference may have been due to the fact that *E. leptostachya* was a sub-dominant of the baseline vegetation at Strathroy, but a highly dominant species at Lana. As previously noted, the grazing pressure on palatable species increases as their representation in the sward declines (Hormay 1970, Tainton and Walker 1993) and releasing the selective grazing pressure may be like 'taking the weight off a spring' for some highly palatable species. The basal diameter of *P. aquatica* increased 47% over two years under cell grazing at the Green Hills site (Fig. 5a).

At the other end of the palatability spectrum, *A. ramosa* and *P. sieberiana* are generally avoided by livestock and tend to flourish under set-stocking in good rainfall years. Little change was recorded in the basal diameters of these species under continuous grazing in the low rainfall years of 1994 and 1995, whereas under cell grazing the basal diameter of *A. ramosa* declined by 45% at Strathroy (Fig. 3d) and the basal diameter of *P. sieberiana* declined by 43% at Green Hills (Fig. 5d).

Harradine and Whalley (1981) found that clipping *A. ramosa* resulted in a concentration of roots in the top 0-10 cm of the soil profile, and suggested that defoliation under field conditions could predispose plants of this normally deep-rooted species to 'premature death'. The problem is that *A. ramosa* is not defoliated when livestock are set-stocked at low stock densities.

The evidence presented here on the decline in *A. ramosa* under cell grazing suggests that the propensity of this species to dominate the vegetation on light-textured soils on the Northern Tablelands (Norton 1971) may be due to 'grazing avoidance' rather than 'grazing tolerance'. The grazing avoidance strategy can be counteracted to some extent by imposing high stock densities during the graze period and under these conditions *A. ramosa* was found to be relatively intolerant of grazing.

The extent to which grazing pressure can be successfully exerted on unpalatable species will depend on their percentage representation in the sward. Unpalatable species of low relative abundance will be difficult to control, particularly at low stock densities, as they are more easily avoided. This may explain the lesser effect of cell grazing on *A. ramosa* in the cell studied at Lana, where it represented only 1% of the sward on a dry weight basis (Table 3) compared with the greater reduction at Strathroy, where *A. ramosa* originally represented 21% of the sward on a dry weight basis (Table 3). In two other cells being monitored on Lana as part of a National Landcare Project, where initial *A. ramosa* populations were considerably higher, basal diameters declined by more than 20% under cell grazing and increased by over 50% under set stocking over a two year period (Jones and Earl, unpublished).

Bothriochloa macra, S. scabra and *S. creber* are generally regarded as being of intermediate palatability to livestock. They are neither highly desirable, nor highly undesirable, pasture components. As with previous examples, the grazing pressure exerted on these species was dependent on the relative palatability and abundance of the other pasture constituents. *Sporobolus creber* occurred at all three sites in this study, and the basal diameter data indicate that at Strathroy and Lana it was a neutral species in terms of palatability and grazing tolerance, responding to seasonal conditions but not to differences in grazing method. At Green Hills, *S. creber* appeared to be of lower acceptability to livestock in comparison with other pasture components such as *P. aquatica* and *T. repens*, and increased in basal diameter, relative frequency and dry weight rank under continuous grazing.

The effect of grazing method on percentage ground-cover

The measurements of percentage plant basal cover recorded in this study are in reasonable agreement with point analysis results obtained by other workers in environments which receive equivalent or lower rainfall (e.g. Edwards 1968, Tainton *et al.* 1978, Lodge and Whalley 1983, Naeth *et al.* 1991). Plant basal cover was very similar in both of the grazing treatments at each site when baseline measurements were determined (Table 2). By the final measurement, it was significantly higher in the cell grazed paddocks than in the continuously grazed paddocks at all three sites.

The level of plant basal cover has well-documented effects on levels of soil biological activity, energy flow, rates of water infiltration, and the losses of dissolved and particulate matter including nutrients and organic matter (Williams and Chartres 1991, Tainton and Walker 1993, Prosser and Hairsine 1995). As Harrington *et al.* (1984) succinctly stated: "Vegetation may change but soils degrade" - and once gone, are gone forever for all intents and purposes.

If we are to improve the effectiveness of the ecological processes which form the foundation of the pasture environment on which livestock, and therefore people, depend (Harrington *et al.* 1984, Lefroy *et al.* 1992, Martyn 1995), surely maintaining and improving ground-cover must be the first step?

It has been suggested that soil stability and watershed function should have greater weight than any other criteria in the assessment of long-term viability and that any management regime which predisposes a pasture system to soil loss is not sustainable (Williams and Chartres 1991, NRC 1994). The significant differences in ground-cover which developed over time between the cell grazed and continuously grazed treatments are therefore of paramount importance with respect to sustaining the resource base. A higher level of basal cover of perennial grasses will also foster biological recycling and restrict the nutrient losses attributable to leaching and erosion, facilitating closure of the nutrient cycle on grazed pastures (Williams and Chartres 1991, Lefroy *et al.* 1992).

Interactions between grazing method and seasonal conditions

The study detailed here commenced during a period of drought, the severity of which intensified until autumn 1995. It is possible that the effects of lack of control over the grazing process are more readily observed in times of below average rainfall. In good years, the importance of sustaining the soil and pasture resource may be more easily overlooked.

It has frequently been stated that the opportunities for manipulating botanical composition are greatest when seasonal conditions favour the desirable species (e.g. Kemp 1993, Garden and Dowling 1995). However, botanical change can be influenced by plant death as well as recruitment, and pasture species weakened by grazing pressure have a reduced chance of survival if climatic conditions are unfavourable. Voisin (1961) suggested that the advantages of a rest/rotational grazing system based on plant requirements were more likely to be observed in dry than in humid regions, or during periods of dry weather in humid and semi-humid regions.

The significant changes in basal diameter of both desirable and undesirable species recorded in the first 12 months of this study may have reflected a heightened response to adverse environmental conditions. That is, the protection from on-going selective grazing afforded by cell grazing may have been more advantageous than usual to the palatable species, and the defoliation of the grazing-intolerant, relatively unpalatable species under cell grazing may have been more disadvantageous than the same degree of defoliation in a high rainfall year. These results suggest that the opportunities for manipulating botanical composition are possibly greatest in dry years, provided that the grazing method used is acting on one or more of the causal mechanisms for vegetation change.

Attitude to change

Set-stocking is the most common grazing method used on the Northern Tablelands. It was somewhat disconcerting to observe that many graziers 'opened all the gates' in the recent drought, which would have facilitated an even greater degree of selective grazing. Any rigid system such as continuous grazing or calendar-based rotation, must at times move the soil-plant-animal interface beyond the tolerances or boundaries within which natural processes operate. The frequency and duration of those occasions will determine the extent of the damage inflicted on the natural capital base, on which we all ultimately depend.

For too long maximum animal production has been the sole focus in agricultural systems and the cost has been degradation of the landscape. Stability of production is a more important goal and is only achievable through improved understanding and controlled utilisation of natural resources. While appropriate grazing practices are important at all times, they are critical during periods of drought, when rapid and permanent damage can be inflicted on both pastures and soils.

We will never have perfect knowledge of ecological processes and sustainability will always be a moving target (Lefroy *et al.* 1992). It is rare for agricultural research to take an ecosystem perspective and all too often the individual components of pasture systems have been studied in isolation (Williams and Chartres 1991). It would also seem that our reluctance to relinquish established ideas on grazing management, even though proved ineffective in practice, has been a major deterrent to the development and use of better grazing methods (Hormay 1970).

Conclusion

Cell grazing is a flexible, adaptive, continually evolving process, in which many tools including the length of the graze and rest periods, are utilised to control plant-herbivore interactions to both protect the vegetation and soils resource and to satisfy animal requirements. It has received a great deal of attention, but little recognition, in scientific circles. The implementation of cell grazing by skilled managers on three properties on the Northern Tablelands of New South Wales, resulted in an improvement in the vegetation resource in comparison with continuous grazing and demonstrated that cell grazing can be a workable and credible management regime in this environment.

There is much evidence to indicate that grazing animals are one of the major contributors to land degradation when allowed to graze under the widely used practice of set-stocking. The same animals, when managed in a different way, may be one of the most valuable tools we have for the effective restoration of grassland communities.

Acknowledgements

The cooperation of the McKemey, Mitchell and Wright families in so generously providing the land and livestock to allow this project to proceed, as well as the time they invested in holding field days, maintaining appropriate stocking rates, and recording stock movements and rainfall, is sincerely appreciated. Thanks also to Helen Nicol for statistical advice, to Alison Bowman, Denys Garden, Lewis Kahn, David Kemp, Greg Lodge, Richard Silcock and Wal Whalley for valuable comments on the manuscript, and to Barbara Blenman for assistance with the typing. The financial assistance received from the Meat Research Corporation in funding this project is gratefully acknowledged.

References

Anderson, E.R. and Roberts, B.R. (1987). Palatability studies on plants in the south-western Orange Free State sandveld. *S. Afr. J. Bot.* **53:** 12-6.

Archer, K., Read, J. and Murray, G. (1993). Pasture decline - real or imagined? Proceedings of the 8th Annual Conference of the Grassland Society of NSW, Orange NSW pp. 8-13.

Beattie, A.S. (1994). Grazing for pasture in the high-rainfall, perennial pasture zone of Australia. *In:* Pasture management - Technology for the 21st Century (Eds D.R. Kemp and D.L. Michalk) pp. 62-90. CSIRO, Melbourne.

Belsky, A.J. (1986). Does herbivory benefit plants? A review of the evidence. *Am. Nat.* **127:** 870-92.

Binnie, R.C. and Chestnutt, D.M.B. (1991). Effect of regrowth interval on the productivity of swards defoliated by cutting and grazing. *Grass Forage Sci.* **46:** 343-50.

Brummer, J.E., Nichols, J.T., Engel, R.K. and Eskridge, K.M. (1993). Efficiency of different quadrat sizes and shapes for sampling standing crop. *J. Range Manage.* **47:** 84-9.

Clark, D.A. (1994). Grazing for pasture management in New Zealand. *In:* Pasture management - Technology for the 21st Century (Eds D.R. Kemp and D.L. Michalk) pp. 53-61. CSIRO, Melbourne.

Crowder, M.J. and Hand, D.J. (1990). 'Analysis of repeated measures'. Chapman and Hall, New York.

Davidson, J.L. (1968). Growth of grazed plants. Proceedings of the Australian Grasslands Conference, Perth W.A. pp. 125-37.

Davidson, J.L. and Milthorpe, F.L. (1965). Carbohydrate reserves in the regrowth of cocksfoot (*Dactylis glomerata*). *J. Brit. Grassl. Soc.* **20:** 15-8.

Doyle, P.T., Grimm, M. and Thompson, A.N. (1994). Grazing for pasture and sheep management in the annual pasture zone. *In*: Pasture management - Technology for the 21st Century (Eds D.R. Kemp and D.L. Michalk) pp. 71-90. CSIRO, Melbourne.

Edwards, P.J. (1968). The long-term effects of burning and mowing on the basal cover of two veld types in Natal. *S. Afr. J. Agric. Sci.* **11:** 131-40.

Friedel, M.H. (1994). How spatial and temporal scale affect the perception of change in rangelands. *Rangel. J.* **16:** 16-25.

Gammon, D.M. and Roberts, B.R. (1978). Patterns of defoliation during continuous and rotational grazing of the Matopos sandveld of Rhodesia. 1. Selectivity of grazing. *Rhod. J. Agric. Res.* **16:** 117-31.

Garden, D. and Dowling, P. (1995). Managing native grasses - background principles. Proceedings of the Community Grasses Project, Albury Workshop, pp. 39-43.

Green, R.H. (1979). 'Sampling design and statistical methods for environmental biologists'. Wiley, New York.

Green, R.H. (1993). Application of repeated measures designs in environmental impact and monitoring studies. *Aust. J. Ecol.* **18:** 81-98.

Grice, A.C. (1994). Grazing for pasture management in the rangelands. *In*: Pasture management – Technology for the 21st Century (Eds D.R. Kemp and D.L. Michalk) pp. 91-9. CSIRO, Melbourne.

Hacker, R. (1993). A brief evaluation of Time Control Grazing. Proceedings of the 8th Annual Conference of the Grassland Society of NSW, Orange NSW. pp. 82-9.

Harden, G.J. (1993). 'Flora of New South Wales'. New South Wales University Press, Sydney.

Harper, J.L. (1977). 'The population biology of plants'. Academic Press, London.

Harradine, A.R. and Whalley, R.D.B. (1981). A comparison of the root growth, root morphology and root response to defoliation of *Aristida ramosa* R.Br and *Danthonia linkii* Kunth. *Aust. J. Agric. Res.* **32:** 565-74.

Harrington, G.N., Wilson, A.D. and Young, M.D. (1984). Management of rangeland ecosystems. *In:* Management of Australia's rangelands (Eds G.N. Harrington, A.D. Wilson and M.D. Young) pp. 3-13. CSIRO, Melbourne.

Haydock, K.P. and Shaw, N.H. (1975). The comparative yield method for estimating dry matter yield of pasture. *Aust. J. Exp. Agric. Anim. Husb.* **15:** 663-70.

Herlocker, D.J., Dirschl, H.J. and Frame, G. (1993). Grasslands of east Africa. *In:* Ecosystems of the world 8B: Natural grasslands. (Ed. R.T. Coupland) pp. 221-64. Elsevier, Amsterdam.

Hill, M.J. (1989). The effect of differences in the intensity and frequency of defoliation on the growth of *Phalaris aquatica* L. and *Dactylis glomerata* L. *Aust. J. Agric. Res.* **40:** 333-43.

Hodgson, J. (1966). The frequency of defoliation of individual tillers in a set-stocked sward. *J. Brit. Grassl. Soc.* **21:** 258-63.

Hormay, A.L. (1970). Principles of rest-rotation grazing and multiple-use land management. US Department of Agriculture Forest Service, Training Text 4(2200). US Government Printing Office.

Hughes, P. (1993). Practical experience with grazing systems. Proceedings of a grazing systems seminar. Soil and Water Conservation Association of Australia, Rockhampton. pp. 20-5.

Hutchinson, K. (1993). Grazing systems overview - theory and practice of grazing management for sustaining productive temperate pastures. Proceedings of the 8th Annual Conference of the Grassland Society of NSW, Orange NSW. pp. 90-7.

Huynh, H. and Feldt, L.S. (1976). Estimation of the Box correction for degrees of freedom for sample data in randomized block and split-plot designs. *J. Educ. Stat.* **1:** 69-82.

Jefferies, R.L. (1988). Vegetational mosaics, plant-animal interactions and resources for plant growth. *In*: Plant evolutionary biology (Eds L.D. Gottlieb and S.K. Jain) pp. 341-69. Chapman and Hall, London.

Jones, R.M. (1993). A review of time-controlled grazing. Proceedings of a grazing systems seminar. Soil and Water Conservation Association of Australia, Rockhampton. pp. 47-55.

Kemp, D. (1993). Managing pastures by grazing. Proceedings of the 8th Annual Conference of the Grassland Society of NSW, Orange NSW. pp. 32-8.

Kemp, D., Michalk, D. and Dowling, P. (1995). Management of pasture composition. Proceedings of the 5th Annual Conference of the Tasmanian Branch of the Grassland Society of Victoria, Launceston Tasmania. pp. 50-7.

Lefroy, E.C. (1995). Farming as if we belong: arguments for an ecocentric and ignorance-based approach to agriculture. Proceedings of the Inaugural Ecological Economics Conference, Coffs Harbour NSW. pp. 507-12.

Lefroy, E.C., Salerian, J. and Hobbs, R.J. (1992). Integrating economic and ecological considerations: a theoretical framework. *In*: Reintegrating fragmented landscapes: towards sustainable production and nature conservation (Eds R.T. Hobbs and D.J. Saunders) pp. 209-44. Springer-Verlag, New York.

Lodge, G. (1995). The role of grazing management in sustaining the pasture community. Proceedings of the 10th Annual Conference of the Grassland Society of NSW, Armidale NSW. pp. 34-42.

Lodge, G.M. and Whalley, R.D.B. (1983). Seasonal variations in the herbage mass, crude protein and in-vitro digestibility of native perennial grasses on the North-West Slopes of New South Wales. *Aust. Rangel. J.* **5:** 20-7.

Lodge, G.M. and Whalley, R.D.B. (1985). The manipulation of species composition of natural pastures by grazing management on the Northern Slopes of New South Wales. *Aust. Rangel. J.* **7:** 6-16.

Lodge, G.M. and Whalley, R.D.B. (1989). Native and natural pastures on the Northern Slopes and Tablelands of New South Wales: a review and annotated bibliography. NSW Agriculture and Fisheries Technical Bulletin 35.

Martyn, S.R. (1995). Permanent pasture - fact or fiction: an economic perspective. Proceedings of the 5th Annual Conference of the Tasmanian Branch of the Grassland Society of Victoria , Launceston Tasmania. pp. 14-20.

Mason, W. and Kay, G. (1995). The temperate pasture sustainability key program. Proceedings of the Community Grasses Project, Albury Workshop. pp. 53-8.

McCosker, T. (1993). The principles of time control grazing. The 3rd National Beef Improvement Association Conference, Armidale, NSW. pp. 87-95.

McNaughton, S.J. (1979). Grazing as an optimisation process: grass-ungulate relationships in the Serengeti. *Am. Nat.* **113:** 691-703.

McNaughton, S.J. (1983). Compensatory plant growth as a response to herbivory. *Oikos* **40:** 329-36.

Michalk, D.L. and Kemp, D.R. (1994). Pasture management, sustainability and ecosystem theory: where to from here? *In* : Pasture management - Technology for the 21st century (Eds D.R. Kemp and D.L. Michalk) pp. 155-169. CSIRO, Melbourne.

Moore, R.M. (1970). Australian grasslands. *In*: Australian Grasslands (Ed. R.M. Moore) pp. 87-100. ANU Press, Canberra.

Moore, R.M. (1993). Grasslands of Australia. *In*: Ecosystems of the World 8B: Natural grasslands (Ed. R.T. Coupland) pp. 315-60. Elsevier, Amsterdam.

Munnich, D.J., Simpson, P.C. and Nicol. H.I. (1991). A survey of native grasses in the Goulburn district and factors influencing their abundance. *Rangel. J.* **13:** 118-29.

Nadolny, C. (1995). Towards integrating farming and nature conservation in Australia. Proceedings of the Inaugural Ecological Economics Conference, Coffs Harbour, NSW. pp. 111-7.

Naeth, M.A., Bailey, A.W., Pluth, D.J., Chanasyk, D.S. and Hardin, R.T. (1991). Grazing impacts on litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta. *J. Range. Manage.* **44:** 7-12.

Norton, B.E. (1971). The grasses of the New England Region of New South Wales, with particular reference to 'natural' grasslands. PhD Thesis, University of New England.

NRC (1994). 'Rangeland health. New methods to classify, inventory and monitor rangelands'. National Academy Press, Washington D.C.

Parsons, S.D. (1995). Putting profit into grazing. Resource Consulting Services, Yeppoon, Qld.

Prosser, I.P. and Hairsine, P.B. (1995). The role of perennial grasses in reducing erosion and nutrient loss. Proceedings of the Community Grasses Project, Albury Workshop. pp. 8-15.

Roberts, B.R. (1967). Pasture quality and its relation to utilization. *Proc. Grass. Soc. S. Afr.* **2:** 157-62.

Roberts, B. (1993). Grazing management in property management planning: concensus and conflict on recommendations. Proceedings of a Grazing Systems Seminar. Soil and Water Conservation Association of Australia, Rockhampton. pp. 26-33.

Robinson, G.G. (1993). Grazing management - not just a rest for your pastures. Proceedings of the 8th Annual Conference of the Grassland Society of NSW, Orange, NSW. pp. 109-11.

Rychnovská, M. (1993). Temperate semi-natural grasslands of Eurasia. *In*: Ecosystems of the World 8B: Natural Grasslands (Ed. R.T. Coupland) pp. 125-166. Elsevier, Amsterdam.

SAS Institute Inc., (1989). SAS/STAT User's guide, Version 6. SAS Institute Inc., Cary, NC.

Stewart-Oaten, A., Murdoch, W.W. and Parker, K.R. (1986). Environmental impact assessment: 'pseudoreplication' in time? *Ecology* **67:** 929-40.

Suijdendorp, H. (1969). Deferred grazing improves soft spinifex association. *J. Agric, West. Aust.* **10** (Fourth Series): 87-8.

Tainton, N.M., Foran, B.D. and Booysen, P. de V. (1978). The veld condition score: an evaluation in situations of known past management. *Proc. Grassl. Soc. S. Afr.* **13:** 35-40.

Tainton, N.M. and Walker, B.H. (1993). Grasslands of southern Africa. *In*: Ecosystems of the world 8B: Natural Grasslands (Ed. R.T. Coupland) pp. 265-90. Elsevier, Amsterdam.

Theron, E.P. (1966) A study of certain chemical and physical properties of ten indigenous grasses and their relationship to animal preference. PhD (Agric.) Thesis University of Natal. Cited by Gammon, D.M. and Roberts, B.R. (1978). Patterns of defoliation during continuous and rotational grazing of the Matopos sandveld of Rhodesia. 1. Selectivity of grazing. *Rhod. J. Agric. Res.* **16:** 117-31.

Vizard, A.L and Foot, J.Z (1994). Animal and pasture maintenance, a partnership. *In* : Pasture management - Technology for the 21st Century (Eds D.R. Kemp and D.L. Michalk) pp. 100-13. CSIRO, Melbourne.

Voisin, A. (1961). 'Grass productivity'. Crosby Lockwood and Son Ltd, London.

Walker, B.H. (1970). An evaluation of eight methods of botanical analysis on grasslands in Rhodesia. *J. Appl. Ecol.* **7:** 403-16.

Ward, B. (1996). Moree District Business Centre Newsletter, August 1996.

Williams, J. and Chartres, C.J. (1991). Sustaining productive pastures in the tropics: 1. Managing the soil resource. *Trop. Grassl.* **25:** 73-84.

Wilson, A.D., and Harrington, G.N. (1984). Grazing ecology and animal production. *In:* Management of Australia's rangelands (Eds G.N. Harrington, A.D. Wilson and M.D. Young) pp. 63-77. CSIRO, Melbourne.

Manuscript received 15 May 1996, accepted 3 October 1996