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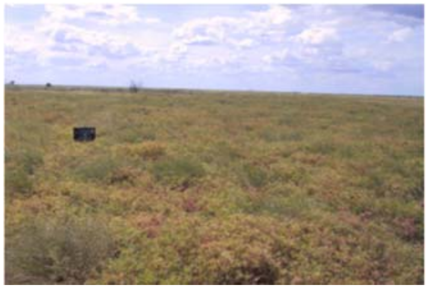
Newcastle Waters Cell Grazing Trial

Comparing cell grazing systems with traditional practice in the north-western Barkly region

Technical Bulletin No. 357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Newcastle Waters Cell Grazing Trial

Comparing cell grazing systems with traditional practice in the north-western Barkly region

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Summary

This study reports the results of a three-year cell-grazing trial conducted at Newcastle Waters Station in the Barkly Tableland Region of the Northern Territory (NT). The overall objective of the study was to determine whether cell grazing was a practical and economically viable method of beef cattle production in the region compared with traditional continuous stocking. Managers expected cell grazing to result in more even pasture utilisation across the paddock, an increase in ground cover and perennial grass abundance around water points, and an improvement in the temperament of stud weaners (through more intensive handling and training).

Between 2003 and 2005 grazing intensity, pasture yield, ground cover, pasture species composition and animal production (live-weight gain (LWG) of weaners) were compared between two cell-grazing paddocks (with four and 10 internal paddocks) and a control paddock that employed a traditional, continuous grazing regime.

Cells generally had lighter defoliation in May, after wet season spelling, but heavier defoliation in November. Defoliation was more spatially uniform at the paddock scale in smaller better-watered cell paddocks compared with the continuously-grazed paddock. However, at the species level, preferred species were still more heavily grazed than less preferred species in both grazing systems. Vegetation trends during the trial were similar in the two grazing systems. Changes in pasture yield, ground cover and species frequency through time reflected rainfall trends and occurred similarly in both the cell and control paddocks, until a fire in the control paddock in late 2004 resulted in lower yields in that paddock the following May. Pasture yield and perennial grass species frequency improved near an old water point in the cell paddocks, although there was also some decline in pasture composition near a new water point in the cell paddocks.

Cell-grazing animals had a 10 to 20 kg lower LWG per animal per year than continuously-grazing animals. Managers attributed this to a high, uniform pasture utilisation in cell-grazing paddocks where cattle could not selectively graze only higher-quality species. Faecal near-infrared spectroscopy (NIRS) sampling was unable to distinguish differences in diet quality between the two systems. Furthermore, differences in supplementation regimes between treatments may have contributed to treatment differences in LWG. Despite a lower LWG/head in the cell group, their LWG per area was higher in the first year due to a higher stocking rate. However, in the second year, a combination of lower stocking rates and lower LWG/head in the cell group led to a lower LWG/area compared with the continuously-grazed group.

Benefits of the cell system included the electric fences, which kept initial infrastructure costs low. Mustering costs were lower per muster and there was a noticeable improvement in animal temperament (a herd of 1000 animals could be moved and yarded on foot by one person). However, labour and operating costs were up to 8 and 10 times higher per animal equivalent and per area, respectively in the cell.

When assessing whether cell systems will pay, producers need to take account of the following:

- Infrastructure setup costs.
- Potential carrying capacity with the new system (compared with the carrying capacity of current or alternative systems).
- Decreased LWG per head in cells.
- Higher ongoing operating costs of cells.
- Higher skill level and ongoing management inputs required to run cells.
- Potentially higher maintenance costs of cell infrastructure.

In conclusion, cell grazing was considered by the managers to be a practical and economically viable production system at Newcastle Waters Station. The more intensive infrastructure and management of the cells facilitated better spatial utilisation of pasture whilst maintaining current land condition. However, it is recommended that when planning more intensive development and deciding whether or not to implement intensive rotational grazing consideration should be given to the most cost-effective scale of development and the higher operating costs of intensive grazing systems. To maximise the success of cell grazing, the

managers at Newcastle Waters Station recommended researching cell design and the choice of materials, being adaptable to new challenges, and stressed the importance of training staff to use the system.

1 Introduction

1.1 Background

Paddocks in northern Australia are often large and poorly watered (e.g. Cowley et al. 2013a). Because cattle usually need to return daily to water to drink, this limits their grazing range away from water points. This can lead to heavy grazing and a decline in land condition around water points, with areas farther from water being relatively ungrazed. An acknowledgement of sub-optimal use of pastures at the paddock-scale has been driving an effort to intensify northern Australian beef cattle operations (Hunt et al. 2007; Petty et al. 2013). One of the most effective and widely implemented ways to increase production is through the development of infrastructure, particularly the subdivision of large paddocks into more manageable areas (Bortolussi et al. 2005; Bubb 2006; Hunt et al. 2007; Petty et al. 2013).

Continuous grazing is the dominant practice on extensive beef cattle properties of northern Australia. However, improving existing water and fencing infrastructure can facilitate the use of alternative grazing systems, such as rotational or cell grazing. These alternative grazing strategies typically involve the development of a number of paddocks (e.g. three to 40) through the installation of internal fencing. Cattle are rotated around the paddocks, with the frequency of movements varying between every few days to being calendar based (McCosker 2000). However in the wet season the rotations can sometimes be impractical due to access problems and cells are often disused during this time.

Cell grazing requires a planned approach to grazing, with active monitoring and managing of pastures. It incorporates two principles of grazing management. The first matches stocking rates to available forage to follow seasonal variability. The second spells pastures (provides rest) from grazing to promote recovery and increase productivity (Hunt et al. 2014; O'Reagain et al. 2014). Cell grazing proponents further advocate short grazing periods to improve diet quality and high stock densities to improve spatial distribution in cell-grazing systems (McCosker 2000), although there is little research that supports these claims. Reviews of studies of cell-grazing systems in rangelands have found equal or lower plant and animal production in cells compared with continuous grazing (Gammon 1978; Holechek et al. 1999; Briske et al. 2008; Hunt et al. 2013; Hall et al. 2014). Therefore, in general, there appears to be no intrinsic productivity or land condition advantage for cell-grazing systems in rangelands. Differences in animal or plant production between a rotational and continuous-grazing system typically reflect differences in average stocking rates between treatments (Heitschmidt et al. 1987; Heitschmidt et al. 1990; O'Reagain et al. 2009; Hunt et al. 2013), although wet season spelling can also improve pasture condition (Ash et al. 2011; Hunt et al. 2014; Scanlan et al. 2014).

Despite the research results suggesting few if any benefits, there is still a lot of enthusiasm for cell grazing amongst extensive rangeland producers in northern Australia who employ cell grazing with the aim of improving cattle behaviour, land condition, productivity and profitability (McCosker 2000). This study reports the results of a three-year cell-grazing trial conducted at Newcastle Waters Station in the Barkly region of the NT. Although cell grazing had been investigated in southern Queensland, southern Australia and elsewhere around the world, it was unknown whether such a system would be economically viable in extensive grasslands in northern Australia. Animal production (LWG) and pasture composition were compared between two cell-grazing paddocks with differing internal paddock numbers and sizes, and a control paddock under a traditional, continuous- grazing regime.

1.2 Project objective

Cell grazing is a relatively new phenomenon in the NT and as such, there is considerable interest regarding its feasibility in these landscapes. The objective of this study was to compare cell grazing with traditional continuously-stocked beef cattle systems used in the region to determine if it was a practical and economically viable alternative.

1.3 Producers' expectations

Managers at Newcastle Waters Station implemented the cell-grazing system in 2001 with a view to achieving three clear outcomes. They expected a higher average utilisation of country through more even utilisation across the landscape, an increase in ground cover and perennial grass abundance around water points, and an improvement in stud weaner temperament through more intensive handling and training.

Producers also expected these outcomes to result in indirect improvements in animal production and profitability, by raising quieter animals that are easier to muster and handle in the yards (less labour intensive) with better temperament that fosters greater LWGs and better calving/mothering outcomes.

2 Methods

2.1 Site description

2.1.1 Location

The cell-grazing trial was conducted at Newcastle Waters Station, approximately 10 km north of Elliott in the northern Barkly Region of the NT (17.391° S, 133.502° E; Figure 1).

2.1.2 Land systems

The trial area consisted predominantly of the Creswell land system defined by very gently undulating terrain and heavy grey pedocal soils (Christian et al. 1951). Dominant grasses were *Astrebla pectinata* (Barley Mitchell), *Eulalia aurea* (Silky Browntop) and *Iseilema* spp. (Flinders grasses) (Figure 2). A proportion of each paddock included the red soil land systems Beetaloo (lateritic red earths) or Elliot (deep sands), with woodland and scrub. Canopy cover was generally low in all trial paddocks, although higher woody cover occurred on the red soils (Table 1).

2.1.3 Climate and rainfall

Mean and median annual rainfall (from July to June) at Newcastle Waters Station (Bureau of Meteorology (BOM) Station 15086) is 500 mm and 476 mm, respectively (BOM 2015a). Approximately 90% of the rainfall occurs in the summer wet season months between November and April. Mean daily evaporation at Elliott (BOM station 15131, approximately 10 km to the south) ranges between 5.6 mm in June and 9.4 mm in both October and November. Mean ambient temperatures at Elliott range between 11.2 and 28.3 °C in July (mid-winter) and between 24.1 and 37.5 °C in January (mid-summer) (BOM 2015b). Rainfall recorded at Newcastle Waters Station during the trial period was well above average in the first two seasons (2002-3 and 2003-4), and below average in the third and final season (2004-5) (Figure 3).

2.2 Experimental design

Runaway paddock, approximately 5 km from the cell-grazing paddock, was used as the control where approximately 250 cows and 10 bulls were run under a traditional system of continuous grazing. Two adjacent paddocks or cells, with four (Brownies) and ten (Langlands) internal paddocks were used in combination for cell grazing (Figure 1, Table 1). These paddocks were adjacent to an old stock route bore (Churchill Bore), which had a history of heavy pasture utilisation and was dominated by annual grasses.

Decisions about where to place cattle and when to move them in the cells were determined by ease of movement through the cell centre, timing of mustering (to ensure animals were close to handling facilities when they were required for processing) and assessments of available feed. Available feed was not a major concern given there was plenty of feed when the cells were in use. Management aimed to ensure that no more than one third of the perennial pasture yield was eaten. The smaller Langlands cells were mostly stocked with stud weaner bulls and heifers, whereas older cattle were used in the larger Brownies cells.

2.3 Paddock attributes

Table 1 lists a range of attributes relating to each of the trial paddocks. Runaway paddock (continuous grazing) was substantially larger than either of the cell paddocks. Runaway paddock and Langlands paddock each contained two water points, whereas Brownies paddock contained one water point. The smaller sizes of the cells in Brownies and Langlands paddocks meant that they were both close to being fully watered (within 3 km of water). All water points were installed more than 10 years before the start of the trial, with the exception of the central water point in Brownies paddock, which was installed in 2001. Total fence distance was similar in all paddocks, because the much larger size of the control paddock was offset by the many internal fences in the cell-grazing paddocks. The Langlands cell was more intensively developed than the Brownies cell (Table 1) with more water points per area and a greater distance of fence lines per watered area. The lower carrying capacity per area (within 3 km watered area) of the Brownies cell system and the control paddock was due to the higher proportion of red soils. All cells in Langlands were spelled during the wet season due to the low percentage of red soils for cattle to retreat to during wet periods.

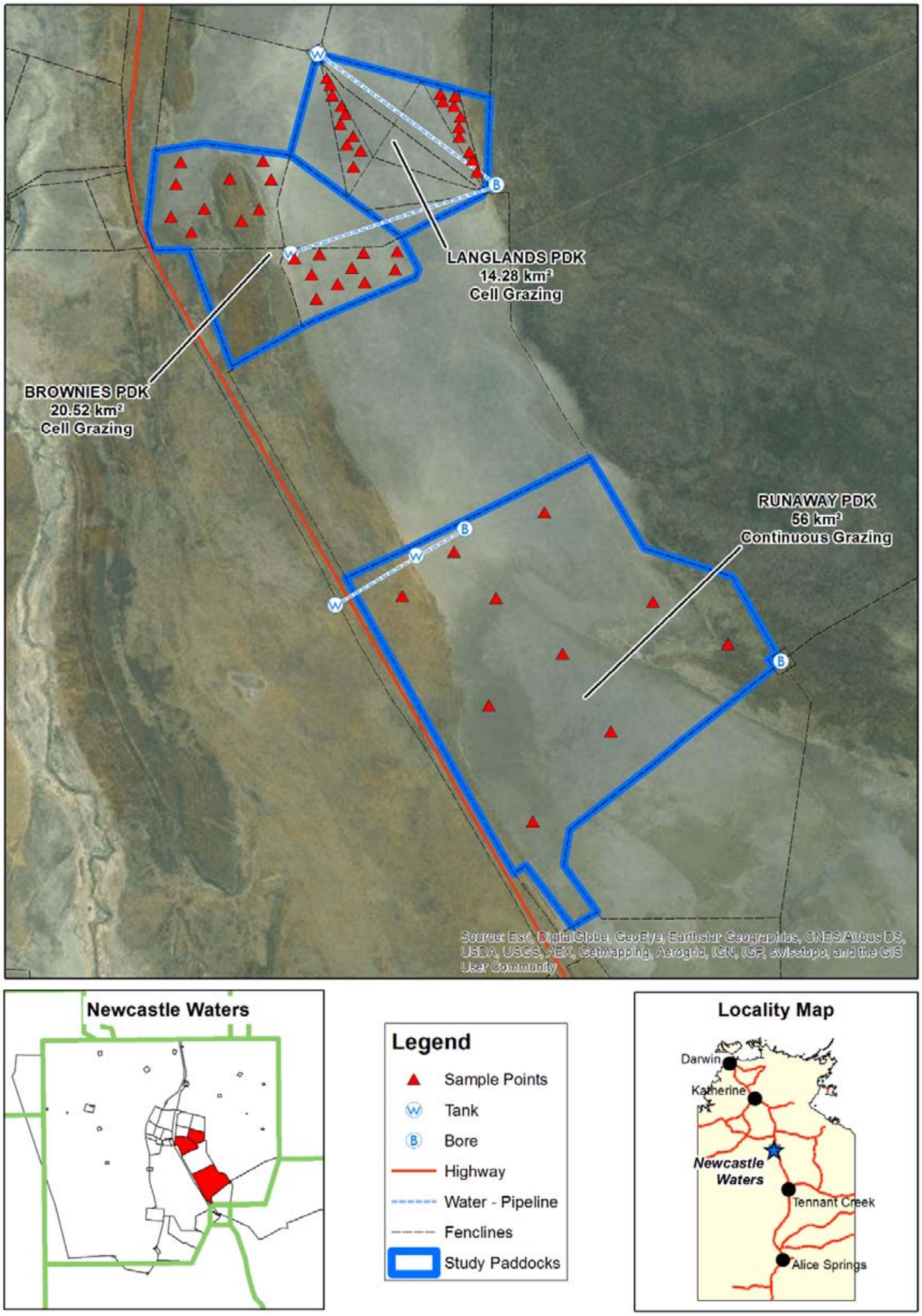

Figure 1. The location of Newcastle Waters Station (bottom right) and the trial paddocks on Newcastle Waters (bottom left), and infrastructure and the location of monitoring points used for pasture sampling (top). The darker more grainy land types along the edges of the paddocks in the top photograph are the red soils. The smoother green/grey land types running through the centre of the paddocks are the black soils.

Figure 2. Cell 5 in Langlands paddock showing the Creswell land system defined by a very gently undulating terrain and heavy grey pedocal soils, dominated by *Iseilema* spp., *Eulalia aurea*, *Astrebla* spp., *Dichanthium* spp. and *Aristida latifolia*

Table 1. Attributes of each of the paddocks in the Newcastle Waters Station cell-grazing trial relating to size, infrastructure, land systems, woody cover and carrying capacity

	Paddock		
	Runaway (control)	**Langlands (cell grazing)**	**Brownies (cell grazing)**
Size (km^2)	56.0	14.3	20.5
Watered area (5 km radius)	45	13.6	20.1
Watered area (3 km radius)	22.6	13.8	18.9
Number of internal paddocks	1	10	4
Range in size of internal paddocks (ha)	na	92-208	373-775
Black soil (Creswell and Joanundah land systems) (% of total paddock area)	87	93	77
Red soil (Beetaloo and Elliot land systems) (% of total paddock area)	13	7	23
Fence distance (perimeter) (km)	33.5	13.6	18.9
Fence distance (internal) (km)	0.0	19.2	10.4
Total fencing distance (km)	33.5	32.8	29.3
Fence distance per 3 km radius watered area (km/km^2)	1.5	2.4	1.6
Number of water points	2	2	1
Number of new water points (established in 2001)	0	0	1
Density of water points (area in km^2/water)	28.0	5.6	8.9
Maximum distance to water (km)	9	3.5	3.9
Canopy cover of sample sites (Bitterlich gauge, May 2003) (%± SE)	4.9 ± 1.3	0.6 ± 0.2	1.5 ± 0.4
Long-term paddock carrying capacity total paddock area AE/km^2 (AE)	9.3 (523)	9.8 (140)	8.6 (175)
Long-term paddock carrying capacity 3 km watered area AE/km^2 (AE)	7.7 (173)	9.8 (136)	7.8 (146)

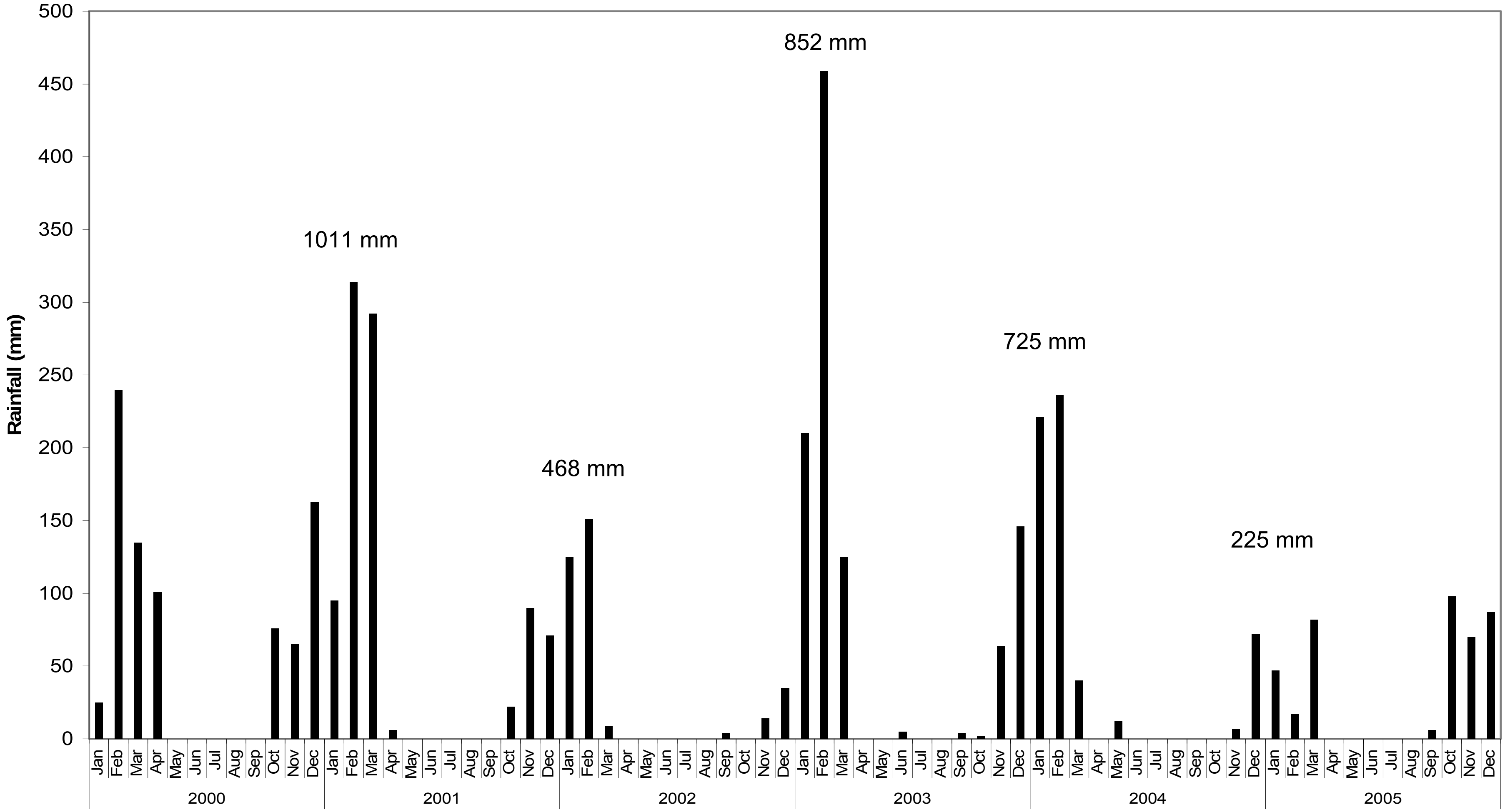

Figure 3. Monthly rainfall recorded at Newcastle Waters Station during the cell-grazing trial (data collected between May 2003 and May 2005) and the preceding three years. Values indicate rainfall totals for each season (July-June). Mean annual rainfall is 500 mm and the median annual rainfall is 476 mm (July-June).

2.4 Stocking rates

A management diary was kept during the trial to record the number, classes and average class weight of stock moved between cells, and into and out of the trial paddocks. From these records, adult equivalent (AE) days were calculated by multiplying the number of AEs for a given time period by the number of days in that period. The total number of AE days and days for a period of interest (e.g. each year) were summed and AE days were divided by days to obtain an AE for that period. AE ratings follow MLA (2010). Average annual intake was assumed to be 8 kg/AE/day, based on a 450-kg animal grazing native pasture with a dry matter digestibility (DMD) averaging 53% (based on paddock NIRS), supplemented for nitrogen (N) and phosphorus (P).

2.5 Carrying capacity and forage budget

Carrying capacity was estimated using the Grazing Land Management methodology (Chilcott et al. 2004). Pasture growth was modelled with GRASP (Littleboy and McKeon 1997) using locally derived land type parameter sets (Walsh and Cowley 2011). A utilisation rate of 20% and 10% was applied to the modelled median pasture growth of 1884 and 999 kg/ha/year for the black and red soil land systems, respectively following Walsh and Cowley (2011).

A forage budget was calculated for the next 365 days, based on 20% utilisation of May's total standing dry matter (TSDM), assuming 40% detachment for the control and 45% detachment for the cell paddocks (due to a higher percentage of annuals and forbs). Detachment rates were based on measurements of detachment at a SWIFTSYND (Day and Philp 1997) site situated on Newcastle Waters Station.

2.6 Wildfire

In October 2004, a wildfire burnt approximately 20% of Langlands paddock, including much of Langlands Cell 9 where half of the sampling points for Langlands were located (Figure 4). Another wildfire burnt most of Runaway paddock (control) in December 2004. Rainfall in the following wet season (2004-5) was well below average (see Figure 3) and the yields of herbaceous vegetation in May 2005 (the last vegetation survey) reflected the combined impacts of fire and below-average rainfall for both locations.

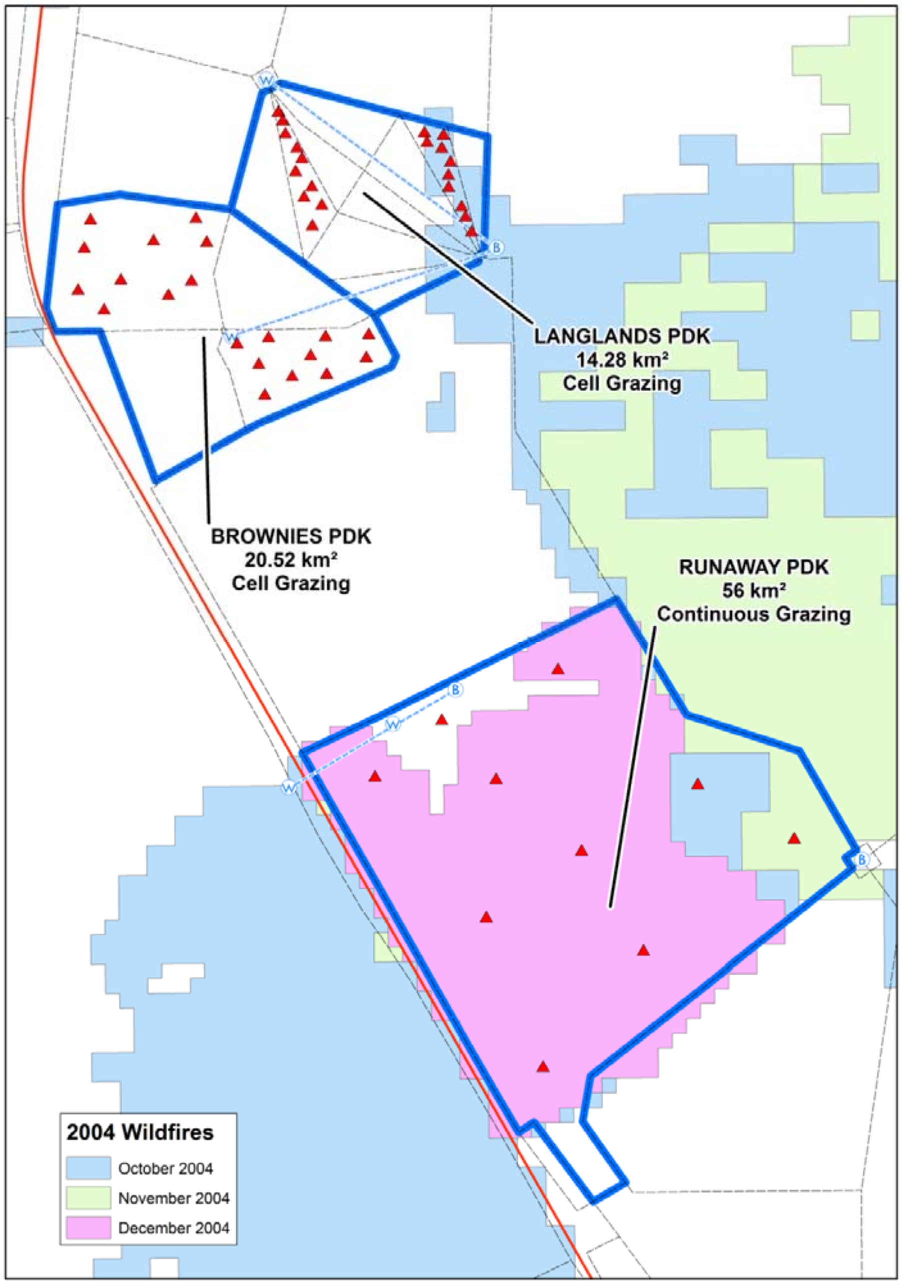

Figure 4. Timing and location of wildfires during the cell-grazing trial at Newcastle Waters Station

2.7 Data sampling

2.7.1 Animal production

Forty weaner steers were selected as indicators of LWG at the start of each season from which 20 were allocated to each treatment (cell-grazing paddocks vs. the control paddock). Animal production was quantified during the trial by weighing the indicator steers and calculating LWG, including daily LWG. All indicator steers were fasted from water and feed for 5 hours before weighing. A list of tagged animals (20 for each paddock) was compiled to ensure similar mean weight between treatments. Average start weaner weights were identical between treatments in May 2003 (248 kg ± 24 SD) and May 2004 (183 kg ± 21 SD). Tagged individuals were subsequently drafted into their respective paddocks. For the first group of weaners in 2003-4, weight was recorded in May 2003, October 2003 and again in April 2004. For the second group of weaners in 2004-5, weight was recorded in May 2004 and April 2005 only.

2.7.2 Diet quality

Faecal samples from the control and treatment paddocks were collected opportunistically throughout the trial. These were dried in a laboratory oven at 60 to 65 °C and sent to the CSIRO Davies Laboratory (Townsville, Queensland) for analysis of diet quality using NIRS (Coates 2000). The proportion of non-grass and percentages of crude protein (CP) and digestibility were measured.

2.7.3 Pastures

The species composition of the pastures in the trial paddocks was sampled in the early (May) and late (November) dry season, between May 2003 and May 2005, using the BOTANAL technique (Tothill et al. 1992). At the start of the trial GIS mapping was used to place pasture sampling points that spanned the full range of distance from water in each paddock. These monitoring points were located using a GPS at each sampling date. Twenty sampling points were located in both cell-grazing paddocks (ten each in Brownies 1, Brownies 3, Langlands 2 and Langlands 9), and ten points were located throughout the control paddock (Figure 1).

At each sampling point, the vegetation was sampled in five 2 × 2 m^2 quadrats, positioned 10 m apart in a U-shaped configuration. In each quadrat the following data were recorded:

- Presence of the top six species contributing the most to TSDM.
- Direct visual estimate of percent yield of the top four species contributing to yield.
- TSDM in kg/ha.
- Ground cover (%).
- Total quadrat defoliation, i.e. the proportion of quadrat herbage mass removed by grazing. This was scored on a 0 to 5 scale with the following grazing classes for defoliation equivalents: 0 (0%), 1 (1-5%), 2 (6-25%), 3 (26-50%), 4 (51-75%) and 5 (76-100%).
- Species level defoliation (scored as above) of the top four species contributing to TSDM.
- Canopy cover (using a Bitterlich gauge).

Yield estimates for individual observers were calibrated daily by visually estimating a set of quadrats (between five and ten each day) which were then harvested, dried and weighed. A regression equation between actual versus estimated yield was calculated for each observer and used to adjust their daily yield estimates.

2.8 Analysis

2.8.1 Animal production

Mean LWGs for the 2003-4 weaners were compared between treatments (cell-grazing paddocks vs. the control paddock) with one-way analysis of covariance (initial live-weight as the covariate) for the dry season (May 2003 to October 2003), wet season (October 2003 to April 2004) and the entire year (May 2003 to April 2004). Animals were not weighed in October 2004, so mean LWGs for the 2004-5 weaners were compared between treatments for the entire year only (May 2004 to April 2005).

LWG per area was calculated as LWG/head multiplied by the number of weaners per km^2. Because different classes of animals were present in each paddock, an equivalent number of weaners per km^2 were calculated as AE/0.6 following the conventions of Chilcott et al. (2004).

2.8.2 Diet quality

NIRS samples were not consistently collected for both treatments on the same dates, so only qualitative comparisons could be made through visual representation of the data.

2.8.3 Pastures

Functional group yield was calculated for annual grasses, perennial grasses, palatable species and forbs. Species were assigned to functional groups palatable/unpalatable or annual/perennial according to local knowledge by NT Department of Primary Industry and Resources staff and relevant literature.

Analyses were performed on key variables: ground cover, total yield, yield of palatable grasses, yield of annual grasses, yield of perennial grasses, per cent perennial grass yield, per cent annual grass yield, per cent forbs and species frequency using repeated measures ANOVA. Averages of each sample point (across five quadrats) were used as the level of replication (see Figure 1). Time of sampling (May 2003, November 2003, May 2004, November 2004 and May 2005) was the within-subject (repeated measures) factor, and treatment (cell grazing, continuous grazing) was the categorical factor. Because there were differences in vegetation variables between the treatment paddocks at the start of the trial, treatment effects will be indicated where trends through time vary significantly between treatments (significant time by treatment interactions). Where necessary, variables were transformed to meet ANOVA assumptions.

Counts of the multinomial variable grazing classes at the quadrat level were analysed using log linear maximum likelihood chi-square to test for the independence of grazing class distributions in pairwise comparisons for different treatments and dates for total quadrat and individual species and functional group defoliation.

Spearman’s Rank Sum correlation coefficient was used to determine associations between vegetation variables and distance to water. The Mann-Whitney U Test was used to compare vegetation variables for a given distance comparison (< 1 km vs. > 1 km, or < 3 km vs. > 3 km), in each year of the trial.

3 Results

3.1 Stocking rates, stocking density and grazing period

Stocking rates (on a total paddock area basis) fluctuated through time in the cell-grazed paddocks, but were constant in the continuously-grazed paddock until pastures burnt by wildfires between October and December 2004 required destocking (Figure 5). On average, stocking rates in the cell-grazing paddocks were slightly higher than stocking rates in the continuously-grazed paddock (Table 2) when compared on a total paddock area basis. However, on a 5-km watered area basis, the control paddock had slightly higher stocking rates. Average stocking rates were close to, or within, the calculated long-term safe carrying capacity (LTCC) for both grazing systems. (LTCC = 7.7 and 8.6 AE/km^2 for control and cell paddocks, respectively) and short-term forage budgeted safe stocking rates (Table 2) through the trial.

Table 2. Stocking rates (AE/km^2) in the Newcastle Waters Station cell-grazing trial

AEs are for the period 1 June to 31 May in the years listed below. Stocking rates are averaged across the two cell systems.

	Actual stocking rate whole paddock		Actual stocking rate 5 km grazing radius		Forage budgeted safe stocking rate*	
	Control	Cell grazing	Control	Cell grazing	Control	Cell grazing
2002-3	6.1	6.8	7.6	7.0	6.8	7.2
2003-4	6.1	8.2	7.6	8.4	11.8	9.8
2004-5	4.4$^{\Delta}$	3.3$^{¥}$	5.5	3.5	1.4	3.5
Average 2003-5	5.2	5.8	6.5	5.9		

* Based on TSDM in paddock in May
∆ December 2004 - 28/03/2005 destocked due to fire in December 2004
¥ December 2004 – 28/03/2005 destocked due to fire in part of cells in October 2004

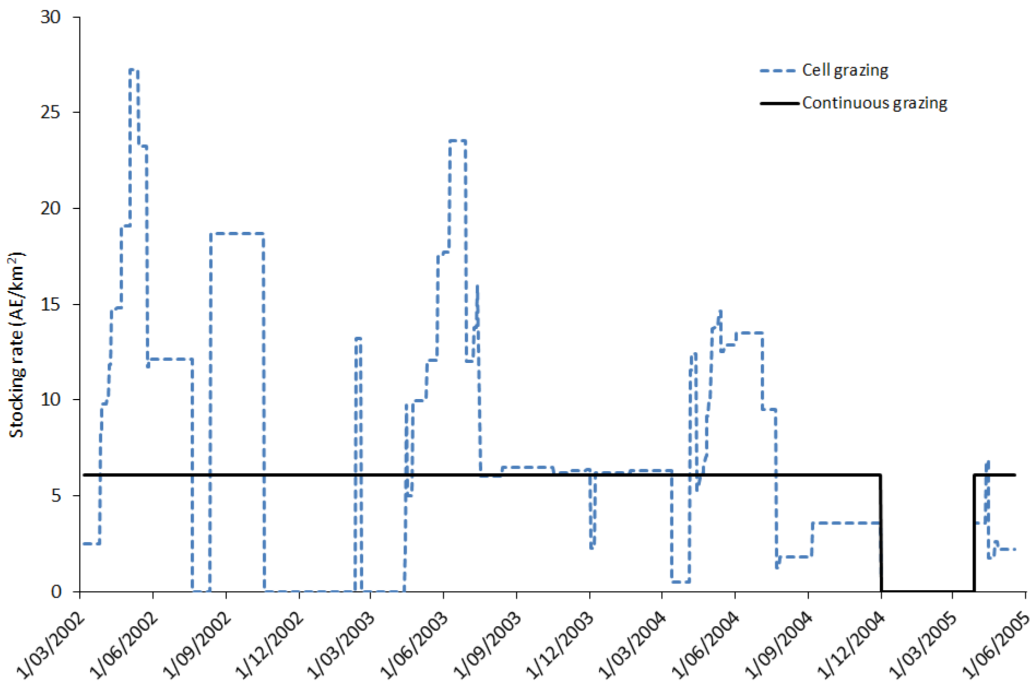

Figure 5. Change in stocking rate (per whole paddock area) through the trial for the different grazing systems at Newcastle Waters Station

While the average annual stocking rate was similar between the different grazing systems, the instantaneous density of stock was much higher in the cell paddocks. Between 2002 and 2003, the cell system stock density averaged 3.7 AE/ha (5.7 head/ha), ranging from 0.4 to 8.9 AE/ha (0.6 to 14.5 head/ha). Stock density was 10 head/ha or higher 8% of the time. This compares with the continuously-grazed paddock where stock density was a constant 0.076 AE/ha (0.06 head/ha) over the same time period (within 5 km from water).

Grazing periods in the cell systems averaged six days, ranging between one to 20 days in 2002 and 2003.

3.2 Pasture – treatment level impacts

3.2.1 Defoliation

3.2.1.1 Quadrat level defoliation

Pasture in May was much more likely to be ungrazed (0% defoliation) than in November (Table 3, Figure 6). Wet season defoliation was low in both grazing systems with more than 70% and 90% of sample sites with defoliation lower than 6% in May 2003 and May 2004, respectively. The very high proportion of ungrazed quadrats in both treatments in May 2004 reflected the very high pasture growth that wet season, while the higher proportion of heavily-grazed quadrats in May 2005 followed extensive wildfires that dramatically reduced pasture availability.

Table 3. The effect of season on the distribution of defoliation classes for different treatments at Newcastle Waters Station

Treatment	Chi-square	*P*	Where distributions differ most (based on components of maximum likelihood chi-square)	
			Defoliation category	Month with more of the defoliation category
All cell grazed pooled	347.75	<0.001	0%	May
All continuously grazed pooled	11.49	0.04	0% 6-25%	May November

(Log linear maximum likelihood analysis, df = 5)

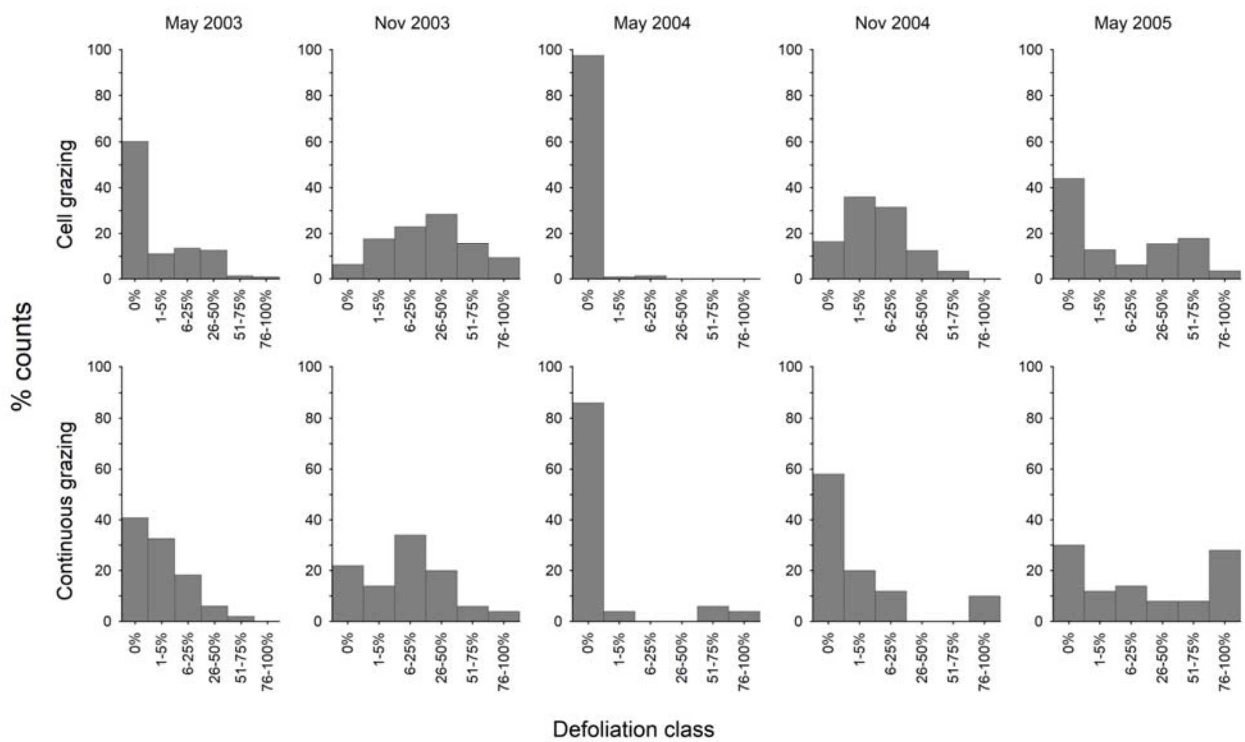

Figure 6. Percentage of sampling points in each defoliation class (per cent of quadrat grazed) at Newcastle Waters Station for cell and continuous-grazing groups

Defoliation was also significantly different between cell and continuous-grazing groups at all time periods (Table 4). In May, cell-grazing paddocks had more ungrazed quadrats than the continuously-grazed paddock, reflecting the wet season spelling of cells. However, this was reversed by November, when cell paddocks were more heavily grazed and the continuously-grazed paddock had more ungrazed sample sites. In November 2003, 53% of cell -grazed sample sites were heavily defoliated (> 25% defoliation) compared with only 30% of continuously-grazed sites.

Table 4. The effect of grazing treatment on the distribution of defoliation classes at Newcastle Waters Station

Date	Chi-square	*P*	Where distributions differ greatest based on components of maximum-likelihood chi-square	
			Defoliation category	Grazing system with more of the defoliation category
May 2003	14.96	0.010	0 %	Cell
			1-5 %	Continuous
Nov 2003	15.80	0.007	0%	Continuous
			51-75%	Cell
May 2004	17.29	0.004	51-100%	Continuous
Nov 2004	55.61	<0.001	0%	Continuous
			1-50%	Cell
			76-100%	Continuous
May 2005	29.86	<0. 001	76-100%	Continuous
All May pooled	39.43	<0. 001	0%	Cell
			1-50%	Continuous
			76-100%	Continuous
All Nov pooled	45.41	<0. 001	0%	Continuous
			26-75%	Cell

(Log linear maximum likelihood analysis, df = 5)

3.2.1.2 Plant species defoliation

The difference in pasture composition between treatments and the small number of quadrats in the continuously grazed paddock meant that there were only a limited number of species with enough defoliation observations in both grazing systems for statistical comparison (Table 5). Of these species, defoliation usually did not differ with the grazing system. Exceptions included the preferred species *Dichanthium fecundum*, which was less likely to be ungrazed and more likely to be heavily grazed in cell paddocks in May and November, 2003 compared with the continuously-grazed paddock (Figure 7). The non-preferred species *Aristida latifolia*, *Eulalia aurea* and *Panicum laevinode* were also less likely to be ungrazed and more likely to be moderately grazed in the cell-grazed paddocks compared with the control at different times (Figure 8).

Of the four species with lighter grazing in the continuously-grazed paddock, three were instances where the species only occurred at distances far from water (>2 to 3 km), which would have led to lower grazing levels independent of grazing system (Sections 3.3.1-3.3.2).

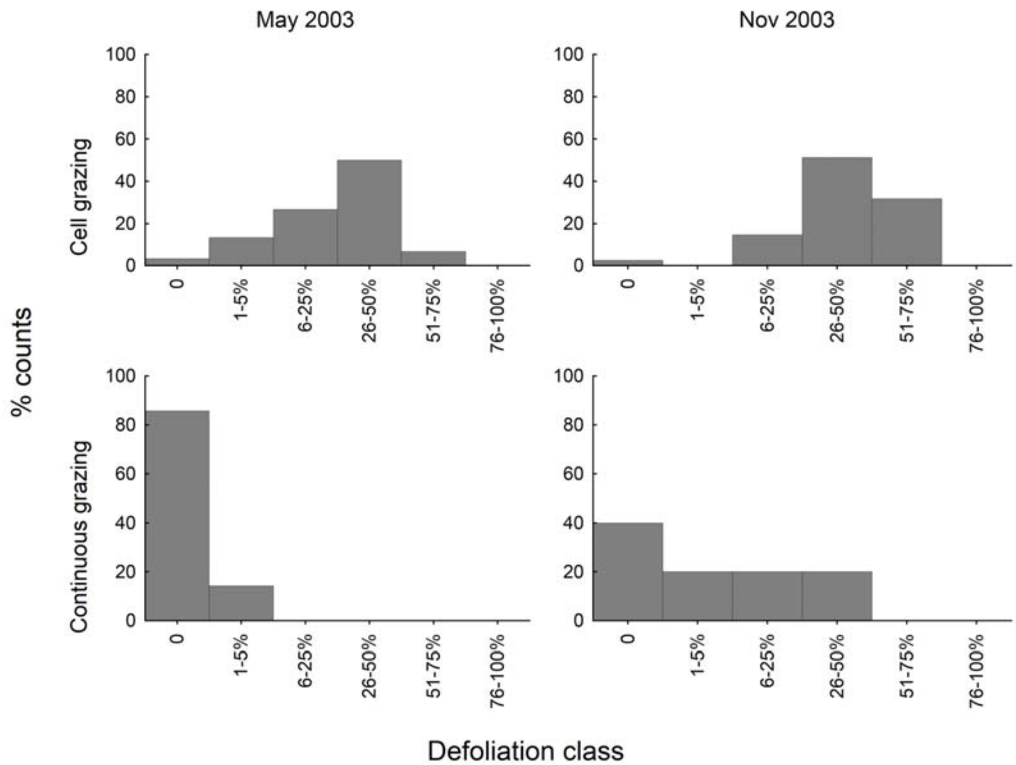

Figure 7. Percentage of sampling points in each defoliation class for *Dichanthium fecundum* for cell and continuous-grazing groups in 2003 at Newcastle Waters Station

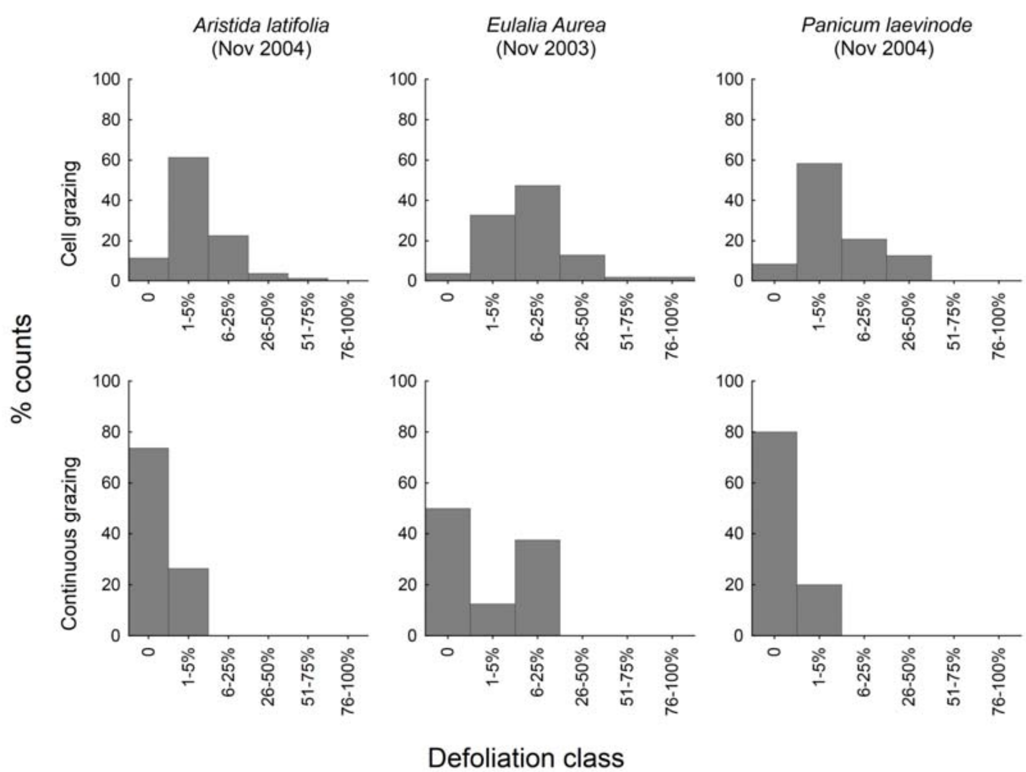

Figure 8. Percentage of sampling points in each defoliation class for species where the distribution of defoliation class varied with grazing treatment at Newcastle Waters Station

Table 5. Count of species defoliation classes and log-linear maximum likelihood chi-square for different grazing treatments (df=5)

Only species with enough defoliation counts for analysis are shown.

Date		**Cell grazed**						**Continuously grazed**							
	Defoliation class	0	1-5%	6-25%	26-50%	51-75%	76-100%	0	1-5%	6-25%	26-50%	51-75%	76-100%	Chi-square	*P*
May 2003	*Astrebla pectinata*	19	2	3	1	0	0	12	5	4	5	0	2	6.55	0.26
	Chrysopogon fallax	9	3	1	1	0	0	8	9	2	2	1	0	2.42	0.79
	Dichanthium fecundum	**1**	**4**	**8**	**15**	**2**	**0**	**6**	**1**	**0**	**0**	**0**	**0**	**19.77**	**0.001**
	Eulalia aurea	14	16	7	10	0	0	8	2	0	0	0	0	8.47	0.13
Nov 2003	*Aristida latifolia*	6	12	11	8	5	3	3	7	4	6	2	0	1.93	0.86
	Astrebla squarrosa	0	3	8	7	2	1	0	1	1	3	0	0	1.33	0.93
	Chrysopogon fallax	1	8	1	1	1	0	6	4	3	3	0	0	6.32	0.28
	Dichanthium fecundum	**1**	**0**	**6**	**21**	**13**	**0**	**2**	**1**	**1**	**1**	**0**	**0**	**12.60**	**0.03**
	Eulalia aurea	**2**	**18**	**26**	**7**	**1**	**1**	**4**	**1**	**3**	**0**	**0**	**0**	**10.91**	**0.05**
	Flemingia pauciflora	22	3	9	2	5	7	3	0	0	0	0	0	0.95	0.99
	Iseilema spp.	1	3	6	21	21	7	0	1	2	3	0	0	6.23	0.28
	Panicum laevinode	3	9	12	3	6	3	1	3	0	0	0	1	4.67	0.46
	Sesbania spp.	12	0	1	11	5	9	6	0	0	0	0	0	7.52	0.18
	Sorghum timorense	2	1	3	3	0	0	2	4	2	1	0	0	2.56	0.77
Nov 2004	***Aristida latifolia***	**9**	**49**	**18**	**3**	**1**	**0**	**14**	**5**	**0**	**0**	**0**	**0**	**28.54**	**<0.001**
	Astrebla elymoides	5	11	11	16	8	0	1	3	0	0	0	0	5.98	0.31
	Astrebla pectinata	0	1	3	3	1	0	1	0	5	0	0	0	4.35	0.50
	Astrebla squarrosa	1	3	2	5	0	0	3	0	1	0	0	0	6.1	0.30
	Chrysopogon fallax	4	8	6	3	0	0	10	3	2	0	0	0	8.13	0.15
	Iseilema spp.	22	62	24	9	2	0	6	6	1	0	0	0	5.55	0.33
	Panicum decompositum	1	4	0	4	0	0	4	2	2	0	0	0	7.24	0.20
	Panicum laevinode	**2**	**14**	**5**	**3**	**0**	**0**	**8**	**2**	**0**	**0**	**0**	**0**	**15.23**	**0.009**
May 2005	***Astrebla pectinata***	**13**	**13**	**9**	**21**	**22**	**11**	**7**	**4**	**5**	**0**	**4**	**8**	**15.17**	**<0.01**
	Dichanthium fecundum	5	1	1	2	13	16	2	0	2	1	0	2	8.60	0.13
	Eulalia aurea	7	5	10	16	22	2	2	1	3	1	4	1	3.00	0.70
	Panicum decompositum	5	4	0	0	2	0	2	3	2	1	0	1	5.08	0.41

Statistically significant results (P<0.05) are highlighted in bold.

3.2.1.3 Preferred and unpreferred species defoliation

In May 2003 and 2004, preferred species were more likely to be ungrazed in the cell paddocks than in the continuously-grazed paddock (Table 6, Figure 9), reflecting the lower total defoliation in cell paddocks after wet season spelling. By November, preferred species in the cell-grazed paddocks were more likely to be more heavily grazed than in the continuously-grazed paddock, again similar to total defoliation patterns.

Defoliation of unpreferred species did not vary with the grazing system except in November 2004 when unpreferred species were more heavily grazed in cell paddocks (Figure 10).

Table 6. The effect of grazing system on defoliation of preferred and unpreferred species

Species group	Date	Chi-square	*P*	Where distributions differ greatest (based on components of maximum-likelihood chi-square)	
				Defoliation category	Grazing system with more of the defoliation category
Preferred	**May 2003**	**33.66**	**<0.001**	**0%** **1-5%**	**Cell** **Continuous**
	Nov 2003	**39.05**	**<0.001**	**0%** **51-75%**	**Continuous** **Cell**
	May 2004	**40.17**	**<0.001**	**51-100%**	**Continuous**
	Nov 2004	**75.01**	**<0.001**	**0%** **26-50%**	**Continuous** **Cell**
	May 2005	**17.47**	**0.003**	**51-75%** **76-100%**	**Cell** **Continuous**
Unpreferred	May 2003	7.03	0.22		
	Nov 2003	6.98	0.22		
	May 2004	3.78*	0.44		
	Nov 2004	**27.09**	**<0.001**	**0%** **1-25%**	**Continuous** **Cell**
	May 2005	7.88	0.16		

Statistically significant results (P<0.05) are highlighted in bold. (Log-linear maximum likelihood chi-Square. df=5 unless *df=4).

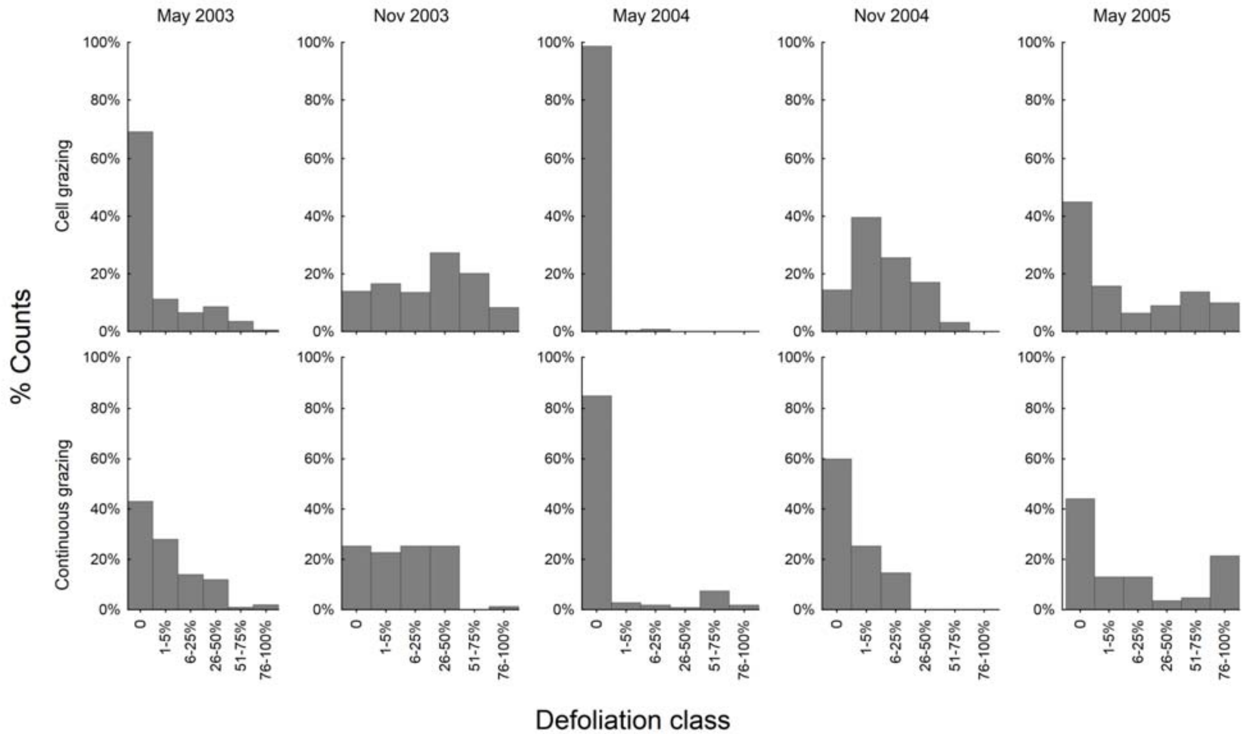

Figure 9. Percentage of sampling points in each defoliation class for preferred species in cell and continuously-grazed groups at Newcastle Waters Station

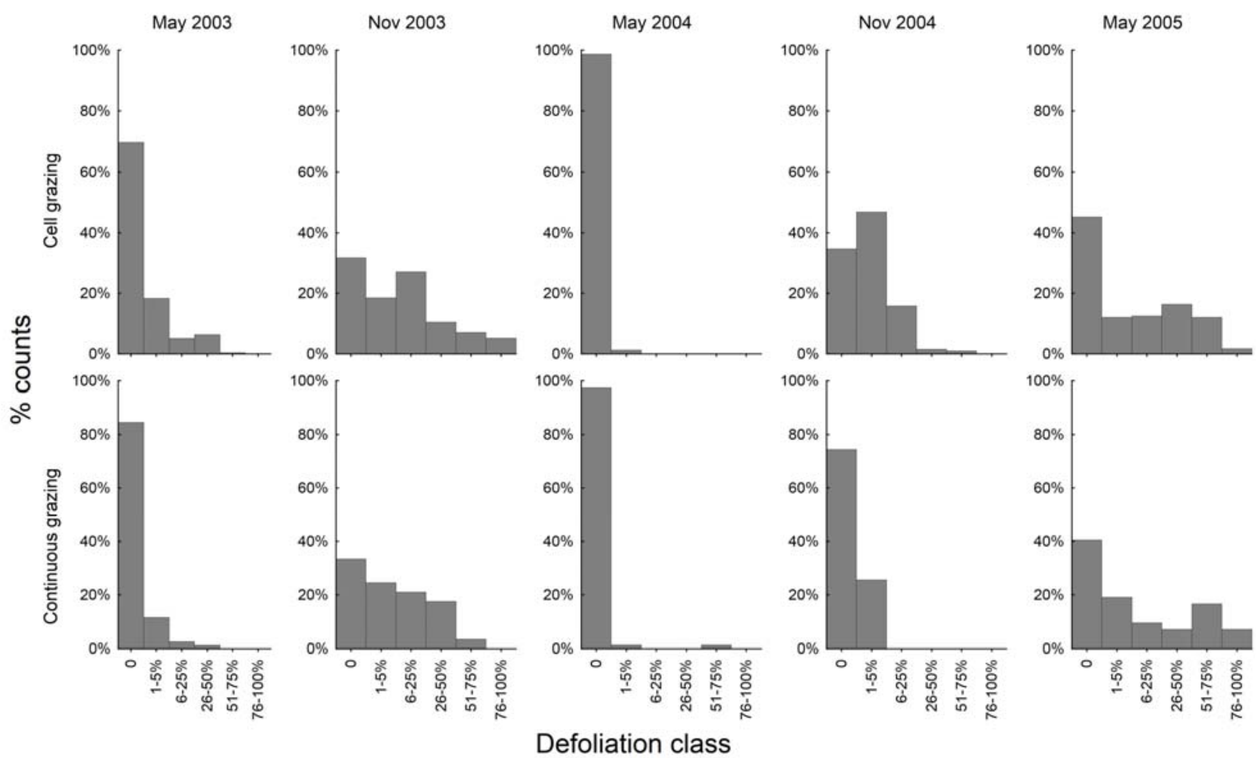

Figure 10. Percentage of sampling points in each defoliation class for unpreferred species in cell and continuously grazed groups at Newcastle Waters Station

Preferred species were more heavily grazed than non-preferred species in the cell paddocks on four out of five occasions. This compares with only once where preferred species had heavier grazing than non-preferred species in the continuously-grazed paddock (Table 7). In cell-grazed paddocks, preferred species were more likely to be heavily grazed and less likely to be ungrazed than non-preferred species.

Table 7. Variation in defoliation between species groups (preferred vs. unpreferred) for the different grazing groups

Treatment	**Date**	**Chi-square**	***P***	**Where distributions differ greatest (based on components of maximum-likelihood chi-square)**	
				Defoliation category	**Species group with more of the defoliation category**
Cell	**May 2003**	**15.06**	**0.01**	**1-5%** **51-75%**	**Unpreferred** **Preferred**
	Nov 2003	**68.08**	**<0.001**	**0%** **6-75%**	**Unpreferred** **Preferred**
	May 2004	4.01*	0.40		
	Nov 2004	**66.97**	**<0.001**	**0%** **6-50%**	**Unpreferred** **Preferred**
	May 2005	**28.37**	**<0.001**	**76-100%**	**Preferred**
Continuous	**May 2003**	**33.37**	**<0.001**	**0%** **1-50%**	**Unpreferred** **Preferred**
	Nov 2003	4.19	0.52		
	May 2004	6.16	0.29		
	Nov 2004	9.03*	0.06		
	May 2005	9.44	0.09		

Statistically significant results ($P<0.05$) are highlighted in bold. (Log-linear maximum likelihood chi-square, df=5 unless *df=4).

3.2.2 Vegetation

Most variables varied significantly through time as a result of season. Only the proportion of annual grass varied significantly between paddocks and this reflected initial paddock differences, rather than treatment effects (Table 8). Although there were some significant time-by-treatment interactions, they were always due to the greater proportion of the continuously-grazed paddock being burnt in late 2004 than the cell paddocks, rather than due to the treatments. The different treatments changed similarly through time for all pasture variables until May 2005. Hence, there was no evidence of an effect of the grazing system on vegetation during the trial.

Table 8. Repeated measures ANOVA comparing pasture-related variables between cell vs. continuous grazing and sampling times

Variable	**Mean**		**Treatment**		**Time**		**Treatment*Time**	
	Cell	**Control**	$F_{(1, 46)}$	***P***	$F_{(4, 184)}$	***P***	$F_{(4, 184)}$	***P***
Ground cover (%)	47	37	3.16	0.08	**21.08**	**< 0.001**	**9.01**	**< 0.001**
Total yield (kg/ha)	1467	1422	0.07	0.79	**59.08**	**< 0.001**	**3.16**	**0.015**
Plant functional groups								
Yield of palatable grasses (kg/ha)	1106	1011	0.26	0.61	**34.73**	**< 0.001**	1.53	0.19
Yield of annual grasses (kg/ha)	403	279	2.38	0.13	**28.73**	**< 0.001**	1.38	0.24
Yield of perennial grasses (kg/ha)	693	767	0.06	0.81	**13.88**	**< 0.001**	**2.89**	**0.02**
Perennial grass abundance as a proportion of total yield (%)	40	47	0.58	0.45	**4.11**	**0.003**	1.45	0.22
Annual grass abundance as a proportion of total yield (%)	**26**	**15**	**4.38**	**0.04**	**12.25**	**< 0.001**	**3.55**	**0.008**
Forbs as a proportion of total yield (%)	17	8	1.41	0.24	**10.21**	**< 0.001**	0.91	0.46
Species frequency								
Aristida latifolia	0.32	0.32	0.00	0.96	0.72	0.49	1.46	0.23
Astrebla spp.	0.42	0.53	0.87	0.35	**11.84**	**< 0.001**	0.21	0.81
Chrysopogon fallax	**0.04**	**0.33**	**38.97**	**< 0.001**	**13.81**	**< 0.001**	**0.38**	**< 0.001**
Dichanthium fecundum	0.16	0.15	0.02	0.88	0.52	0.59	0.18	0.83
Eulalia aurea	0.27	0.21	0.30	0.58	1.05	0.35	0.44	0.65
Flemingia pauciflora	0.34	0.23	0.81	0.37	0.88	0.42	0.18	0.84
Iseilema spp.	**0.58**	**0.25**	**12.95**	**< 0.001**	**33.7**	**< 0.001**	**4.21**	**0.017**
Panicum decompositum	**0.03**	**0.12**	**7.89**	**< 0.001**	2.71	0.07	0.59	0.55

Statistically significant results ($P<0.05$) are highlighted in bold.

3.2.2.1 Ground cover

Ground cover was approximately 40% in both treatment groups at the first sampling period (May 2003) and decreased slightly in the following dry season to approximately 30% (Figure 11). For the wetter year of 2004, May cover was approximately 50% and generally remained at this value until the last sampling time (May 2005). The one exception to this pattern was in the continuously-grazed paddock, where cover was < 10% in May 2005, following wildfire in December 2004. Langlands' cell 9 experienced a fire in October 2004, though this affected only one quarter of the sampling locations for the cell-grazing group.

Seasonal and inter-annual variability most likely resulted in the significant effect of time on ground cover (Table 8). Whilst differences in cover in May 2005 (after the wildfire) contributed to a significant treatment-by-time interaction, the difference between treatments was not significant overall (Table 8).

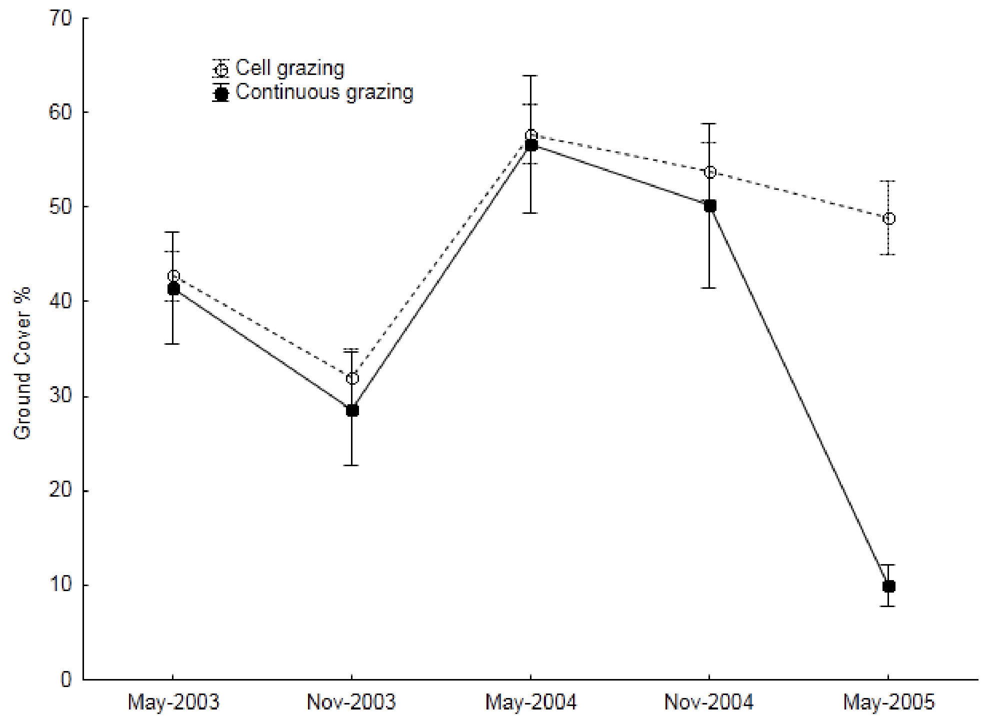

Figure 11. Mean ± SE of per cent ground cover at Newcastle Waters for cell and continuous grazing groups

3.2.2.2 Pasture yield

Wildfires in late 2004 combined with low wet season rainfall resulted in both the treatment and control paddocks having very low yields (350 to 950 kg/ha) in May 2005 (Figure 12). The higher yield in the cell paddocks in May 2005 can be attributed to a smaller area of them being burnt. Seasonal conditions and fire resulted in a significant effect of time and a significant time-by-treatment interaction (Table 8). However, yield varied little between treatments before May 2005, such that there was no effect of treatment overall (Table 8).

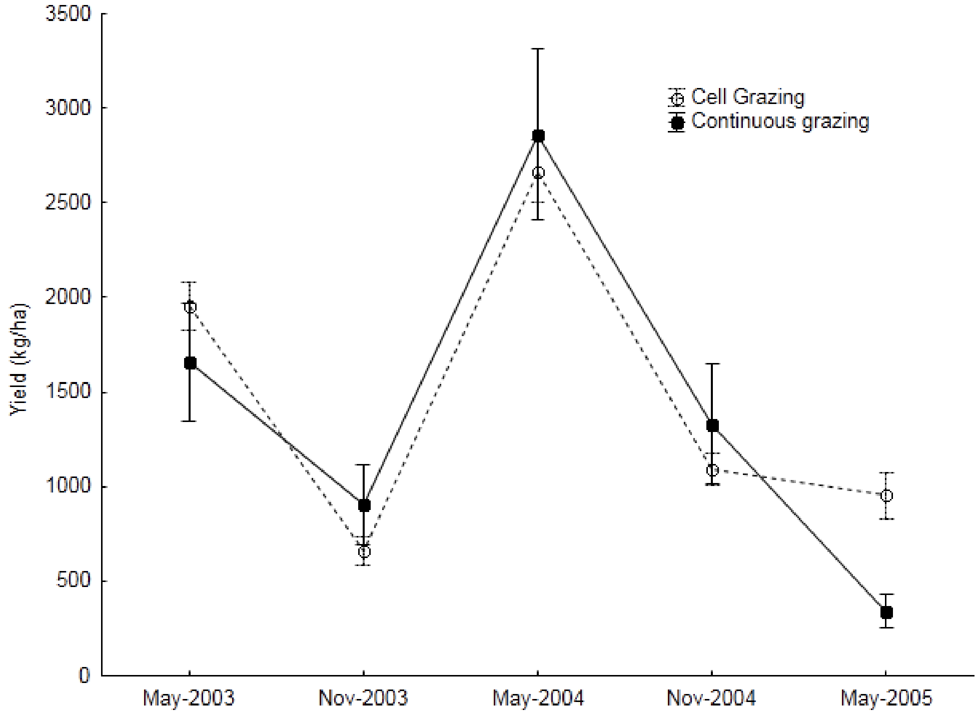

Figure 12. Mean ± SE pasture yield for cell and continuous grazing groups at Newcastle Waters Station

The yield of palatable grasses, annual grasses and perennial grasses had similar patterns of inter- and intra-annual variation to total yield (Figures 13, 10 and 11) with a significant effect of time but not treatment (Table 8).

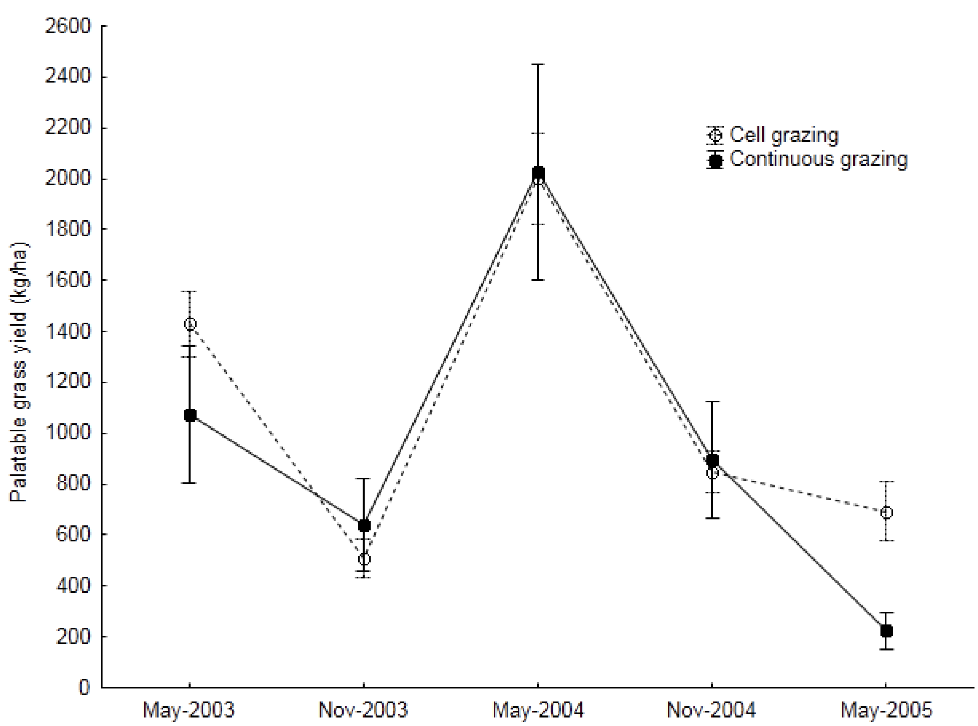

Figure 13. Mean ± SE palatable grass yield for cell and continuous-grazing groups at Newcastle Waters Station

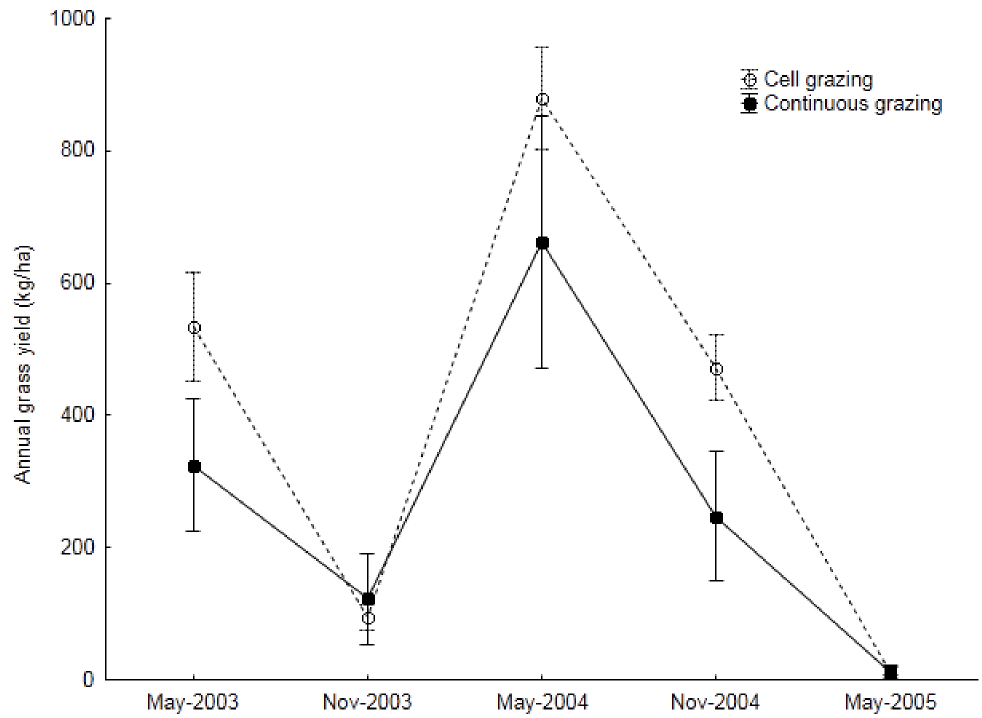

Figure 14. Mean ± SE annual grass yield for cell and continuous-grazing groups at Newcastle Waters Station

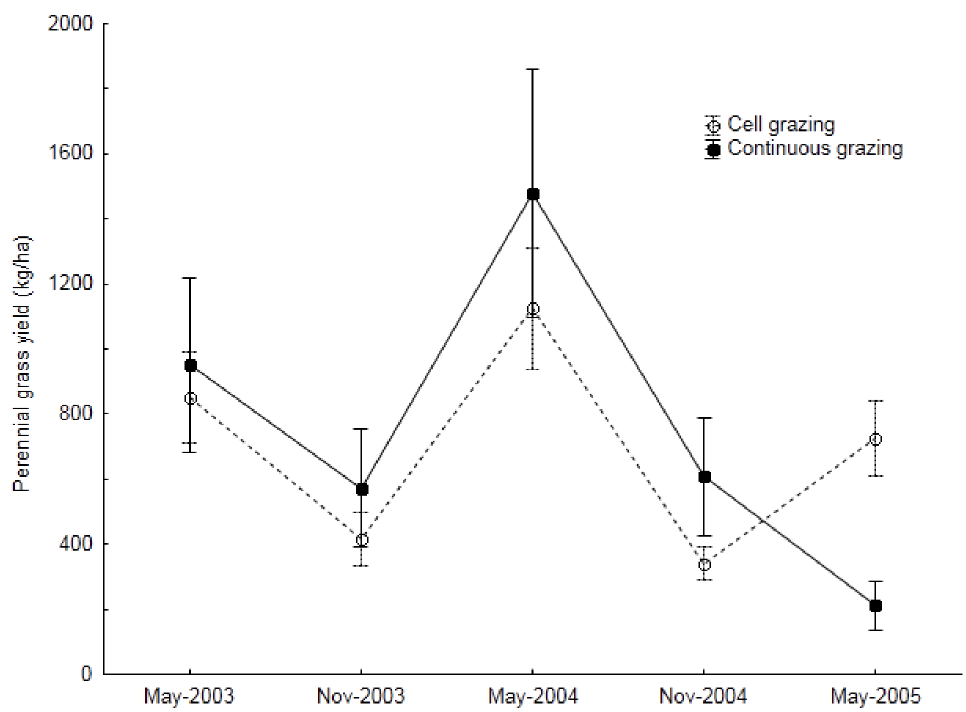

Figure 15. Mean ± SE perennial grass yield for cell and continuous-grazing groups at Newcastle Waters Station

3.2.2.3 Proportion of functional groups in pasture

Despite consistently higher average per cent perennial grass yield in the continuously-grazed paddock (40 to 50%) vs. the cell-grazed paddocks (25 to 45%) (Figure 16, Table 8), variation within treatments was large and hence treatment differences were not significant.

The proportion of annual grasses varied significantly through time between 20 and 40% in the cell-grazed paddocks and around 10 to 20% of the continuously-grazed paddock (Table 8, Figure 17), except in May 2005 following wildfire in the previous dry season where levels were about 5% of total yield. The proportion of annual grasses was higher in the cell–grazing paddocks than in the continuously-grazed paddock throughout the trial (although only significantly higher in November 2004, Fisher's LSD P<0.001), resulting in a significant effect of treatment overall.

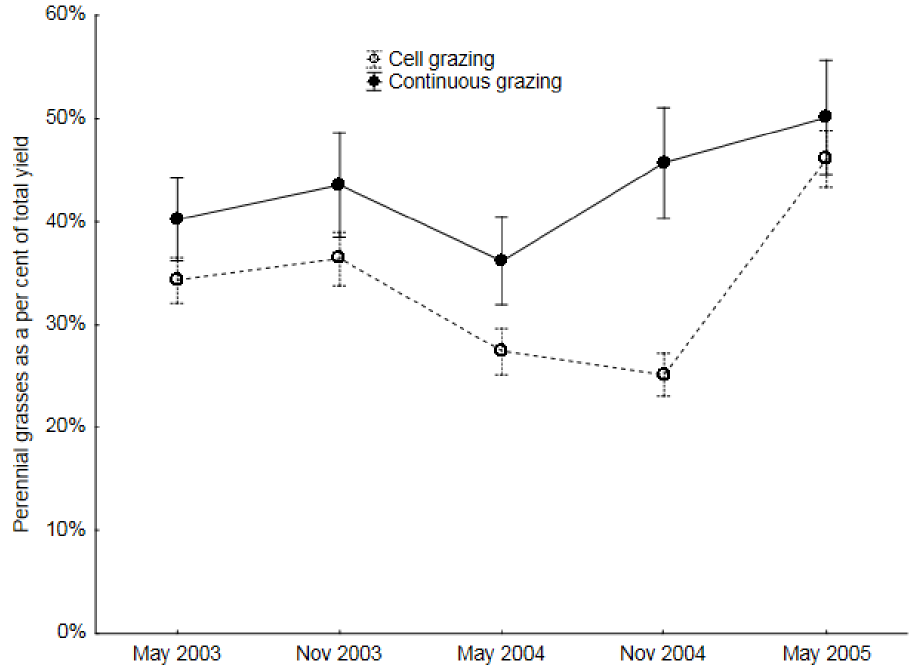

Figure 16. Mean ± SE per cent perennial grass yield for cell and continuously-grazed groups at Newcastle Waters Station

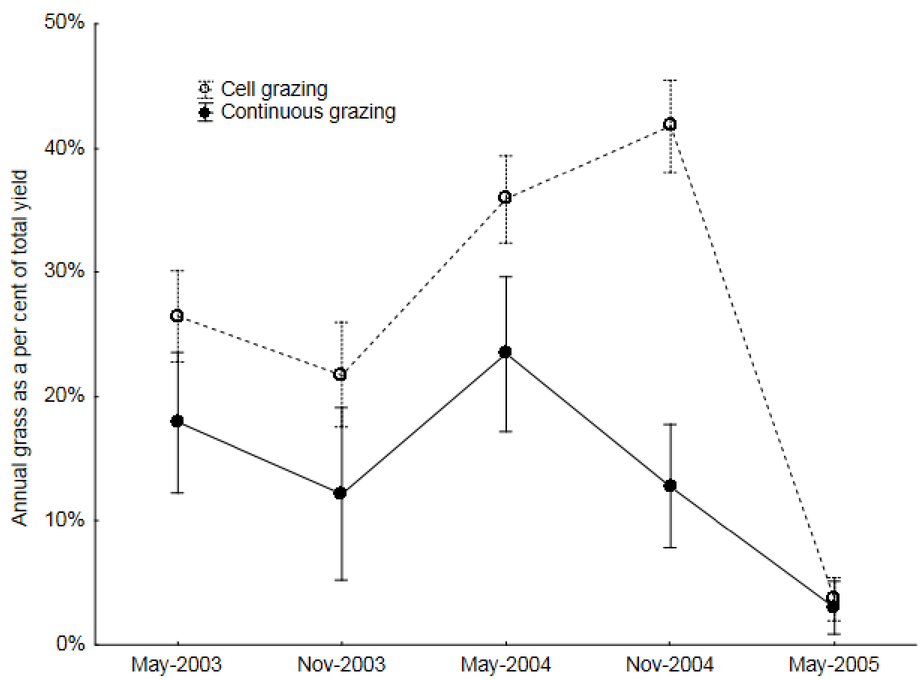

Figure 17. Mean ± SE per cent annual grass yield for cell and continuously-grazed groups at Newcastle Waters Station

The proportion of forbs was highest in the pasture following the wet season and about 7 to 10% lower the following late dry season, with similar patterns in both groups, resulting in no time-by-treatment interaction (Figure 18, Table 8). The cell paddocks had a consistently higher proportion of forbs than the control, but differences were small compared with the variability within treatments and were not significant.

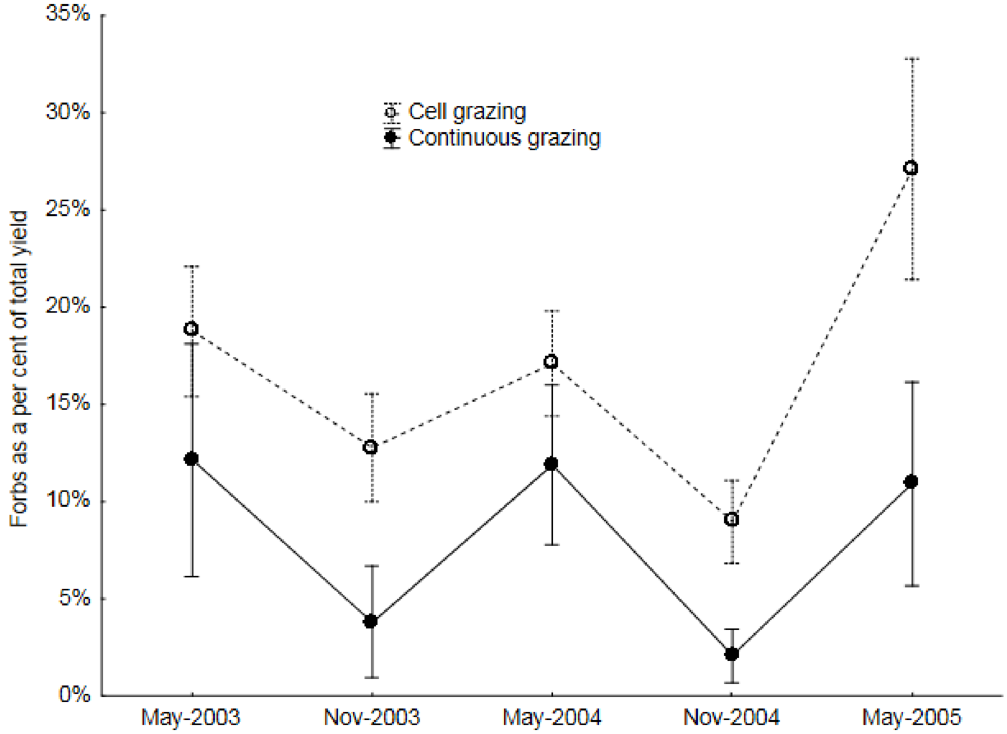

Figure 18. Mean ± SE per cent forb yield for cell and continuously-grazed groups at Newcastle Waters Station

3.2.2.4 Plant species frequency and diversity

A total of 105 plant species were recorded in the grazing trial (early and late dry season data pooled). Of these, 86% occurred in the cell-grazing paddocks and 60% in the control paddock (Table 17, Appendix 1). The higher number of species recorded in the cell paddocks likely reflects the larger number of sampling points (cell-grazing paddocks had four times the number of sampling points of the control paddock). The cell-grazing paddocks had significantly lower frequencies of *Chrysopogon fallax* (Figure 19) and *Panicum decompositum* (Figure 20), and a significantly higher frequency of *Iseilema* spp. (Table 8, Figure 21, Table 17). These differences represent initial differences in paddock composition (May 2003 samples) rather than any treatment effect.

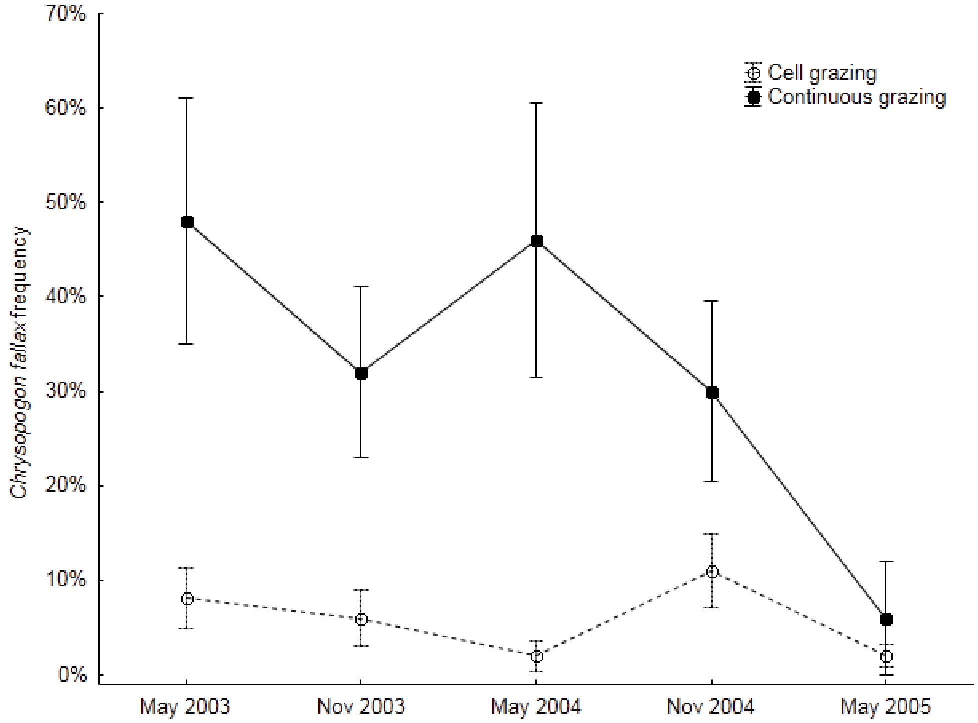

Figure 19. Mean ± SE *Chrysopogon fallax* frequency for the cell and continuous-grazing groups at Newcastle Waters Station

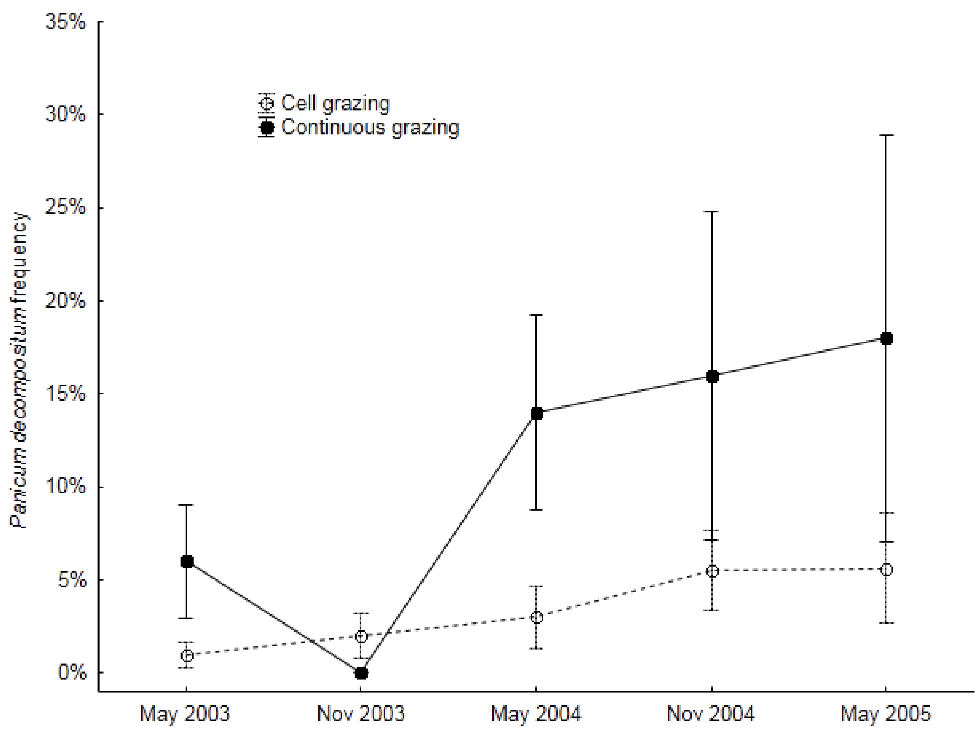

Figure 20. Mean ± SE *Panicum decompositum* frequency for the cell and continuous-grazing groups at Newcastle Waters Station

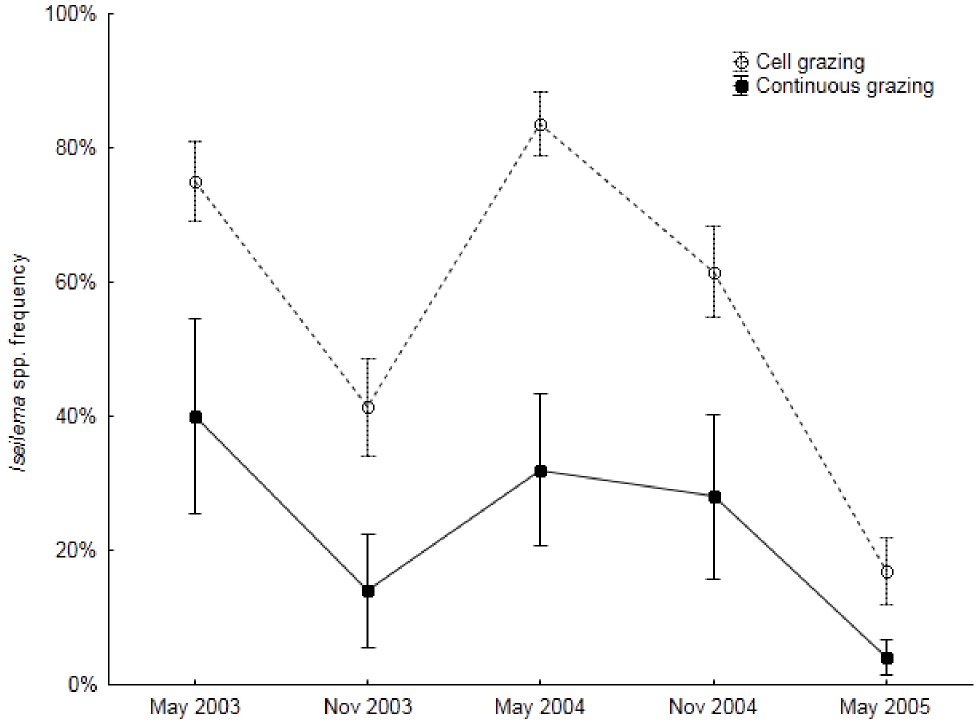

Figure 21. Mean ± SE *Iseilema* spp. frequency for the cell and continuous-grazing groups at Newcastle Waters Station

Trends in species frequency were usually similar through time between the treatments (more species graphs are shown in Appendix 2). Where there was a significant time-by-treatment interaction, it was due to the fire in late 2004, rather than a treatment-induced impact.

3.3 Spatial distribution of grazing and vegetation within paddocks

3.3.1 Grazing, yield and cover distribution with distance to water

The two cell paddocks were analysed separately for distance to water effects because the Langlands paddock used pre-existing water (referred to as the old-water cell), and hence is more likely to have had pre-existing grazing gradients, while the Brownies cell system used new water (referred to as the new-water cell).

Grazing (as measured by defoliation) was initially more even with distance to water in the cell paddocks than in the continuously-grazed paddock, where defoliation was markedly higher closer to water (Table 9, Figure 22). By November 2004, defoliation was also higher closer to water in the cells.

Table 9. Difference in defoliation between less than and greater than 2 km or 1.5 km from water for different grazing groups and times

Treatment	Date	Chi-square	*P*	Distance comparison	Where distributions differ greatest (based on components of maximum-likelihood chi-square)	
					Defoliation category	**Location with more of the defoliation category**
Cell grazing – new water	May 2003	3.84	0.57	< > 1.5 km		
	Nov 2003	7.99	0.16	< > 2 km		
df=3	May 2004	3.90	0.27	< > 1.5 km		
	Nov 2004	**11.80**	**0.04**	**< > 2 km**	**1-5%** **6-75%**	**Far** **Near**
	May 2005	**20.40**	**0.001**	**< > 2 km**	**0-5%** **26-75%**	**Far** **Near**
Cell grazing – old water	May 2003	5.28	0.39	< > 1.5 km		
	Nov 2003	6.67	0.25	< > 2 km		
df=1	May 2004	0.04	0.84	< > 2 km		
	Nov 2004	**12.85**	**0.02**	**< > 1.5 km**	**1-5%** **26-50%**	**Far** **Near**
	May 2005	3.94	0.56	< > 1.5 km		
Continuous grazing	**May 2003**	**21.28**	**<0.001**	**< > 1.5 km**	**0-5%** **25-75%**	**Far** **Near**
	Nov 2003	**16.52**	**0.006**	**< > 1.5 km**	**51-100%**	**Near**
df=2	May 2004	3.43	0.18	< > 2 km		
	Nov 2004	**11.51**	**0.04**	**< > 2 km**	**6-25%** **76-100%**	**Far** **Near**
	May 2005	10.68	0.06	< > 3 km		

Statistically significant results ($P<0.05$) are highlighted in bold. df=5 unless otherwise specified due to fewer grazing class comparisons (most significant distance comparison shown only)

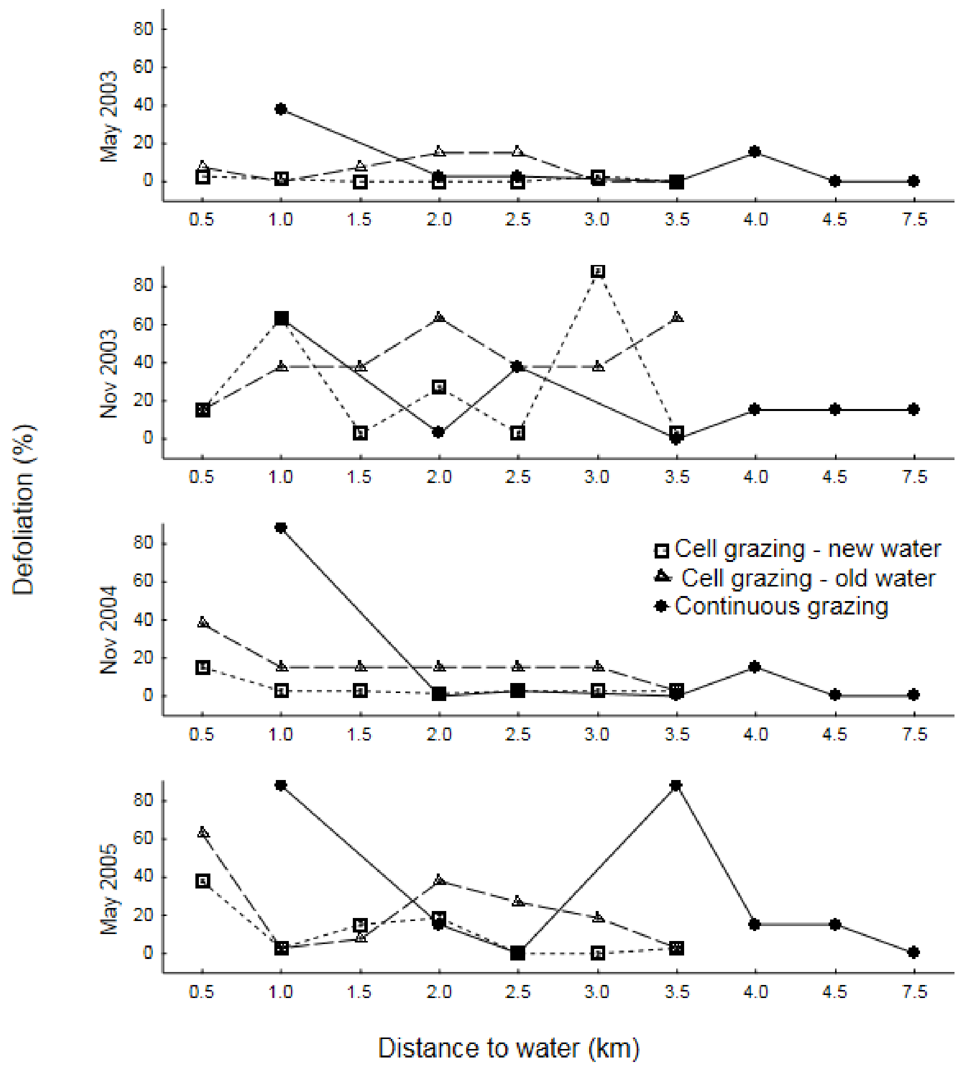

Figure 22. Median defoliation class mid-point with distance to water in cell and continuously-grazed groups at Newcastle Waters Station

Defoliation in May 2004 was uniformly low so not shown for clarity.

The heavier grazing close to water in the continuously-grazed paddock was reflected in the lower ground cover, yield and proportion of palatable perennial grass yield (%PPG) closer to water in this treatment (Figures 23, 25, Tables 10, 11).

The old-water cell initially had low %PPG immediately adjacent the trough in May 2003 (Figure 25), but this increased through time, so that by 2005 it was equivalent to levels of %PPG near the trough in the new water cell paddock.

Table 10. Spearman's correlation coefficient (r_s) for associations between pasture characteristics (distance to water and yield, cover and proportion of perennial grass yield) and the grazing treatments

Significant correlations are highlighted in bold.

	Date	Cell grazing new water (n=20)		Cell grazing old water (n=20)		Continuous grazing (n=10)	
		r_s	*P*	r_s	*P*	r_s	*P*
Total yield	May 2003	-0.30	0.20	-0.09	0.70	0.69	**0.03**
	Nov 2003	-0.08	0.73	-0.05	0.82	0.77	**0.009**
	May 2004	0.12	0.61	-0.08	0.74	0.52	0.13
	Nov 2004	0.19	0.43	-0.03	0.90	0.68	**0.03**
	May 2005	-0.13	0.60	0.06	0.79	0.45	0.19
Cover	May 2003	0.29	0.20	-0.24	0.31	0.44	0.20
	Nov 2003	0.35	0.13	0.35	0.14	0.38	0.28
	May 2004	-0.03	0.89	-0.07	0.75	0.90	**0.0003**
	Nov 2004	0.29	0.22	0.05	0.85	0.58	0.08
	May 2005	0.39	0.10	-0.07	0.75	0.41	0.24
Palatable perennial grass yield (%)	May 2003	-0.30	0.20	-0.06	0.81	0.30	0.40
	Nov 2003	0.24	0.31	0.03	0.90	0.66	**0.04**
	May 2004	0.003	0.99	-0.02	0.92	0.67	**0.03**
	Nov 2004	0.06	0.81	-0.19	0.42	0.49	0.15
	May 2005	0.09	0.70	-0.05	0.81	0.66	**0.04**

Although defoliation was starting to increase closer to water in the new-water cell by late 2004, yield, cover and %PPG remained unrelated to distance to water throughout the trial (Table 10).

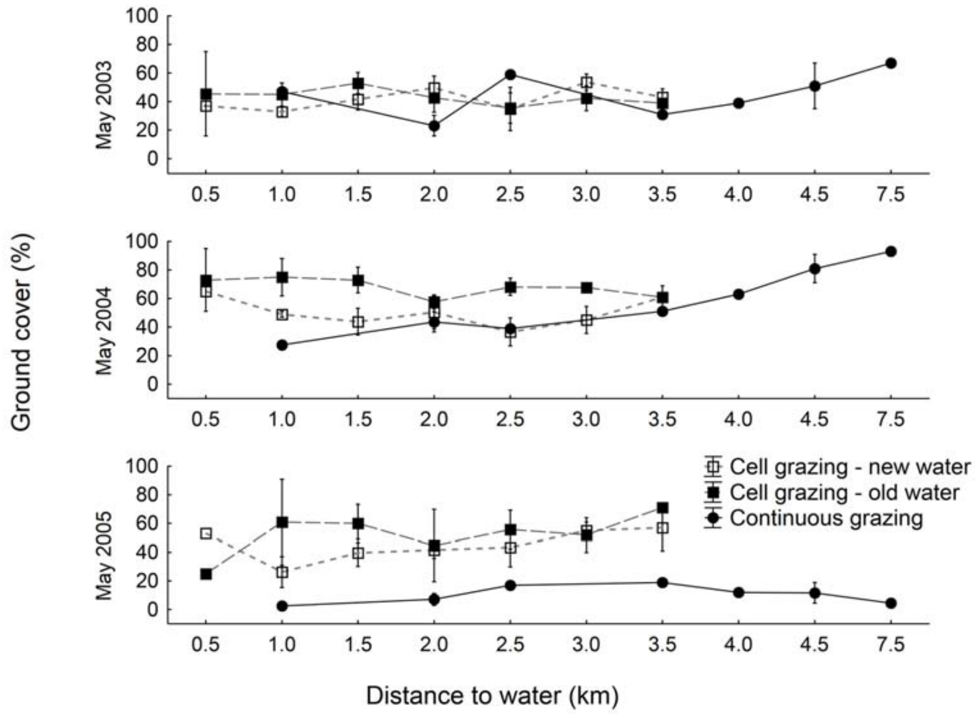

Figure 23. Mean ± SE ground cover with distance to water in the cell and continuously-grazed paddocks at Newcastle Waters Station

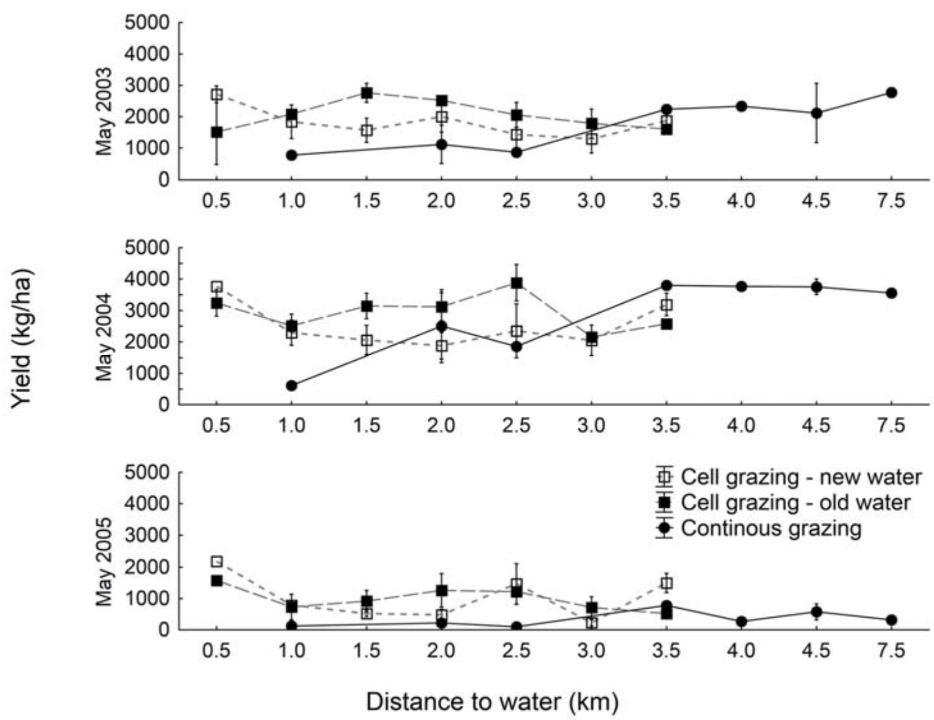

Figure 24. Mean ± SE pasture yield in May with distance to water in the cell and continuously-grazed paddocks at Newcastle Waters Station

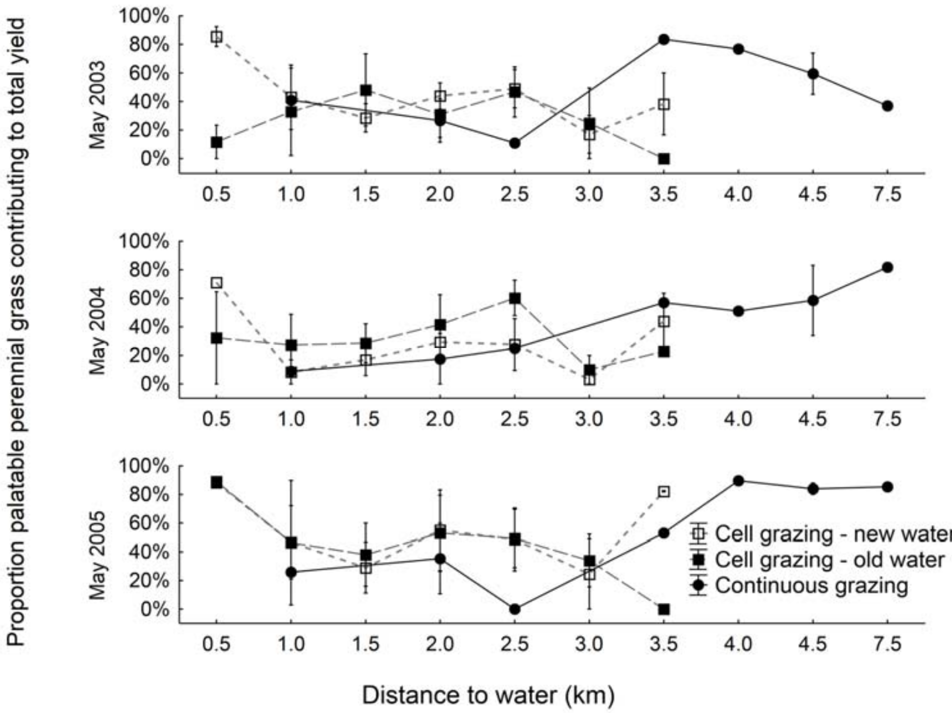

Figure 25. Mean ± SE per cent palatable perennial grass yield with distance to water in the cell and continuously- grazed paddocks at Newcastle Waters Station

3.3.2 Species distribution with distance to water

Patterns of species frequency with distance to water varied between the treatment paddocks.

In the larger continuously-grazed paddock, the frequency of three palatable perennial grass species declined closer to water (Tables 11, 12). These were *Astrebla* spp. (Figure 26), *Dichanthium fecundum* (Figure 27) and *Panicum decompositum* (Figure 28). In contrast, *Brachyachne convergens* (a disturbance-tolerant annual grass), had its highest frequency closer to water in the continuously-grazed paddock (Figure 29), although trends were never statistically significant.

In May 2003 in the old water cell patterns in species frequency were somewhat similar to the continuously-grazed paddock, with a trend of lower *Dichanthium fecundum* and higher *Brachyachne convergens* frequency immediately adjacent to the water (Table 11, Figures 27, 28). However the frequency of *Dichanthium fecundum* increased and *Brachyachne convergens* decreased through time immediately adjacent to the trough in the old water cell, so that by 2005 *D. fecundum* was highest adjacent to the water and *B. convergens* was not recorded. The grazing-sensitive palatable annual grass *Chionachne hubbardiana* tended to have a higher frequency farther from water in the old water cell (Figure 30, Tables 11, 12).

In the new-water cell, there were initially few trends for any species frequency with distance to water, except that the *Dichanthium fecundum* frequency was highest adjacent to the water (Figure 28, Tables 11, 12), but this pattern had disappeared by 2004. The frequency of the unpalatable short-lived perennial grass *Aristida latifolia* was highest and increased most through time closer to water (Figure 31, Tables 11, 12). *Panicum decompositum's* frequency (Figure 28, Tables 11, 12) increased through time farther than 3 km from water in the new-water cell, but differences were not significant.

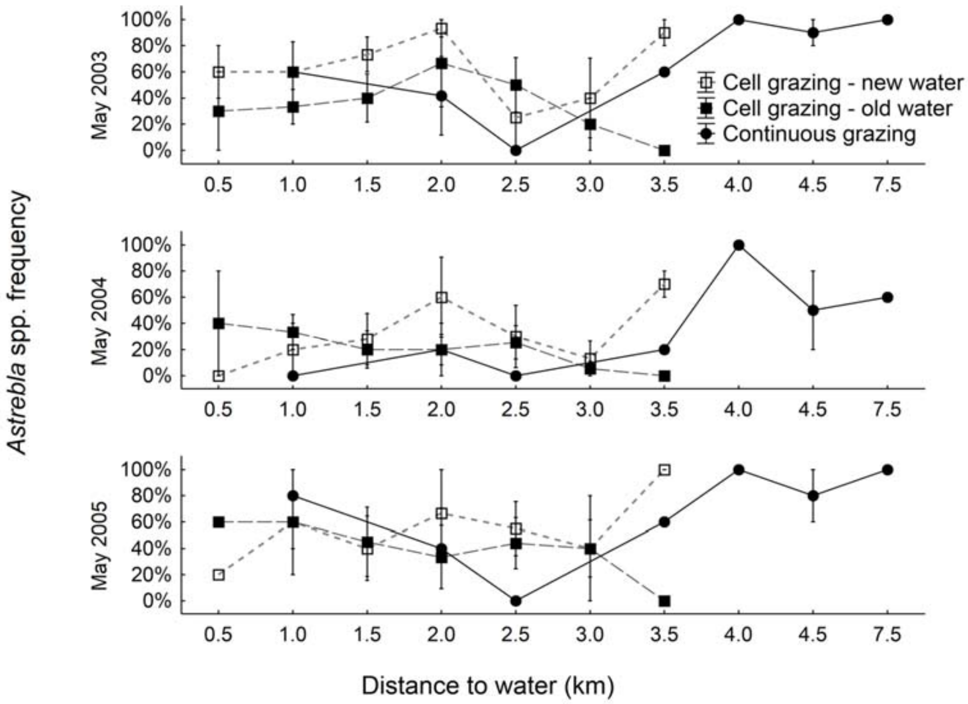

Figure 26. Mean ± SE all *Astrebla* spp. frequency with distance to water in the cell and continuously-grazed groups at Newcastle Waters Station

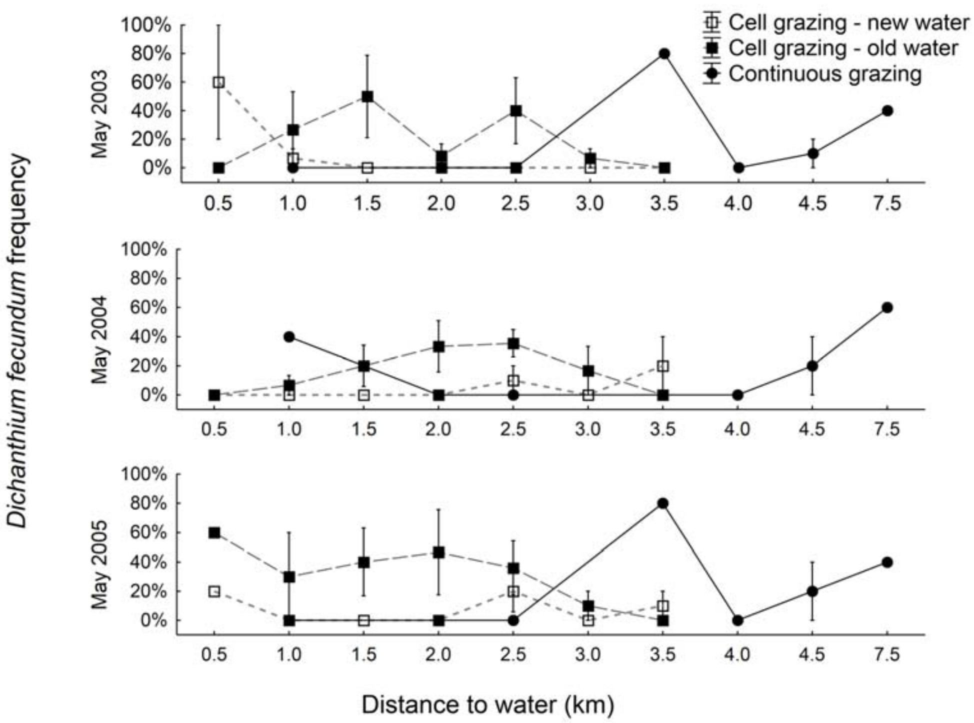

Figure 27. Mean ± SE *Dichanthium fecundum* frequency with distance to water in the cell and continuously-grazed groups at Newcastle Waters Station

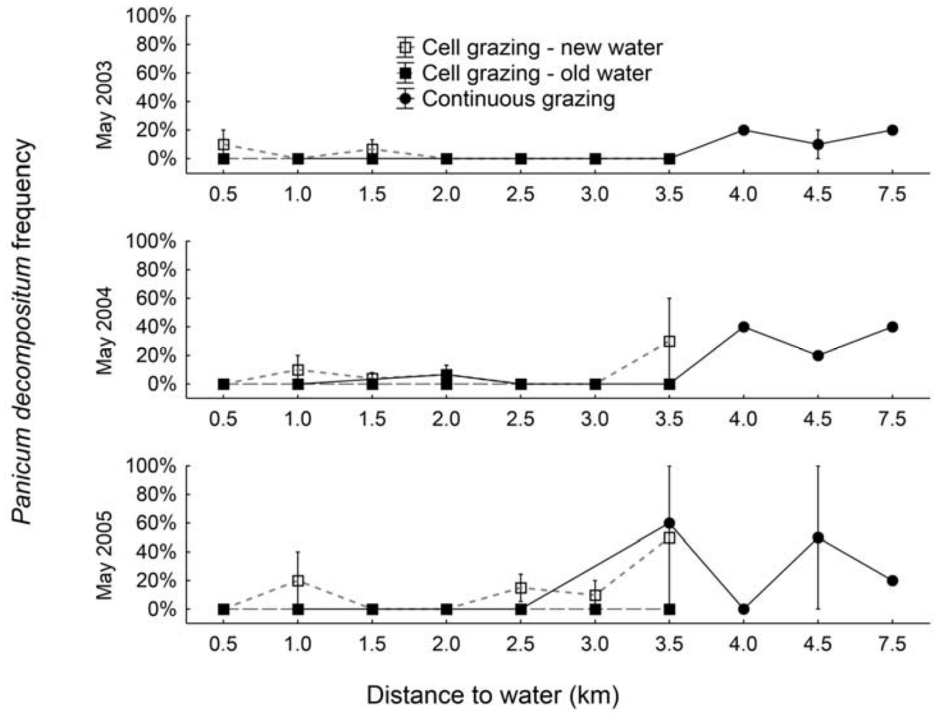

Figure 28. Mean ± SE *Panicum decompositum* frequency with distance to water in the cell and continuously-grazed groups at Newcastle Waters Station

Table 11. The effect of distance to water on yield, cover, per cent palatable grass yield and species frequency at Newcastle Waters Station

The Mann Whitney U-test for the relevant distance comparisons is listed. Only significant effects are shown. Where more than one distance comparison is significant, the highest significance comparison is shown.

Species	**Year**	**Cell grazing new water**		**Cell grazing old water**		**Continuous grazing**	
		Distance comparison	***P***	**Distance comparison**	***P***	**Distance comparison**	***P***
Yield	May 2003					<3 km vs. >3 km	0.046
	Nov 2003					<3 km vs. >3 km	0.04
Cover	Nov 2003	<3 km vs. >3 km	0.03				
	May 2004					<3 km vs. >3 km	0.02
% Palatable perennial grass yield	May 2003					<2 km vs. >2 km	0.01
	Nov 2003					<3 km vs. >3 km	0.01
	May 2004					<3 km vs. >3 km	0.04
	May 2005					<3 km vs. >3 km	0.036
Aristida latifolia	May 2004	<1.5 km vs. >1.5 km	0.04				
	May 2005	<1 km vs. >1 km	0.01				
Astrebla spp.	May 2004					<3 km vs. >3 km	0.04
Brachyachne convergens	Nov 2003	<1 km vs. >1 km	0.03				
Chionachne hubbardiana	May 2003			<2 km vs. >2 km	0.03		
	May 2005			<2 km vs. >2 km	0.05		
Dichanthium fecundum	May 2003	<1 km vs. >1 km	0.002				

Table 12. Spearman's correlation (r_s) between distance to water and species frequency in the cell and continuously-grazed groups

		Cell grazing new water (n=20)		Cell grazing old water (n=20)		Continuous grazing (n=10)	
	Date	r_s	***P***	r_s	***P***	r_s	***P***
Aristida latifolia	May 2003	**-0.47**	**0.03**	0.14	0.57	0.53	0.12
	Nov 2003	-0.20	0.41	0.16	0.49	0.50	0.14
	May 2004	**-0.47**	**0.03**	0.13	0.59	0.11	0.76
	Nov 2004	-0.31	0.18	0.07	0.74	**0.76**	**0.01**
	May 2005	**-0.48**	**0.04**	0.17	0.48	0.12	0.74
Astrebla all spp.	May 2003	-0.02	0.95	0.06	0.81	0.58	0.08
	Nov 2003	0.00	0.99	0.14	0.57	**0.70**	**0.02**
	May 2004	0.25	0.29	-0.39	0.09	**0.67**	**0.04**
	Nov 2004	-0.10	0.66	-0.21	0.36	0.33	0.34
	May 2005	0.18	0.46	-0.15	0.51	0.45	0.20
Brachyachne convergens	May 2003	0.06	0.81	-0.38	0.10	-0.54	0.10
	Nov 2003	-0.34	0.14	-0.25	0.28	np	np
	May 2004	np	np	-0.35	0.13	-0.52	0.12
	May 2005	np	np	-0.09	0.72	-0.52	0.12
Chionachne hubbardiana	May 2003	np	np	**0.59**	**0.006**	0.17	0.63
	Nov 2003	0.38	0.10	0.53	0.02	np	np
	May 2004	0.18	0.45	0.25	0.28	np	np
	Nov 2004	np	np	0.27	0.24	0.41	0.24
	May 2005	np	np	**0.61**	**0.004**	-0.41	0.24
Dichanthium fecundum	May 2003	**-0.62**	**0.003**	0.07	0.77	0.53	0.12
	Nov 2003	-0.20	0.39	0.01	0.96	0.56	0.09
	May 2004	0.32	0.17	0.27	0.25	0.27	0.45
	Nov 2004	0.01	0.96	-0.22	0.35	**0.70**	**0.02**
	May 2005	0.13	0.59	-0.13	0.58	0.52	0.13
Panicum decompositum	May 2003	-0.38	0.10	np	np	**0.72**	**0.02**
	Nov 2003	-0.11	0.65	-0.30	0.20	np	np
	May 2004	-0.02	0.92	np	np	0.70	0.03
	Nov 2004	0.05	0.82	0.26	0.27	0.25	0.49
	May 2005	0.32	0.18	np	np	0.62	0.06

(np = not present; significant correlations are highlighted in bold)

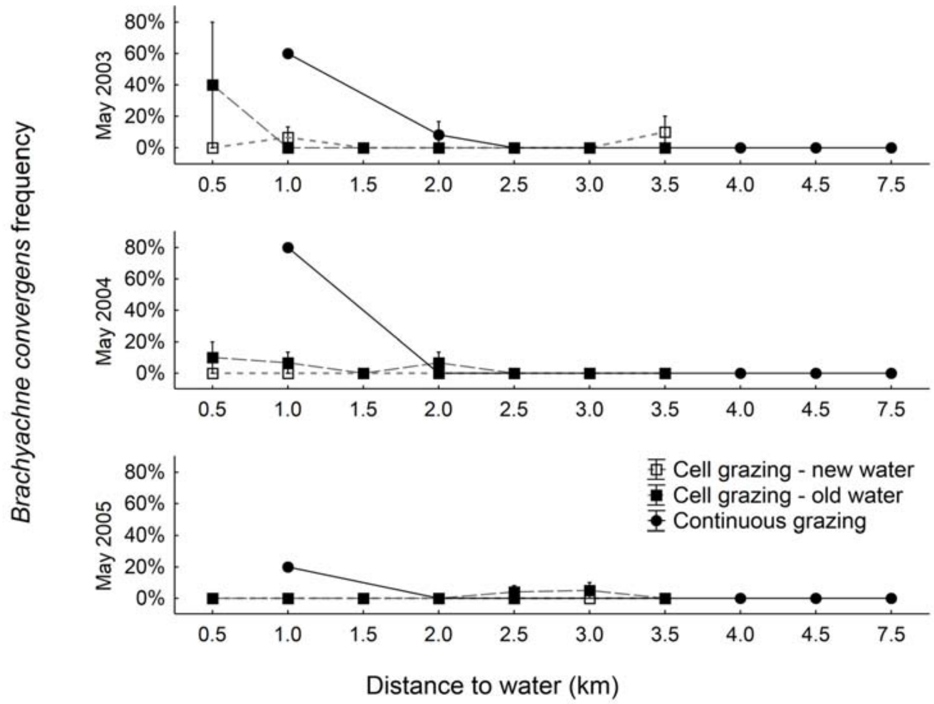

Figure 29. Mean ± SE *Brachyachne convergens* frequency with distance to water in the cell and continuously-grazed groups at Newcastle Waters Station

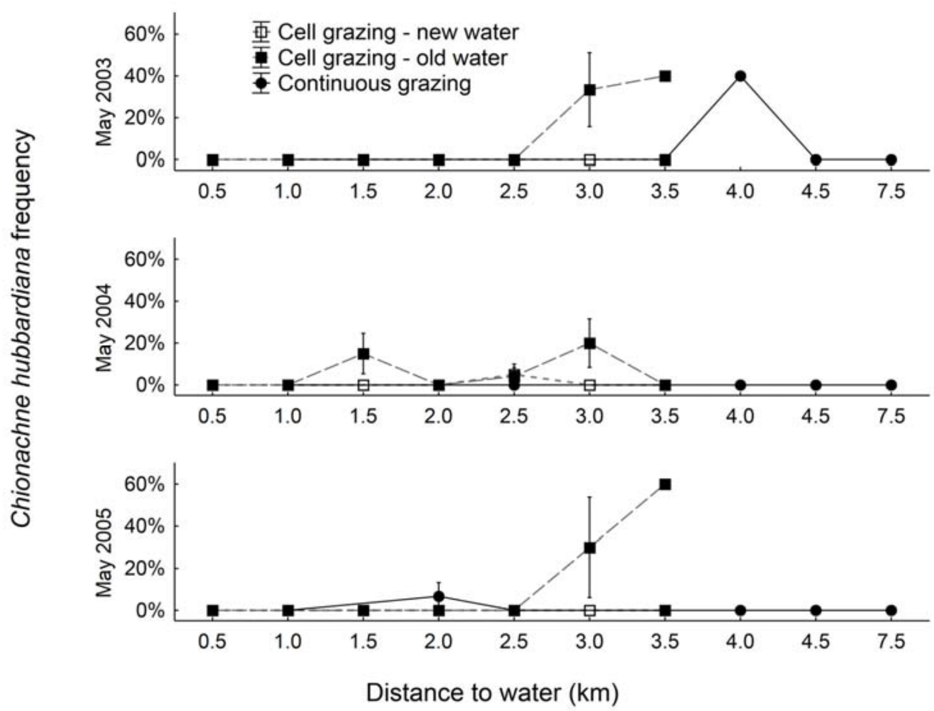

Figure 30. Mean ± SE *Chionachne hubbardiana* frequency with distance to water in the cell and continuously-grazed groups at Newcastle Waters

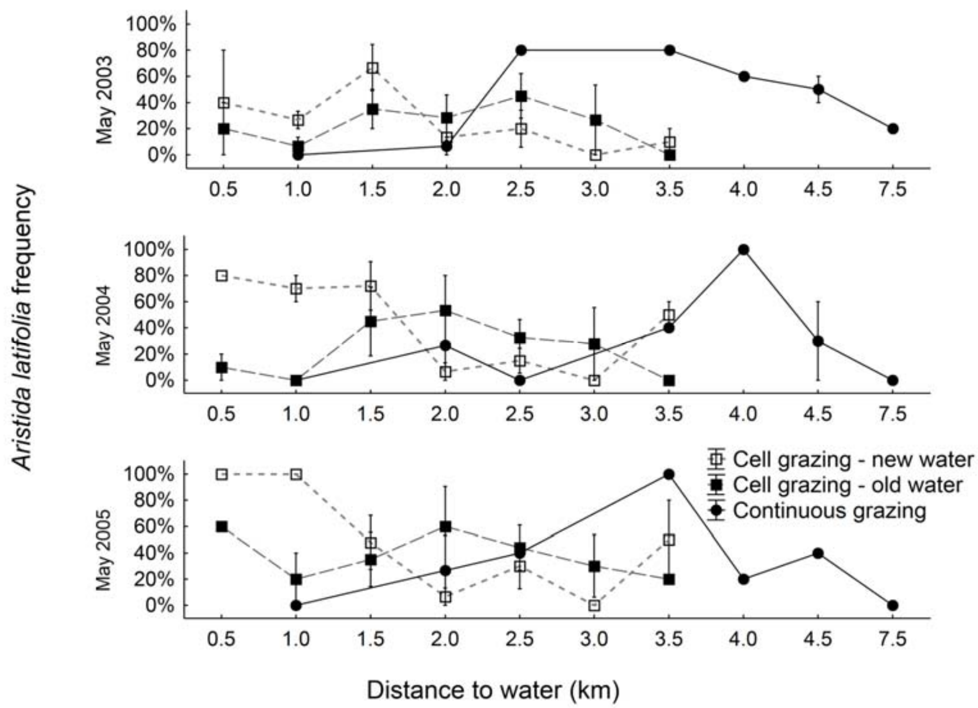

Figure 31. Mean ± SE *Aristida latifolia* frequency with distance to water in the cell and continuously-grazed groups at Newcastle Waters Station

3.4 Animal production

3.4.1 Diet quality

Dietary CP showed distinct seasonal differences during the trial (Figure 32). CP ranged between 3 and 7%, peaking during the wet season, and was at its lowest during the dry season. Without a measurement of sample variability to calculate an error term, or data from both treatments at each sample period, it is difficult to interpret the differences between treatments. Where NIRS samples were collected for both treatments in the same month, there was no consistent difference between treatments, although for 2004 CP did appear to be slightly higher in the continuously-grazed paddock.

Dietary DMD varied seasonally between 49 and 57% throughout the year (Figure 33). Means between the two treatments were very similar (within 1 to 2%) when samples were collected from both paddocks in the same month.

There was no clear seasonal or treatment-related trend in the non-grass fraction of the diet (Figure 34). The proportion of non-grass in the diet tracked the proportion of forbs in the pasture (apart from in May 2003) which ranged from 2 to 27% of total pasture yield (Figure 18).

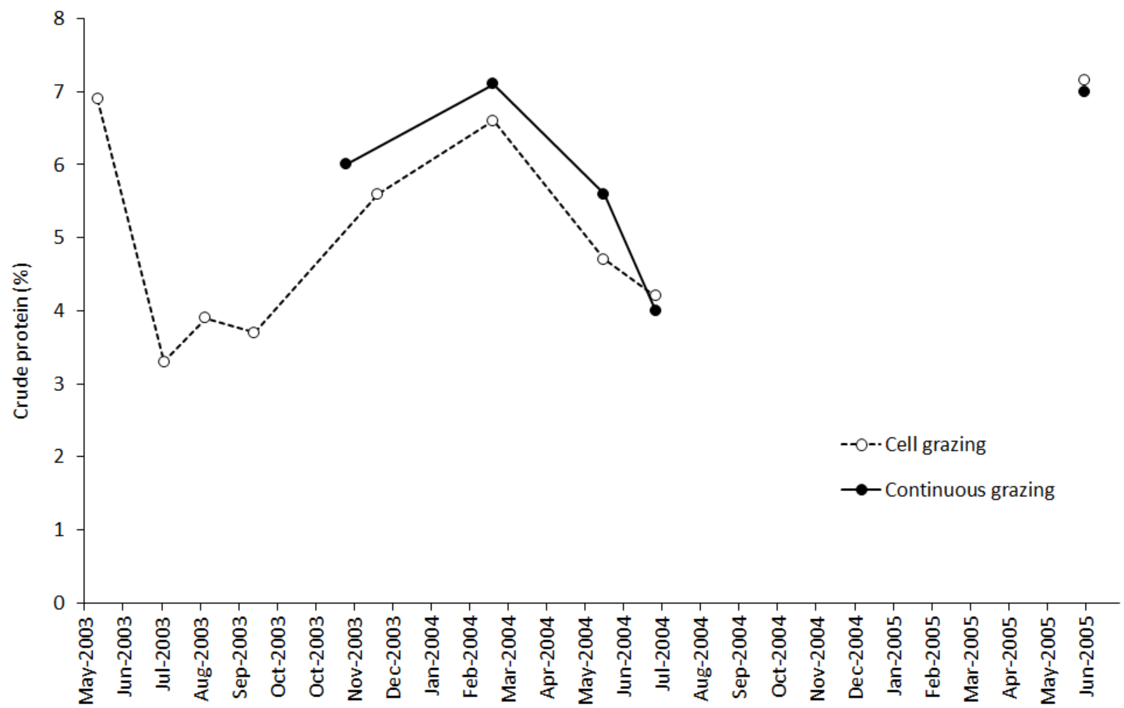

Figure 32. NIRS percent crude protein in the different grazing systems at Newcastle Waters Station

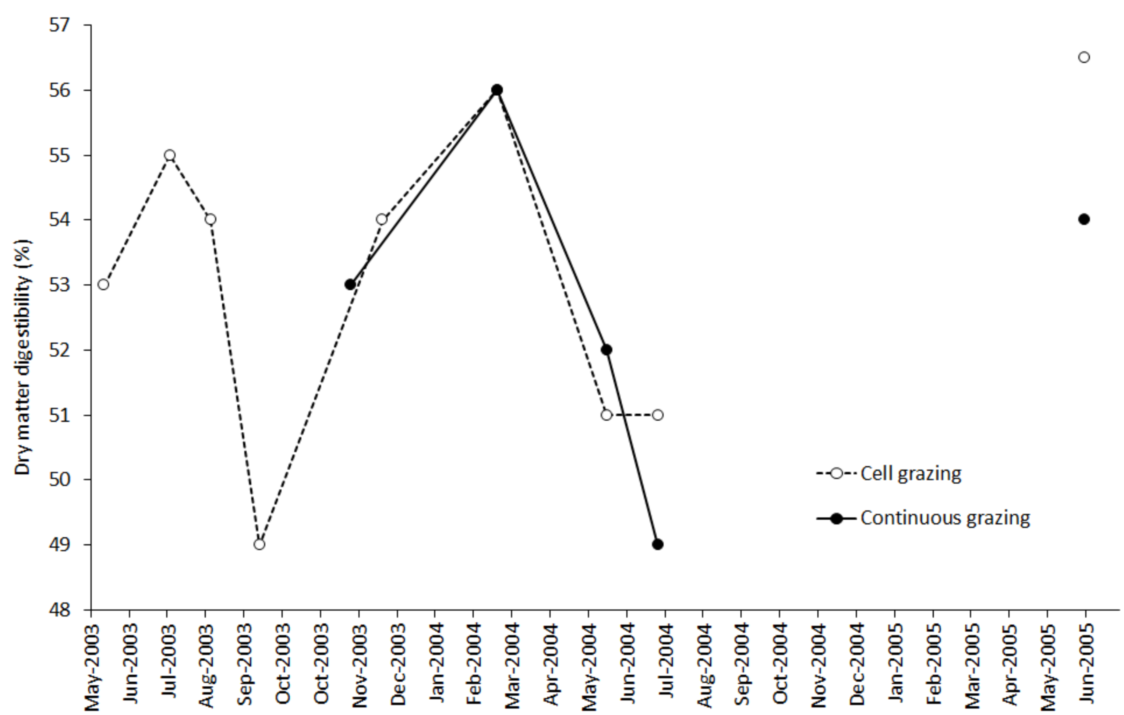

Figure 33. NIRS faecal dry matter digestibility in the different grazing systems at Newcastle Waters Station

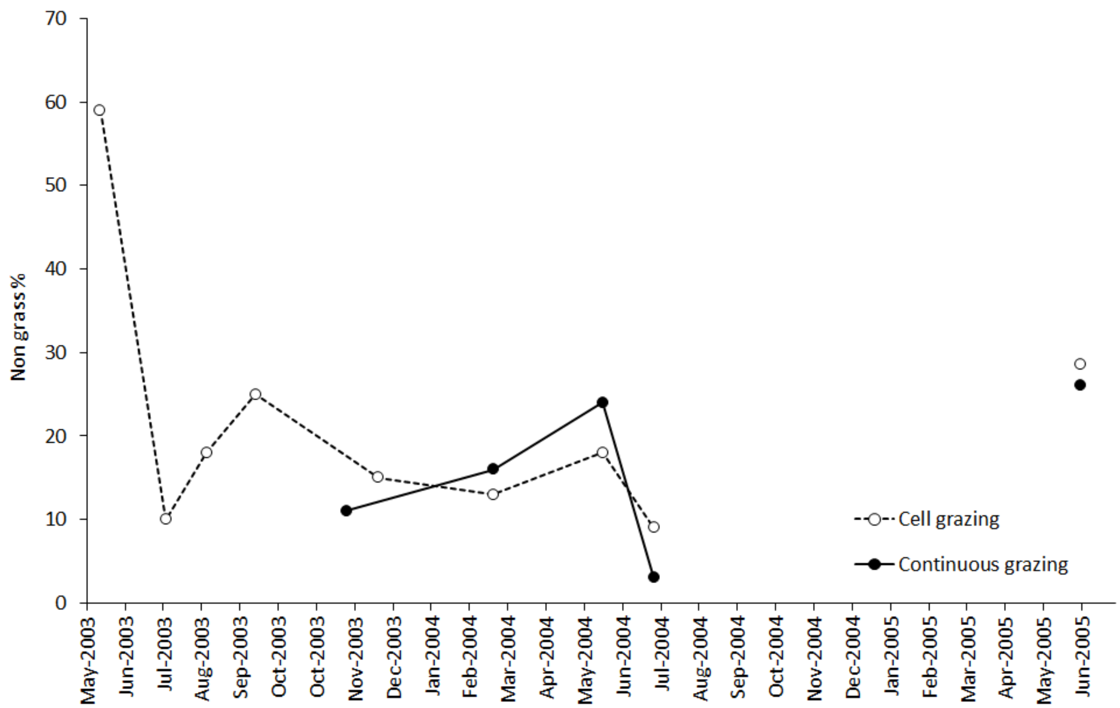

Figure 34. NIRS faecal non-grass per cent of the diet in the different grazing systems at Newcastle Waters Station

3.4.2 Live-weight gain per head

Mean LWG for the first year (May 2003 to May 2004) was approximately 20 kg higher for weaners in the continuously-grazed paddock than those in the cell-grazed paddocks (0.25 and 0.21 kg/day, respectively). Most of this difference between treatments reflected LWGs during the wet season (Table 13), although higher LWGs in the continuously-grazed paddock were also evident throughout the dry season (but differences were not significant).

Mean LWG in the second year (2004 to 2005) was significantly higher (by 12 kg) in the continuously-grazed paddock (0.22 vs. 0.18 kg/day, Table 13).

3.4.3 Live-weight production per area

In the first year, the lower LWG per head in the cell-grazing group was offset by the higher stocking rate which led to an 8% higher LWG per area (Table 14). In the second year, the lower stocking rates and LWG per head in the cell paddocks led to a lower LWG per area.

3.5 Economics

Notes on the design and cost of continuous and cell grazing at Newcastle Waters Station are presented in Appendix 3. The cost of fencing per km was approximately 10 times higher in the control paddock than in the cell paddocks because of the materials used. Cell-grazing paddocks used single or double hot wire fences at a cost of $350/km and $450/km, respectively; whereas traditional star picket-barb wire fencing was used in the control paddock (Table 15). Although there were no internal fences in the continuously-grazed paddock, the cheap hot wire meant that cell grazing was still much less expensive when considering both perimeter and external fencing together. The Brownies cell system fencing was the cheapest on a watered area basis, because internal paddocks were larger and there was less internal fencing than in the Langlands cell system (Table 1).

Table 13. Live-weight gain of cell and continuously-grazed steers and ANCOVA results

Live-weight gain period	Mean (SE) live-weight gain (kg)		*F*	*P*
	Continuous grazing	Cell grazing		
Dry season, Year 1 (May 2003 – October 2003)	20.6 (3.6)	17.9 (3.6)	$F_{(1, 38)} = 0.29$	0.59
Wet season, Year 1 (October 2003 – April 2004)	**61.6 (3.3)**	**51.7 (3.3)**	$\mathbf{F_{(1, 38)} = 4.71}$	**0.04**
Total Year 1 (May 2003 – May 2004)	82.2 (4.9)	69.6 (4.9)	$F_{(1, 38)} = 3.49$	0.07
Total Year 2 (May 2004 – May 2005)	**73.1 (2.9)**	**61.0 (3.3)**	$\mathbf{F_{(1, 34)} = 7.75}$	**0.009**

Statistically significant results (P<0.05) are highlighted in bold.

Table 14. Live-weight gain per area (kg/km^2) in the cell and continuously-grazed groups at Newcastle Waters Station

Year	Continuous grazing	Cell grazing
2003-2004	9.3	10.0
2004-2005	5.6	3.4
Average	7.4	6.7

A significant cost for both systems was water-point installation (Table 15). Whilst many paddocks destined for cell grazing may already have water points, the cost of installing them has been included to ensure a fair comparison between the systems. The cost of fencing materials, labour and water-point development resulted in the control paddock being much more expensive to establish than the cell-grazing paddocks at Langlands or Brownies, when considered on a watered area basis, partly because the large control paddock was not fully watered. The lifespan of the different fence constructions is not considered, but could lead to different cost effectiveness when considered on a long-term basis if, for example, the electric fencing required more frequent maintenance or replacement.

Whilst electric fencing was substantially cheaper in the cell-grazing paddocks than the permanent fencing in the control paddock, the cell paddocks required constant checking and so labour cost was much higher (Table 16). An hour was spent each day checking cattle, water points and power in the fence and identifying or preventing possible problems (this also increased vehicle running costs). Mustering costs were, however, significantly cheaper in the cell-grazing paddocks per muster, as considerably fewer staff were required to move animals (usually only one person, compared with five or six and a helicopter/plane or motorbike in the continuously-grazed paddock). However, the lower cost of moving animals in the cell paddocks was offset by the higher number of times animals were moved in them, such that annual mustering costs were similar in both systems. The labour and vehicle operating costs in the cell paddocks were 5.5 to 7.8 times higher (Table 16) when compared on a per AE basis, and 7.3 to 10.5 times higher when compared on a per area basis.

Table 15. Costs of constructing the cell-grazing and continuous-grazing systems at Newcastle Waters Station - hypothetical expenditure if starting from 'scratch' (i.e. no water points or fences)

	Runaway (continuously grazed)	**Langlands (cell grazing - small cells)**	**Brownies (cell grazing – large cells)**
Perimeter fencing (materials)	$3,000/km	$350/km	$450/km
Expenditure	$100,500	$4,760	$8,505
Internal fencing (materials)	n/a	$350/km + $3,000 (energiser)	$350/km + $3,000 (energiser)
Expenditure	$0	$9,720	$6,640
Labour (fence construction)	included in above cost	$600/week/person	$200/km
Expenditure	$0	$4,800	$5,860
Expenditure /km	$0	$353	$310
Total fence expenditure /km of fencing	$3,000	$703	$760
Waters	2 bores, 2 turkey nests, 2 troughs	1 turkey nest, 1 tank, 2 troughs, 1/2 a bore	1 turkey nest, 1 trough, 1/2 a bore
Turkey nests	$20,000	$10,000	$10,000
Bores	$30,000	$7,500	$7,500
Troughs	$6,000	$6,000	$3,000
Tanks		$10,000	
Waters total cost	$56,000	$33,500	$20,500
TOTAL EXPENDITURE	$156,500	$52,780	$41,505
Cost per km^2 (total paddock area)	$2,795	$3,691	$2,025
Cost per km^2 watered area (paddock within 3 km from water)	$6,925	$3,825	$2,196

Table 16. Annual operating costs of the different grazing systems at Newcastle Waters Station

	Paddock		
	Runaway (continuously grazed)	**Langlands (cell grazing)**	**Brownies (cell grazing)**
Bore and fence check			
Details @$10/hr labour	Check twice weekly @ 1 hr	Check 7 times per week @ 1 hr	Check 7 times per week @ 1 hr
Expenditure	$1,248	$4,368	$4,368
Vehicle costs bore and fence check			
Details @$0.72/km	Twice weekly at 10 km	7 times a week @15 km	7 times a week @15 km
Expenditure	$520	$2,730	$2,730
Moving animals			
Details	twice yearly 7 hrs x 6 people on horses + bike + plane @ $200/hr for 1 hr	once per week @ 3 hrs when stocked (assumed 75% of time)	once per week @ 3 hrs when stocked (assumed 75% of time)
Expenditure	$1,408	$1,404	$1,404
Total operating costs	$3,176	$8,502	$8,502
Operating cost / AE*	$9.30	$72.67	$51.22
Operating cost per km² (whole paddock)	$56.71	$594.55	$414.73

*Based on AE in the systems in 2003-2004

4 Discussion

4.1 Implementation of treatments

The cell-grazing system was implemented as rotational grazing with spelling, with rests sometimes occurring for an extended period during the wet season due to difficulties accessing the cracking clay site when wet. The cell- grazing system adjusted stocking rates to available forage on a weekly basis and rested pastures for around three months each wet season as well as shorter duration rests between rotations during the dry season. The different grazing systems had similar average stocking rates (considered across the whole paddock), but varied in paddock design and grazing system (timing and density of stocking and resting). The different paddock design influenced spatial distribution of grazing in the two systems; the continuously-grazed paddock was much larger and less well watered. Hence, while the average annual stocking rate was similar, the shorter-term stocking rates varied between the systems, both temporally and spatially.

Visual estimates of defoliation in the late dry season can be a good indicator of utilisation (Hunt et al. 2013). Wet season defoliation was low in both systems, but by the end of the dry season in November 2003, defoliation in the cell paddocks was higher than recommended (>25%) at more than half the sampled sites. This compares with 20 to 25% annual utilisation rates recommended for more productive black soils of the Victoria River District (Cowley et al. 2007) and Barkly Mitchell grasslands (Walsh and Cowley 2011). However, pastures are most susceptible to grazing in the wet season when they are actively growing (Ash and McIvor 1998) and higher utilisation, when pastures are largely dormant in the late dry season, has been found to be compatible with maintaining pasture condition in northern Australia (Ash and McIvor 1998; Ash et al. 2011). The high defoliation in May 2005 was a direct result of the low rainfall and fire removing all or part of the previous season's growth, and occurred despite the removal of most stock from the paddocks directly after the fires, demonstrating the challenges in managing utilisation to within safe levels in a variable climate with the added complication of random, but sometimes extensive, wildfire activity.

4.1.1 Were the principles of cell grazing successfully applied in this study?

The managers at the site were very keen for the implementation of the cell grazing to follow the six principles of cell grazing. Four of the six cell grazing principles were successfully applied at the cell grazed site:

1. Plan, monitor, manage – Stock movements were recorded on grazing charts. Animals were moved according to the utilisation of forage in the cells. A backup "holiday" paddock was reserved for when cells ran out of forage due to grazing or wildfire.
2. Rest - Rest was incorporated as part of the cell rotation and in the latter years also during the wet season.
3. Match stocking rate to carrying capacity – The cells were stocked according to carrying capacity and adjusted to the seasonal variation in the available forage.
4. Manage livestock effectively – The stock were quiet and calm due to their regular handling with low-stress techniques.
5. Maximum stock density – The stock density of the cells was much higher (10 to 234 times higher) than the continuously grazed treatment, but it was still usually lower than recommended levels of 10 head/ha.
6. Manage for biodiversity to improve ecosystem services – We did not attempt to quantify this.

The cell grazing literature frequently refers to the aim of keeping plants in phase II growth, but especially avoiding phase 1 growth, where plants have been defoliated so much that they have to redraw on root reserves to replace their leaves (McCosker 1993). Given the reliably short growing season in the Barkly, it is not possible to keep plants in phase II all year round, as they run out of water. However, the combination of the regular application of rest and matching stocking rate to carrying capacity in smaller more accessible paddocks probably contributed to the lower levels of severely defoliated plants in the cell paddocks and presumably would have prevented plants from being overgrazed to the point of returning them to phase I growth. High stock density is purported to contribute to positive trampling effects by converting unpalatable plants to litter (McCosker 1993), although this has not been scientifically demonstrated. Stock densities were lower in this study than those recommended by cell grazers for positive trampling effects and there was no attempt to measure the effect of trampling. There was no difference in ground cover, TSDM or species trends that could be attributed to the application of cell grazing during the study.

4.2 Pasture composition

4.2.1 Pre-existing land condition differences between systems

Species composition varied between the two systems. Throughout the trial, annual grasses comprised a greater proportion of the total yield in the cell-grazing paddocks. This was apparent from the first sampling in May 2003 and is likely due to the historical use of the cell paddocks as holding paddocks on the Barkly Stock Route more than 20 years ago.

Despite differences in species composition, average yield and ground cover were quite similar between grazing systems from the beginning of the trial until May 2005 following the fire in late 2004.

4.2.2 Change through the trial – whole paddock

Managers observed that paddocks heavily grazed for two to four weeks followed by rest (in the dry or wet season), led to a greater abundance of perennial grasses. Although yield and defoliation fluctuated seasonally, there was little evidence of treatment-related impacts on cover, yield or species composition at the paddock scale. There was no evidence of paddock-scale land condition improvement in either system despite good seasonal conditions in 2004, low wet season defoliation levels and wet season spelling in the cell paddocks. The absence of an effect of grazing system on rangeland condition found here is consistent with research over the last 50 years both internationally (Briske et al. 2008) and in a recent study at nine sites across Queensland (Hall et al. 2014). However, the lack of vegetation change at Newcastle Waters may simply reflect the short duration of this study. Recent guidelines for resting to promote pasture recovery suggest several full wet season rests during good seasonal conditions are required to promote land condition recovery from C (poor) condition (Hunt et al. 2014). The low proportion of perennial grasses in the cell paddocks indicates C condition.

There was no decline in pasture composition despite higher than recommended defoliation in the cell paddocks in late 2003, consistent with guidelines that suggest higher late season defoliation is sustainable when combined with moderate wet season utilisation and wet season spelling (Ash and McIvor 1998; Ash et al. 2011).

Fire in the late dry season, coupled with a poor wet season in the months following, appeared to influence the yield of annual grasses more than perennial grasses (compare Figures 14 and 15). Perennial grasses often sprout vigorously following disturbance and so exhibit low mortality during fire (Mott and Andrew 1985; Sarmiento 1992). Resistance to fire by perennial grasses (indicated by perennial grass yield expressed as a proportion of the total yield) has important consequences for maintaining the stability of the ecosystem.

Annual grasses and forbs, on the other hand, must rely on effective seed bank processes - a bank of viable seeds in the soil that germinate to become the next generation of plants, in order to persist (Thompson and Grime 1979; Fenner and Thompson 2005). The combined effect of fire followed by low rainfall is likely to have contributed to the crash in annual grasses in May 2005. Many of the annual grass seeds on the soil surface were likely to have been destroyed during the fires in late 2004 and annual grasses can experience low rates of establishment and desiccation (leading to mortality) where follow-up rainfall after germination is inadequate (Andrew and Mott 1983; O'Connor 1994; Crowley and Garnett 1999). Conversely, the proportion of annual grasses in the pasture increased in 2004, responding to the run of wetter than average years.

4.2.3 Evenness of grazing – within paddock patterns

Average paddock-scale changes are at best only rough indicators of change because grazing and land condition are often spatially variable in extensive rangeland systems (Hunt et al. 2007). An examination of within-paddock scale patterns in defoliation and vegetation showed more complexity than at the whole paddock level.

High density short duration stocking in cell-grazed systems is thought to reduce animal selectivity, leading to more even utilisation between species, reduced patch grazing and more even grazing across paddocks (McCosker 1993, Savory and Butterfield 1999; Briske et al. 2008, Norton et al. 2013).

At the plant scale, there was little evidence that different species were grazed more evenly in the cell system where preferred species were still more heavily grazed. This was rarely the case in the continuously-grazed paddock, although this may partly be an artefact of sample design because the area where the highest grazing occurs (within 500 m of water), was not sampled in the control. Furthermore, preferred species were most commonly found at least 2 to 3 km from water in the continuously- grazed paddock, probably due to historically heavy grazing closer to water. Because grazing is lower far from water, preferred species far from water will tend to have lighter grazing. The heavier grazing of preferred species in the cell paddocks reflects their distribution within the grazing range of water. This could advantage less preferred species leading to changes in species composition over time, although the regular rest of plants from grazing may prevent this. A review of grazing management impacts on grazing distribution (Norton et al. 2013) also found that defoliation of individual plants was not altered by grazing regime. However it has also been argued that stocking densities of less 10 head/ha are inadequate to improve the evenness of grazing (McCosker 2000). Hence, following this logic, stocking densities in this study may have been too low to reduce selective grazing.

At the small-patch scale (4 m^2 quadrat) the wet-season spelling in cell-grazed paddocks meant more quadrats were still ungrazed in May than in the continuously-grazed paddocks. However, by the end of the dry season in November, cell grazed-paddocks were less likely to have ungrazed or heavily-grazed patches, suggesting a more evenly-grazed pasture than in the continuously-grazed paddock.

At the paddock scale, the cell paddocks were also more evenly grazed out from water. Cattle spend most of their time within 3 km from water (Hunt et al. 2013). Hence, the more accessible water in the cell paddocks, which were mostly within 3 km of water, meant that most of the cell paddocks were within grazing range. This compares to the larger continuously grazed paddock where 57% of the total area was farther than 3 km from water. Smaller paddock sizes also lead to more uniform grazing (Barnes et al. 2008). Hence, both smaller paddock size and full access to water could have contributed to more even spatial use in the cell paddocks (Norton et al. 2013), as demonstrated with fewer ungrazed quadrats in November (11% vs. 40% in the continuously-grazed paddock, averaged over two years).

In the Victoria River District (VRD) of the NT, cell grazing was also associated with more uniform grazing distribution at the paddock scale (Cowley et al. 2013b). Whether the short duration, high-intensity grazing of the cell paddocks contributed to more even grazing in either this or the VRD study is unknown, but it is possible that paddock configuration alone could have led to more even grazing in the cell paddocks.

In the later part of this and the VRD study of cell grazing (Cowley et al. 2013b) heavier grazing closer to water in the cell paddocks was becoming evident. This suggests that with time, typical grazing gradients may also develop in cell paddocks. A longer period of monitoring would confirm this. Both these studies had time frames in the order of three years, whereas grazing gradients continue to develop over many years (Hunt 2001; Scott et al. 2010).

4.2.4 Spatial distribution of pastures

Higher historical utilisation closer to water in the continuously-grazed paddock and the old water cell is likely to have contributed to the pattern of lower yield and cover, %PPG and higher *Brachyachne* (a short disturbance tolerant annual) frequency closer to water in these paddocks in 2003. Lower yield and cover, and higher *Brachyachne* presence have previously been associated with high utilisation across the Mitchell grasslands (Cowley et al. 2007; Orr and Phelps 2013). Elsewhere in the region, old water points with a long history of grazing also have lower yield and cover, and a higher frequency of *B.convergens* closer to water points (Fisher 2001; Scott et al. 2010).

The more spatially uniform grazing in the cell-grazed paddocks was reflected in their more spatially uniform yield and cover. Managers at Newcastle Waters Station reported an anecdotal increase in perennial grasses close (less than 1.5 km) to watering points in cell-grazing paddocks. Adjacent to the pre-existing water in the old water cell, the increase in total yield, %PPG yield and the frequency of several palatable perennial grass species between May 2003 and May 2005, combined with a decline in the disturbance tolerant *Brachyachne*, suggests there was recovery of the overgrazed area near water with the introduction of cell grazing in the old water cell. The absence of a recovery in ground cover adjacent to the water in the old water cell, despite improvements in yield and %PPG, suggests that the vegetation was quite patchy, with smaller areas of high-yielding palatable perennial grass tussocks interspersed with patches of very low cover.

Conversely, the increase in the frequency of the unpalatable *Aristida latifolia* and a decline in *Dichanthium fecundum* frequency near water in the new water cell suggest a slight decline in pasture condition immediately adjacent to the new water, despite ground cover remaining relatively high.

In the continuously-grazed paddock, some palatable species (*Chionachne hubbardiana* and *Dichanthium fecundum*) existed only at distances greater than 3 km from water, which will tend to reduce the grazing they have experienced, and suggests the heavier grazing within 3 km was not compatible with their persistence. Similarly, the lighter grazing at distances greater than 3 km from water in the new water cell may have influenced the increase in *Panicum decompositum* frequency observed there.

4.3 Animal production

4.3.1 Diet quality

Seasonal differences in faecal CP and DMD reflected seasonal changes in the pasture growth phase and composition. The concentration of N and P in plant tissue increases sharply during the early wet season and then steadily decreases over the dry season in tropical grassland systems (Norman 1963; McIvor 1981).

It is often claimed that cell grazing can improve diet quality by keeping pastures in the high nutrient value vegetative growth phase, known as ‘phase 2’ (e.g. Savory and Butterfield 1999), and the managers at Newcastle Waters Station reported green growth on plants during August to October (without rainfall). Once the air temperatures started increasing after July, the plants responded to moisture in the soil. The potential to keep plants in phase 2 growth in northern Australia is, however, limited by a short growing season, with growth limited by low water availability for much of the year (Mott et al. 1985). A combination of field measurements and modelling of pasture growth measured at SWIFTSYND sites on Newcastle Waters Station suggests the growing season (when any growth can occur) varies between one to 10 months a year, but averages about six months (R. Cowley unpublished data), which is consistent with estimates for similar regions (Hall et al. 1998). During the dry season, the potential for growth is close to zero, so any increase in yield and/or diet quality with this observed regrowth in cell-grazed paddocks is likely to be very small. Furthermore, the opportunity to take advantage of phase 2 pasture growth in cell grazing in northern Australia is also limited because it is restricted to the mid-wet season, which lasts for approximately two to three months a year, when paddocks are often inaccessible.

Hence, both here and in other studies comparing diet quality between cell and continuously-grazed systems in northern Australia, there was no evidence that cell grazing had higher diet quality. Rather, studies have found either no effect of grazing system on diet quality (Hunt et al. 2013) or the opposite (Hall et al. 2016), with diet quality higher in continuously-grazed compared with cell-grazed systems. This is consistent with the higher faecal CP levels in the continuously-grazed system in 2004, in this study. However, the lack of data from both treatment groups at each sample period limited the capacity to adequately test this here.

The managers noted that differences in diet quality may have reflected the naivety of weaners grazing cell paddocks. The relatively short grazing periods, before animals being moved on, meant cell animals were less familiar with pastures in the cell paddocks, which can lead to a lower quality diet as well as lower total intake (Provenza and Balph 1987; Provenza et al. 1992). This is in contrast to the breeding herd, where the cattle spent years in the paddock and were more familiar with its pastures and may have developed grazing habits that maximised their diet quality and quantity.

4.3.2 Live-weight gain

The higher LWG in the wet season compared with the dry season reflected the seasonal changes in diet quality and quantity observed at the site and is consistent with intra-annual LWG patterns in northern Australia (Bray et al. 2015; Hunt et al. 2013; Streeter et al. 2013).

The higher LWG in the year ending in May 2004 reflected a better wet season and pasture growth that year.

LWG in this study (0.18 to 0.25 kg/head/day) was very low compared with proposed reference LWG for one- to two-year-old steers in the Barkly (0.31 kg/head/day, Bray et al. 2015) and to a study in the VRD (0.26 to 0.36 kg/head/day, Hunt et al. 2013). However, LWG was closer to the lower range of LWGs found on Barkly stations (Streeter et al. 2013) where two stations had mean LWGs of 0.20 and 0.26 kg/head/day. LWG per area (3.4 to 10 kg/ha/year) was also much lower in this study compared with that measured in the VRD (15 to 25 kg/ha/year, Hunt et al. 2013)

The consistently higher LWG in continuous grazing compared with cell grazing, regardless of seasonal or inter-annual variability in rainfall and pasture growth is consistent with the lower stocking rate during the growing season in the continuously-grazed paddocks (Figure 5). Average stocking rates across the entire year were similar between treatments whether considered on a whole or a watered-area basis. Most LWG occurs during the wet season (e.g. Bray et al. 2015; Streeter et al. 2013) when N and P are less limiting to animal growth. Hence, it follows that wet season utilisation will be critical to the LWG achieved. The different pasture composition may have also contributed to differences in LWG between the treatments, as suggested by the slightly higher crude protein levels in the continuously-grazed paddock.

Most grazing trials that compare rotational and continuous grazing conclude that differences in LWG reflect differences in stocking rates within the different treatments (Heitshmidt et al. 1987; Heitshmidt et al 1990; O'Reagain et al. 2009). LWG declines with higher stocking rates and utilisation (Jones and Sandland 1974; Cowley et al. 2007; O'Reagain et al. 2009). Given the similar yields in cell and continuous groups, higher stocking rates could have led to a reduced quantity, and possibly quality, of forage available per animal in the cell paddocks.

However, factors other than grazing treatments and stocking rates may have influenced indicator steer LWGs here. The managers disclosed that cattle in the control paddock were fed Anipro (a molasses based protein and mineral supplement) for six weeks a year, while the cell group were not, which in itself could have contributed to higher LWG in the control steers. Furthermore, following fires in December 2004, indicator steers were moved out of the cell paddocks and put in the control paddock, until the control paddock was burnt and all animals were moved to a farther paddock.

In cell paddocks, despite the lower LWG per head in the first year, LWG per area was slightly higher because stocking rates were higher. In the second year the lower LWG per head and the reduced stocking rates both lowered the LWG per area. This highlights the need to achieve higher stocking rates to make the more intensive cell system pay its way, both for the infrastructure setup and higher operating costs. The managers thought that the cell paddocks were not used to their capacity, so that with higher use, the LWG per area could have been increased beyond what was observed in this study.

Establishing a network of smaller paddocks and/or water points, such as in a cell-grazing system, can increase the paddock's watered area and increase grazing distribution at the paddock and landscape scales (Hunt et al. 2007; Hunt et al. 2013; Scott et al. 2010). Whilst this may increase animal production per unit area, LWG per head is still dependent on within-paddock factors relating to utilisation and diet selection (Hunt et al. 2007). In this trial, the more intensive cell system resulted in a decline in production per head.

4.4 Economics

Cell grazing had lower setup costs but much higher operating costs. Despite the higher operating costs, cell grazing was considered by management to be cost-effective. This would depend on the returns from the different systems. In the first year, LWG per area was greater in the cell system, which may have offset the higher costs of operation.

When considering whether it is more economical to convert to a cell system the following factors should be assessed:

- Infrastructure setup costs.
- Potential carrying capacity with the new system (compared with the current carrying capacity and compared with other ways to increase carrying capacity).
- Decreased LWG per head in cells.
- Higher ongoing operating costs of cells.
- Higher skill level and ongoing management inputs required to run cells.
- Potentially higher (long-term) maintenance costs of cell infrastructure.

Whether the cell system can sustain higher stocking rates than the current infrastructure will be a key factor in determining whether the cell system will be more profitable, given the considerably higher operating costs. In this study, the cell paddocks were better watered, which meant that nearly all the cell paddock's area was within 3 km from water. This alone meant that the carrying capacity of the cell paddocks was higher when considered on a total paddock-area basis.

Other options to increase carrying capacity could be considered. For example, additional water points could be added to increase the watered area without the additional fencing infrastructure required for cell paddocks. In the Pigeon Hole Project in the VRD, the higher operating and infrastructure costs of the cell system did not result in higher carrying capacity, compared with fully watered continuously-grazed systems of similar paddock size (Hunt et al. 2013). This meant that the cell paddocks had lower economic returns at equivalent stocking rates. However, the study did find that adding water points was less effective unless additional fences were also installed to achieve a better use of a paddock. The VRD study considered the optimum paddock size for best use and least cost and found it to be around 30 to 40 km^2 with two water points. Factors to consider when developing northern Australian cattle enterprises are described in detail in Petty et al. (2013).

An unknown in this study is whether over the longer term, cell grazing would lead to better land condition and hence carrying capacity, which could potentially improve the economics of implementing cell grazing. This is a clear expectation in the cell-grazing literature (Savory and Parsons 1980), but we were unable to demonstrate it here, possibly because of the short timeframe of this study. The cell-grazing system here incorporated wet season spelling, which in itself may lead to improved land condition (Hunt et al. 2014), without the added short-duration high-intensity grazing implemented in the cell paddocks here and with considerably less infrastructure required than the most intensive cell setup. Indeed, provided grazing systems were stocked according to carrying capacity and included spelling, there was no difference in ecological results or stocking rates achieved between continuous, extensive or intensive rotation systems in a review of Queensland case studies (Hall et al. 2014). Hence, careful consideration of likely costs and advantages of potential grazing systems is pertinent.

4.5 Implications for industry

4.5.1 Practicality

The cell-grazing system implemented at Newcastle Waters Station was practical to run as it complemented other operations at the station. Therefore, the practicality of the system may be dissimilar at other locations where operations are considerably different. Cattle were inducted into the system using an electrified training wire at weaning and by using low-stress stock handling skills throughout. When animals were inducted properly, there were few problems with their behaviour. The only exception to this was if feed or water became unavailable, or wild dogs were present; cattle would then run through the electric fence, but settled down once the source of the problem was removed. A nightly practice (for a few nights) of locking cattle up in the yard would help control frightened rushes (B. Krafft pers. comm.). The presence of wild dogs would also result in weaners being huddled in a mob, which the managers considered undesirable in terms of pasture utilisation and temperament. Stud weaners in the cell-grazing paddocks were far easier to manage than weaners in the continuously-grazed paddock by virtue of the additional handling, such that one person on foot could walk 1000 head and yard them alone in the cell paddocks. The cell system was very flexible and responsive to variable climatic conditions.

4.5.2 Animal production

The managers reported that greater production (per hectare rather than per head) was achieved in the cell-grazing paddocks, but this varied annually during the trial depending on the stocking rates in the cell paddocks. Mortality was much lower in the cell-grazing paddocks (< 0.05%; one animal) than in the continuously-grazed paddock (3%), perhaps due to frequent observation of cell paddocks (every two to three days to check water and fences) or due to smaller distances to water. The higher mortality in the continuously-grazed paddock was attributed to the different class of animals (a breeding herd), which would naturally have higher mortality levels than weaners. For example, the mature cows in the control paddock were older than the cell animals and were subject to higher rates of mortality resulting from pregnancy and calving. Control paddock cattle may have needed to walk farther to find nutritious feed, as the control paddock was less well watered. In the cell paddocks, problems that could lead to mortality, such as the presence of wild dogs, supplement or water deficiencies, or sick animals, could be quickly addressed. The frequent observations of weaners in the cell-grazing paddocks gave managers a better handle on their development and nutrition (B. Krafft pers. comm.).

4.5.3 The future of cell grazing at Newcastle Waters Station

New management at Newcastle Waters Station chose not to cell graze Langlands and Brownies paddocks. Whilst the reasons for this are unclear, it is evident that the success of any novel grazing system relies on the enthusiasm and skills of the people running it. Cell grazing requires more intensive management with daily decision making based on pasture observations, which without relevant training, may be daunting or appear difficult. Other stated reasons for discontinuing the trial included the extra labour required and ongoing problems with electric fence maintenance. Cell grazing requires daily management and therefore must have adequate resources. The former managers of Newcastle Waters Station have expressed a desire to continue to implement cell grazing elsewhere if opportunities arose.

4.5.4 Lessons learned

A number of key lessons became apparent to the managers from the results of this trial:

- Staff training is essential. People need to be trained properly about running an intensive grazing system, otherwise it will not work.
- Cell grazers must be prepared to change what they are doing very quickly (adaptability is essential).

- Cell grazing provides an excellent way to train staff (e.g. jackeroos and jillaroos) about animal behaviour, husbandry and pasture composition, as well as how to train dogs and horses to work with cattle.
- Cell grazers should seek professional advice regarding cell design.
- The limitations of different types of country must be understood. For example, how much Mitchell grass can be consumed and still have the capacity to regenerate and when will animals consume weeds, etc.
- It may be feasible to use a single-sire herd or joiner heifer mob to 'knock down' rank pasture and provide green pick for a group of stud weaners. However, with black soil paddocks, animals cannot be placed in them until the end of the wet season, when pastures have progressed past the initial growth phases.

The previous managers of Newcastle Waters Station have the following practical advice for running cell grazing:

- Make sure animals are well trained onto a hot wire before letting them loose in the cell (they must learn to respect the single hot wire). A small training paddock with a yard is suitable for this purpose (animals can be locked up at night to prevent rushing).
- Use smaller paddocks – the cell-grazing paddocks in this trial were generally too large to achieve a uniform grazing pressure. However, the cost effectiveness of this may be problematic, given the cells were already fully watered; hence, further infrastructure would not increase carrying capacity, unless improvements in land condition could be achieved.
- Always look at available feed and only take a small percentage.
- Cattle will generally tell you if they need to shift (by escaping).
- Get good advice on electric fencing and the biggest available energizer.
- Isolate each fence with switches to send more volts where needed and for problem solving (e.g. determining the location of faults).

5 Conclusions and Recommendations

The managers at Newcastle Waters Station implemented the cell-grazing system with the aim of achieving better pasture utilisation, an increase in grass cover and perennial grass abundance around water points, and an improvement in the temperament of stud weaners. The additional infrastructure in cell paddocks increased their carrying capacity because it increased the area within grazing range (3 km) from water. Vegetation changes that occurred over time reflected changes in rainfall intensity, timing and fire rather than the grazing system. Any changes in pasture composition, as a result of a grazing system are only likely to become evident over a longer period of time (e.g. greater than five years). The trial did, however, demonstrate more even grazing and recovery in perennial grass species and yield adjacent to a pre-existing water in the cell paddocks, but this was partly offset by a decline in pasture composition out from the new water point. Managers also reported that more intensive handling in cell grazing led to better temperament in stud weaners allowing easier management.

The primary objective of this study was to gain an understanding of whether cell grazing was a practical and economically viable method of beef cattle production in the region compared with traditional continuous stocking. The managers judged that cell grazing was a practical and economically viable production system. Whilst cell grazing resulted in lower LWG per head compared with continuous grazing, in years where higher stocking rates can be sustained in cell-grazing paddocks, the high stocking rates are likely to be partly compensatory (on a kilograms of meat per hectare basis). However, it is unknown whether this would be enough to compensate for the considerably higher operating costs of the cell system. The longer-term impact of cell grazing on rangeland condition remains unknown. It is recommended that when planning more intensive development and deciding whether or not to implement intensive rotational grazing, consideration should be given to the most cost-effective scale of development and the higher operating costs of intensive grazing systems.

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Appendix 1

Table 17. Mean species frequency (%) in May, in the cell and continuous grazing paddocks, at Newcastle Waters (average 2003-2005)

Cell-grazing paddocks	Frequency (%)	Continuously-grazed paddock	Frequency (%)
Iseilema spp.	34.8	*Astrebla pectinata*	28.4
Flemingia pauciflora	34.6	*Chrysopogon fallax*	20.0
Aristida latifolia	33.1	*Aristida latifolia*	19.2
Eulalia aurea	27.1	*Flemingia pauciflora*	13.6
Iseilema vaginiflorum	24.5	*Neptunia* spp.	12.8
Neptunia spp.	22.9	*Eulalia aurea*	12.4
Rhynchosia minima	22.0	*Sorghum timorense*	12.4
Astrebla pectinata	20.5	*Polymeria longifolia*	11.2
Astrebla elymoides	18.5	*Rhynchosia minima*	9.2
Sesbania spp.	18.0	*Dichanthium fecundum*	8.8
Polymeria longifolia	16.8	*Iseilema* spp.	8.8
Dichanthium fecundum	15.6	*Aristida holathera*	8.0
Panicum laevinode	14.3	*Dichanthium sericeum*	7.6
Ludwigia perennis	12.1	*Panicum decompositum*	7.6
Dichanthium sericeum	12.1	*Iseilema vaginiflorum*	6.4
Operculine aequisepala	8.6	*Fimbristylis* spp.	6.0
Astrebla squarrosa	7.7	*Ludwigia perennis*	5.2
Phyllanthus maderaspatensis	5.2	*Panicum laevinode*	5.2
Indigofera ewartiana	4.9	*Solanum tumulicola*	4.8
Sida spinosa	4.9	*Brachyachne convergens*	3.6
Chionachne hubbardiana	4.0	*Phyllanthus maderaspatensis*	3.2
Chrysopogon fallax	4.0	*Sesbania* spp.	2.8
Fimbristylis spp.	3.9	*Astrebla squarrosa*	2.8
Triodia spp.	3.9	*Sida spinosa*	2.4
Eriachne obtusa	3.5	*Astrebla elymoides*	2.4
Hibiscus trionum	3.5	*Corchorus sidioides*	2.0
Sorghum timorense	3.4	*Cyperus bifax*	2.0
Crotalaria spp.	3.4	*Tephrosia brachyodon*	2.0
Cyperus bifax	3.2	*Eragrostis tenullela*	2.0
Panicum decompositum	3.2	*Aristida inaequiglumis*	1.6
Streptoglossa spp.	2.9	*Indigofera ewartiana*	1.6
Trichodesma zeylanicum	2.5	*Spermacocae auriculata*	1.6
Sida spp.	2.0	*Waltheria indica*	1.2
Dactyloctenium radulans	1.8	*Chionachne hubbardiana*	1.2
Brachyachne convergens	1.8	*Enneapogon polyphyllus*	1.2
Glycine falcata	1.5	*Crotalaria* spp.	0.8
Polymeria ambigua	1.5	*Eragrostis* spp.	0.8
Ptilotus spicata	1.5	*Ipomoea* spp.	0.8
Bothriochloa ewartiana	1.5	*Phyllantus* spp.	0.8
Eragrostis spp.	1.3	*Portulaca* spp.	0.8
Schizachyrium fragile	1.2	*Rostellularia adscendens*	0.8
Ipomoea spp.	1.2	*Sida filiformis*	0.8
Sporobolus spp.	1.0	*Sporobolus* spp.	0.8
Vigna lanceolata	1.0	*Glycine falcata*	0.8
Aristida holathera	1.0	*Streptoglossa* spp.	0.8
Heliotropium spp.	1.0	*Teucrium integrifolium*	0.8

Cell-grazing paddocks	Frequency (%)	Continuously-grazed paddock	Frequency (%)
Indigofera linifolia	1.0	*Bulbostylus barbarta*	0.4
Oldenlandia mitrasacmoides	1.0	*Cymbopogon* sp.	0.4
Wedelia asperrima	0.8	*Desmodium muelleri*	0.4
Enneapogon polyphyllus	0.8	*Enneapogon purpurascens*	0.4
Alternanthera pungens	0.7	*Eragrostis* spp.	0.4
Abelmoschus ficulneus	0.7	*Gomphrena canescens*	0.4
Aeschynomene indica	0.7	*Goodenia fascicularis*	0.4
Solanum tumulicola	0.7	*Indigofera colutea*	0.4
Paratephrosia lanata	0.7	*Indigofera linifolia*	0.4
Bulbostylus barbarta	0.5	*Ptilotus spicata*	0.4
Corchorus trilocularis	0.5	*Trianthema pilosa*	0.4
Cucumis melo	0.5	*Wedelia asperrima*	0.4
Sporobolus australicus	0.5	*Indigofera trita*	0.4
Echinochloa colona	0.5		
Phyllantus spp.	0.5		
Sida filiformis	0.5		
Spermacocae auriculata	0.5		
Cymbopogon sp.	0.5		
Desmodium muelleri	0.3		
Portulaca spp.	0.3		
Rostellularia adscendens	0.3		
Commelina agrostophylla	0.3		
Goodenia fascicularis	0.3		
Boerhavia paludosa	0.2		
Cenchrus ciliaris	0.2		
Chloris pectinata	0.2		
Chloris spp.	0.2		
Digitaria sp.	0.2		
Euphorbia sp.	0.2		
Goodenia strangfordii	0.2		
Paspalidium spp.	0.2		
Sida trichopoda	0.2		
Teucrium integrifolium	0.2		
Eragrostis spp.	0.2		
Indigofera trita	0.2		
Themeda triandra	0.2		
Abutilon andrewsianum	0.2		
Astrebla lappacea	0.2		

Appendix 2

Trends in species frequency of common species over time are shown in Figures 35 to 40.

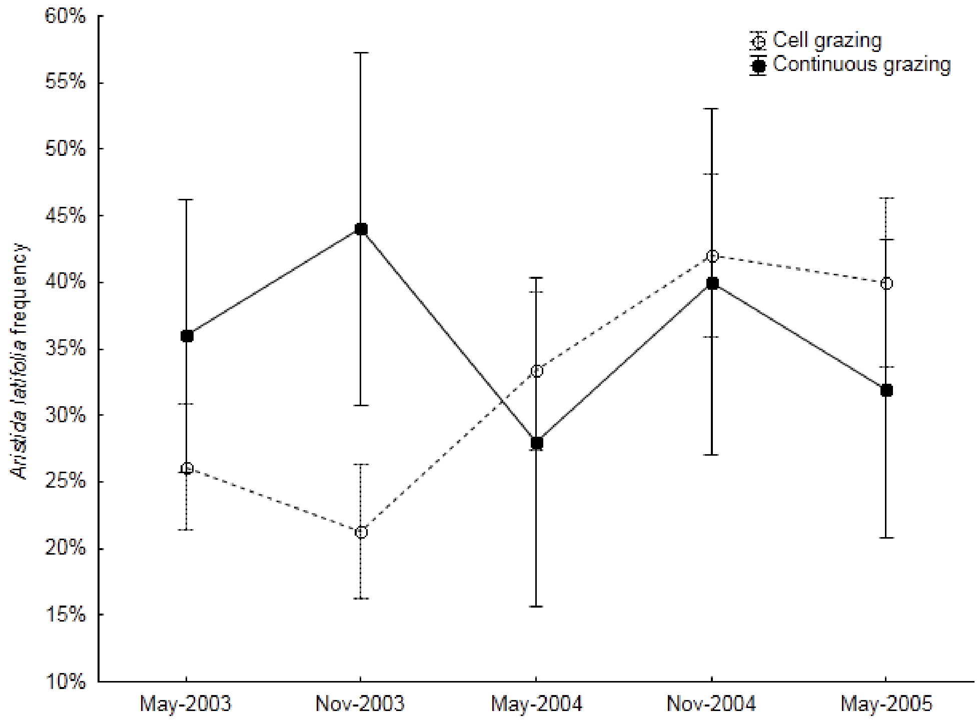

Figure 35. Mean ± SE *Aristida latifolia* frequency with grazing system through time at Newcastle Waters

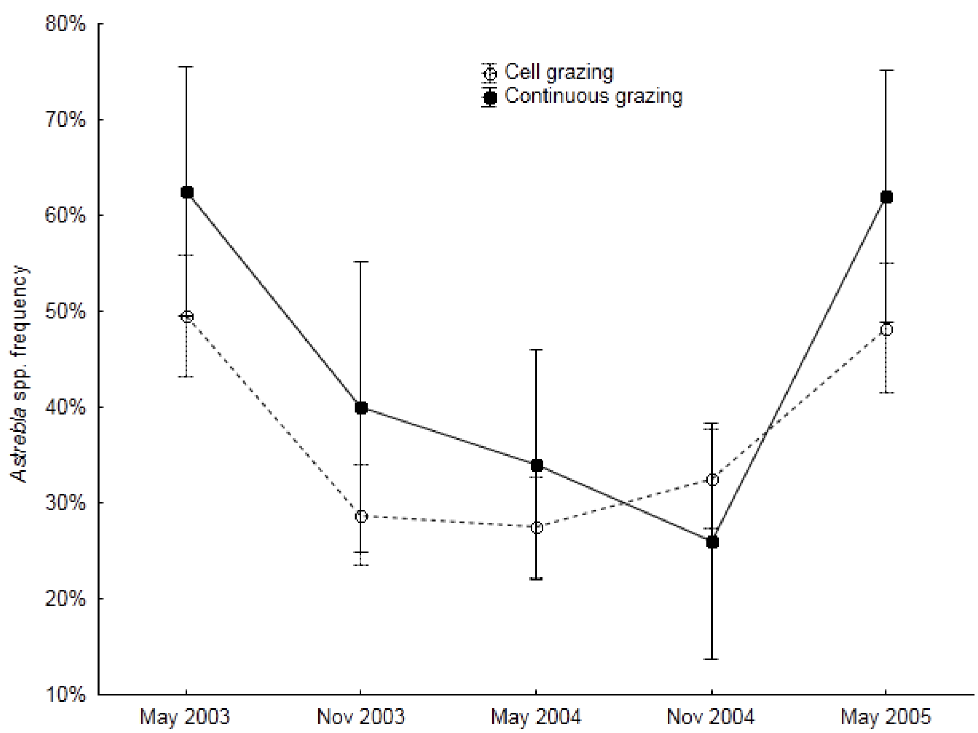

Figure 36. Mean ± SE *Astrebla* spp. frequency with grazing system through time at Newcastle Waters

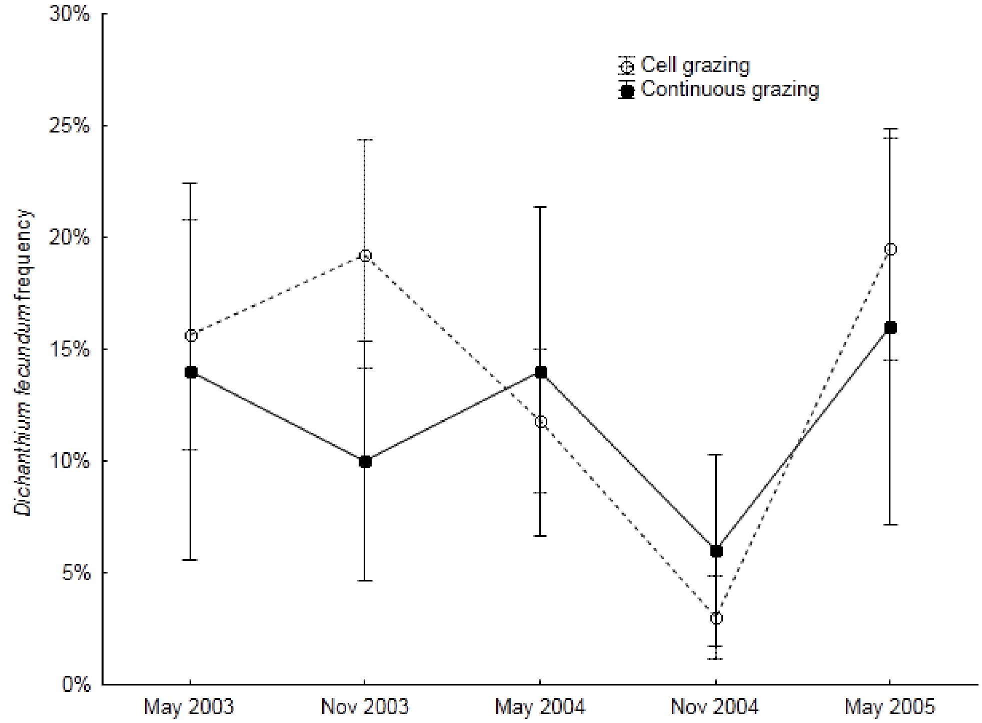

Figure 37. Mean ± SE *Dichanthium fecundum* frequency with grazing system through time at Newcastle Waters

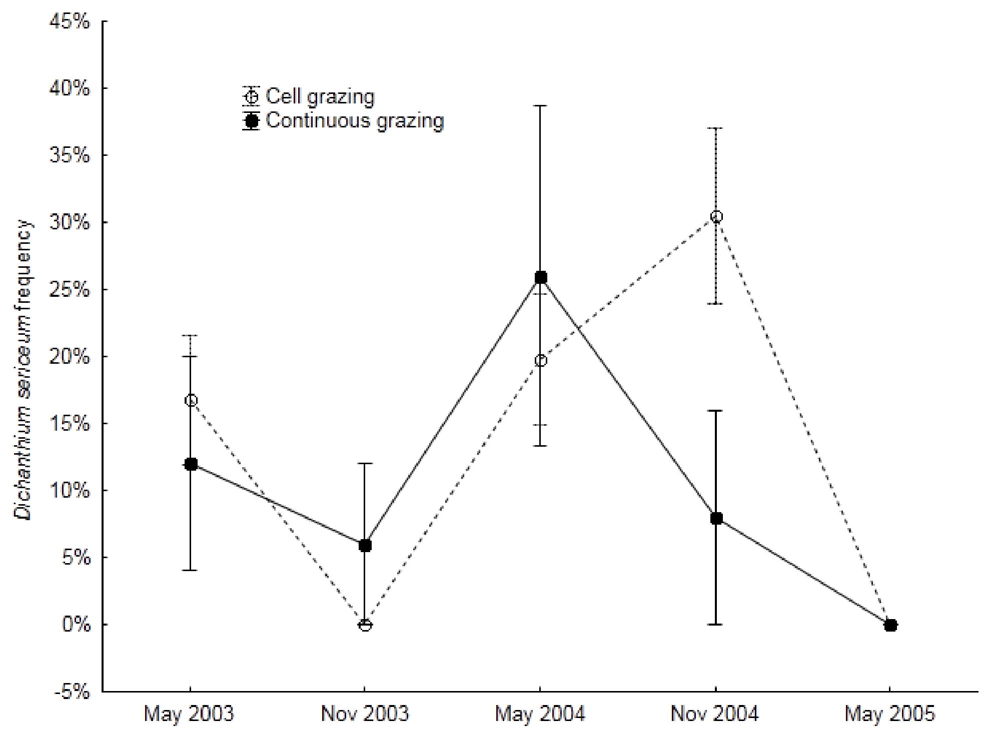

Figure 38. Mean ± SE *Dichanthium sericeum* frequency with grazing system through time at Newcastle Waters

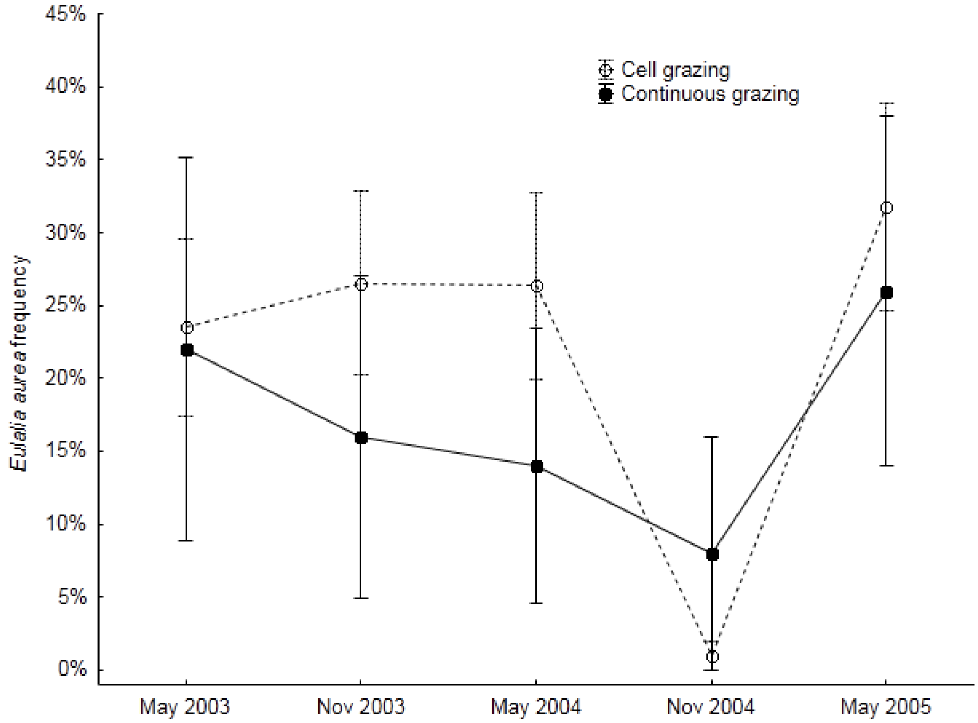

Figure 39. Mean ± SE *Eulalia aurea* frequency with grazing system through time at Newcastle Waters

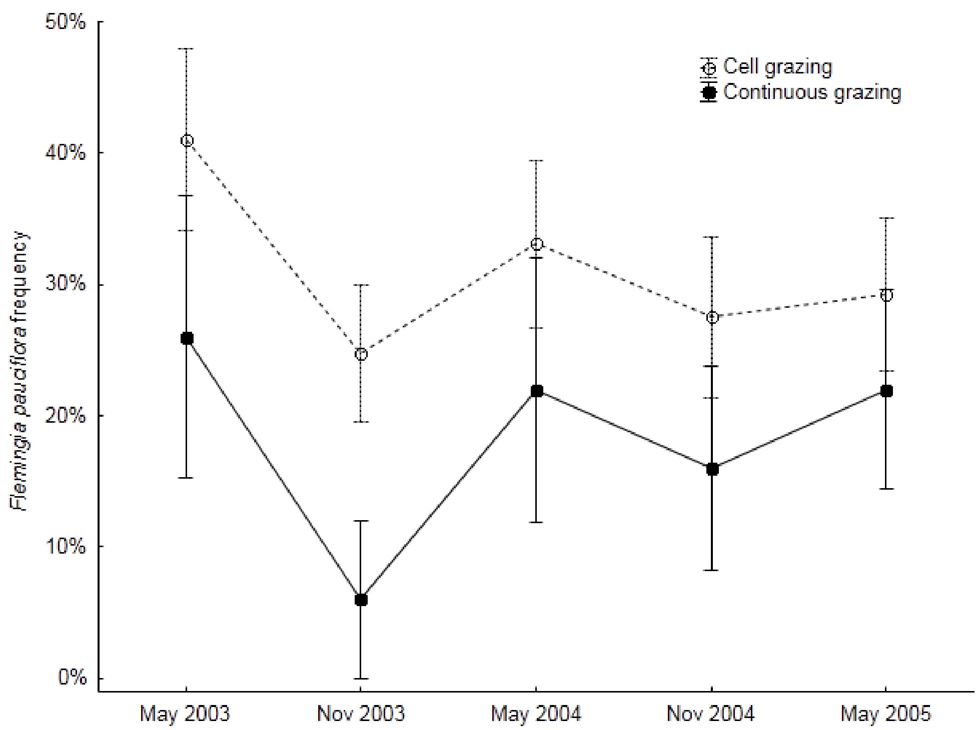

Figure 40. Mean ± SE *Flemingia pauciflora* frequency with grazing system through time at Newcastle Waters

Appendix 3

Managers' description of cell (Brownies and Langlands paddocks) and continuous grazing (Runaway paddock) costs in the Newcastle Waters cell-grazing trial, with specific comments and recommendations as they relate to cell design:

Langlands paddock (cell grazing)

Fencing:	$8,000 – Fencing (single hot wires) – 1500 m wire = $100 Pickets every 20 m = 50 pickets per km Insulators = $1 each (roughly)
Materials:	1 trough Energisers (one for Brownie's, one for Langlands) + New energizer @ $3,000 with Solar Panels
Labour:	2 weeks; 4 men @ $600 per week, per man 2 water points in the cell Hours per day for waters etc. = 2 hours per day 30 km per day Toyota @ 5 km/L
Supplementation:	Uramol = 10 cents per day per head in dry season Phosphorus: 14 cents/head/day in wet season for 6 weeks after wet season finishes
Mortality:	0-0.05% (maximum). Only one death in two years.
Manager's comments:	Good manageable size & system for 1 person Make sure animals are properly trained on hot (electrified) wire before entering cell and well handled Paddock would have run 100 x 350 kg heifers all year round before cell was put in.

Brownie's paddock (cell grazing)

Costs:	Turkey nest & pipe trough - $20,000 2 hot wire external and one hot wire internal $450/km for 2 hot wires & pickets $350/km for 1 hot wire $200/km labour
Manager's comments:	Area put under rotation was not previously utilized & would have run 100 x 350 kg heifer all year round if water was available. Under cell grazing it could run 1000 easily. Paddocks were too big to get an even graze If cells in wet areas (i.e. black soil), make sure to have a mix of hard country if possible

Runaway paddock (continuous grazing)

Costs:	Fencing @ $3,500 per km (55.98 km^2 = approx. 29.92 km perimeter fence therefore $105,000 to fence) Limited hours checking waters & fencing 220 head (cows with calves) – 70% branding
Mortality:	3%
Supplementation:	Phosrite blocks in wet (same as cell) = 14 c/head/day Breeder mix in dry season = 10 cents/head/day Anipro in late dry season = 35 cents/head/day (six weeks of Anipro)
Managers' comments:	Cattle had to walk out further to get a feed due to flogging at watering point.
Labour:	Twice a week checking water and stock – 2 hours per week