Impact of short-term exclosure from grazing on pasture recovery from drought in six Queensland pasture communities

D.M. ORR, M.C. YEE AND D.J. MYLES
Department of Primary Industries and Fisheries, Rockhampton, Queensland, Australia

Abstract

A study conducted during 2003 and 2004 examined the impact of either 0-, 3-, 6- or 12-month exclosure from grazing on pasture recovery following drought in 6 pasture communities, selected to include a range of pasture conditions on a range of soil types at Injune, Theodore, Charters Towers, Rockhampton, Nebo and Charleville, Queensland, Australia. Unreplicated plots of 25 × 25 m were established at each location in autumn 2003 and sampled at approximately 3-monthly intervals until autumn 2004. Drought prevented sampling at 2 locations until spring 2003.

Rainfall was generally below average to average (deciles 2 to 5) except at the Rockhampton site, which received twice the mean monthly rainfall in 2 consecutive months. There were no major changes in total perennial grass basal area between 2003 and 2004 except at Rockhampton. At that location, basal area of *Heteropogon contortus* increased substantially with the 12-month exclosure but not in the other 3 treatments. Perennial grass basal area at 4 other locations was moderate, despite prolonged drought and consequent heavy grazing pressure. However, a feature of the pasture at these 4 locations was the high contribution of undesirable species.

Total pasture yields in autumn 2004 were generally highest in the 12-month exclosure treatments. Apart from one treatment at Rockhampton, there were few major changes in perennial grass species composition. At 2 of the 4 locations with relatively high basal area of undesirable grasses, these undesirable species showed the greatest increase in yield. Nitrogen yield increased with increased exclosure from grazing at all locations reflecting dry matter yields.

We concluded that further research is required to improve the understanding of vegetation dynamics in relation to seasonal rainfall and that this research be conducted over a longer period, with spelling during the period of pasture growth.

Correspondence: Dr D.M. Orr, DPI&F, PO Box 6014, Rockhampton Mail Centre, Qld 4702, Australia. E-mail: david.orr@dpi.qld.gov.au

Introduction

From a survey of pasture communities throughout northern Australia during the early 1990s, Tothill and Gillies (1992) concluded that there had been widespread deterioration in most pasture communities. This deterioration was evidenced by undesirable changes in pasture composition and was related to increased grazing pressure resulting from rainfall deficiencies in the 1980s and a substantial increase in livestock numbers since the beef crisis of the 1970s.

Extreme drought conditions existed throughout much of central and southern Queensland during 2002, which substantially increased the risk of further widespread pasture deterioration. This, in turn, put any post-drought recovery of pasture and animal production at extreme risk, compounding and prolonging the impact of drought on grazing enterprise productivity and equity. Similarly, some areas of northern Queensland appeared to be entering crisis mode with a delayed start to the 2002–03 wet season, and many producers retaining stock in the hope of a late wet season. Again, the approach to both retention of stock and post-drought restocking would greatly affect pasture recovery, especially in areas where pastures were still recovering from the impact of droughts of the early-mid 1990s. These perceptions of poor pasture condition due to drought and associated heavy grazing were supported by district-scale assessments by regional DPI&F pasture staff in native pasture communities during November–December 2002 (DPI&F, unpublished data).

Decisions on the retention of stock during drought and the timing of restocking following drought have important implications for land condition and pasture recovery. From an examination of historical records, McKeon *et al*. (2004) identified 8 'degradation events' in Australia's grazing lands since extensive grazing commenced in the 1870s. Among the major drivers of all 'degradation events' were high livestock numbers and extended drought. These authors concluded that 'the challenge now is to prevent the next degradation event'. Stone *et al*. (2003) indicated that some of the precursors for the next degradation event were already present in April 2002. Furthermore, although stock numbers were reduced between 2002 and 2003, with the reduced pasture growth during this period, the reduction in stock numbers may not have been sufficient in some areas to reduce grazing pressure below critical levels.

The importance of tactical management of grazing pressure, both during and subsequent to drought conditions, seems logical and is supported in principle by results from limited grazing studies. For example, Orr and Paton (1997) demonstrated the benefit of tactical rest following spring burning, while the ECOGRAZE project (Ash *et al*. 2002) demonstrated the benefit of early wet season spelling. However, in conventional set-stocked grazing studies, existing pasture condition is a result of the imposed grazing treatment within the recovery period and there is a paucity of data to predict the impacts of various tactical management strategies on post-drought pasture recovery.

Ash and McIvor (1995) identified an important link between pasture condition and the loss of potential nitrogen uptake across a range of pasture communities in northern Australia. This finding has been important in the simulation of effects of stocking rate on pasture productivity in simulation studies conducted by McKeon *et al*. (2000) and Ash *et al*. (2000). The study reported in this paper offered an opportunity to expand on this link between pasture condition and nitrogen yield, particularly because this study was conducted across a range of pasture communities in Queensland with inherently different levels of soil nitrogen.

This paper reports on a study to examine the impact of short periods of exclosure from grazing on pasture recovery between autumn 2003 and autumn 2004 in 6 diverse pasture communities in Queensland. Furthermore, these field data will be incorporated into GRASP model simulation studies (McKeon *et al*. 2000) to improve model output in relation to the impact of drought.

Methodology

Selection of locations

Six field locations were selected in a matrix of pasture condition and soil fertility (Table 1) across a range of pasture communities in Queensland. These pasture communities were selected on the basis that some understanding of the pasture community dynamics was available and the 6 locations were selected as being representative of those pasture communities and included:

- Commercially grazed *Heteropogon contortus* (black speargrass) pasture near Rockhampton.
- Commercially grazed *Aristida-Bothriochloa* (wiregrass-bluegrass) pasture near Injune. (Site of the '50% utilisation with trees cleared' treatment from the former *Aristida-Bothriochloa* grazing study; Hall and Douglas 2005).
- Commercially grazed *Dichanthium sericeum* (Queensland bluegrass) pasture near Nebo. (Site of 'Species composition and pasture productivity study' by G. Bahnisch, personal communication).

Table 1. Pasture condition and soil fertility matrix for 6 field locations across Queensland.

		Pasture condition		
		Good	Fair	Poor
Soil fertility	Good	*Cenchrus ciliaris* (buffel grass) on *Acacia harpophylla* (brigalow), Theodore	*Dichanthium sericeum* (Queensland bluegrass), Nebo	
	Fair		*Heteropogon contortus* (black speargrass), Rockhampton	*Bothriochloa pertusa* (Indian couch), Charters Towers
	Poor		*Aristida-Bothriochloa*, Injune	*Acacia aneura* (mulga) woodland, Charleville

- Formerly heavily grazed, commercial *Acacia aneura* (mulga) pasture now managed as a DPI&F research station near Charleville.
- Commercially grazed *Bothriochloa pertusa* (Indian couch) pasture near Charters Towers. (Site of 'Sustainable grazing for a healthy Burdekin' project).
- Commercially grazed time controlled grazing ('cell grazing') *Cenchrus ciliaris* (buffel grass) pasture on cleared *Acacia harpophylla* (brigalow) scrub near Theodore.

Treatments

At Rockhampton, Injune and Nebo, 4 unreplicated treatment areas, each 25 × 25 m, were established in March 2003. Three of these areas were exclosed to measure the impact of 3-, 6- or 12-month exclosure from grazing on pasture condition, while the fourth was continuously grazed. The 3- and 6-month exclosures were removed in August and December, respectively, and the 12-month exclosures removed in April at Nebo and Injune and in May at Rockhampton. At Theodore, treatments were located in June 2003 within an existing time controlled grazing system, where unreplicated treatment areas of 25 × 25 m were established in 4 adjacent cells. Each cell was grazed for a total of either 5 or 6 days between June 2003 and April 2004 to give an overall annual stocking rate of 3.1 steers/ha. (It is recognised that these treatments are notional rather than precise as indicated by the fact that the notional 3-month exclosure treatment was actually exclosed for 4–5 months).

Severe drought at Charters Towers and Charleville over the 2002–03 summer delayed the commencement of pasture sampling, which requires active plant growth to identify plants as alive and, where possible, to species level, until rain in spring 2003. Consequently, only 2 unreplicated exclosures (3- and 6-month exclosure), together with a grazed area, were established at Charters Towers during October 2003 and at Charleville during November 2003. These 3- and 6-month exclosures were removed in March and May at Charters Towers and February and April at Charleville.

Pasture measurements

During March and June 2003, as each location (except Charleville and Charters Towers) was established, each treatment was sampled for pasture yield and composition using BOTANAL (Tothill *et al.* 1992) with 3 or 4 trained operators assessing 40 quadrats per treatment area. Subsequently, pasture yield and composition were recorded in each treatment at each location when the 3-, 6- and 12-month exclosures were removed. At Theodore, pasture yield and composition were recorded at similar intervals to those locations where treatments had been exclosed. With the severe drought conditions, sampling for pasture yield and composition was conducted when the 3- and 6-month exclosures were removed at Charters Towers in March and May 2004 and at Charleville in February and April 2004.

Basal area of perennial grass was measured with a point frame apparatus consisting of 5 points spaced 15 cm apart, and 1000 to 1250 points were recorded for each treatment site at each location at each recording. All recordings were made by the senior author. At Rockhampton, Injune, Nebo and Theodore, basal area of perennial grass was measured at the establishment of those locations in March and June 2003 and again at the end of the study in April–May 2004. Basal area of perennial grass was measured at Charters Towers in March and May 2004 and at Charleville in February and April 2004.

Nitrogen yield for all treatments was determined in autumn 2004 in conjunction with the final pasture sampling. Three bulk pasture samples were collected from each treatment site, dried and analysed for N concentration. Nitrogen yield was the product of N concentration and total pasture yield.

Results

Rainfall

Rainfall throughout this study was generally at or below the long-term means for most locations (Figure 1) with rainfall deciles of 2, 3, 4, 5 and 5 for Charters Towers, Nebo, Theodore, Charleville and Injune, respectively. Most locations experienced rainfall above the long-term mean for that location for at least 1 month during summer. However, the Rockhampton location received above-average rainfall (decile 7) due largely to above long-term monthly means for both December 2003 and January 2004.

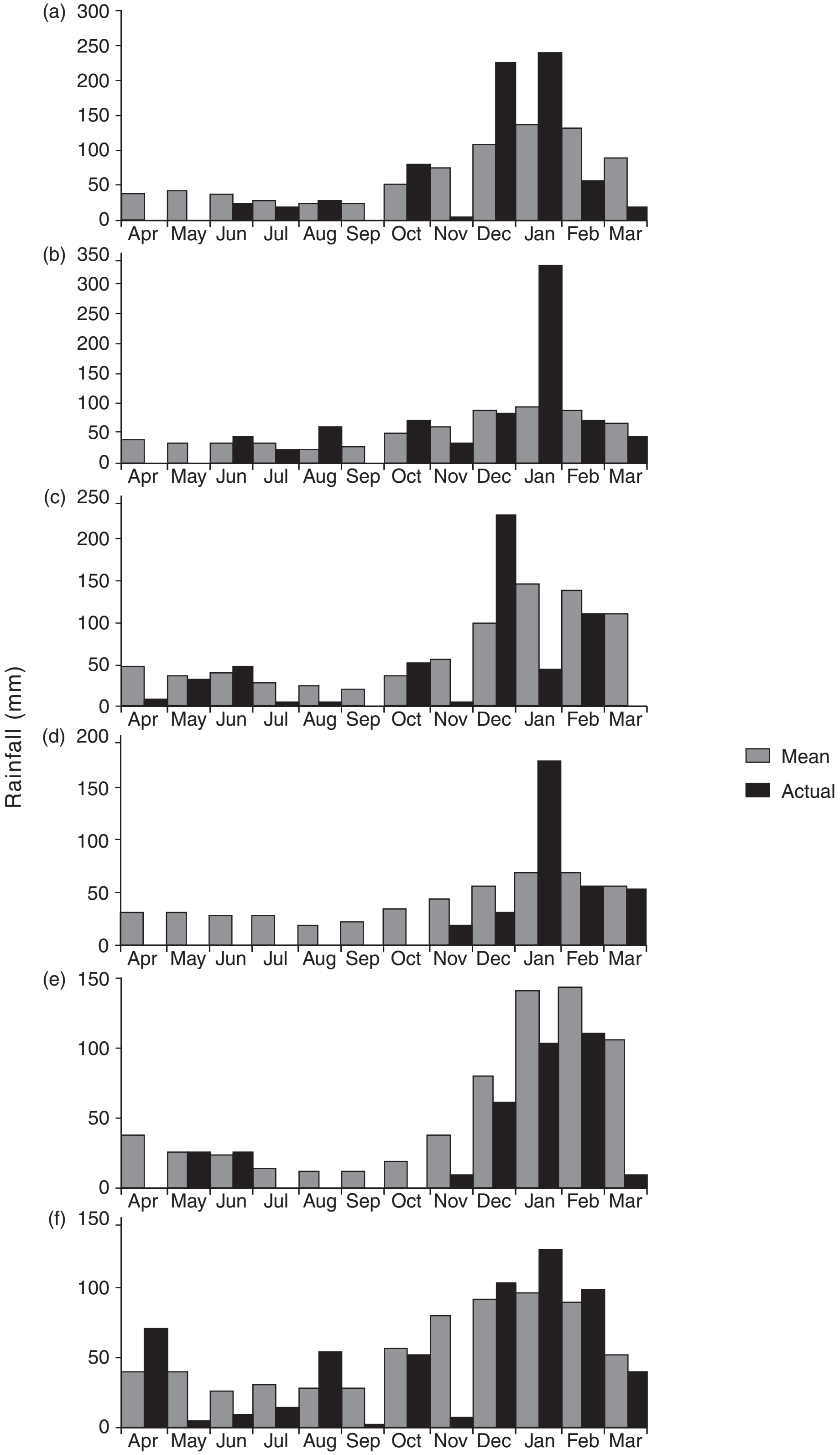

Figure 1. A comparison of actual (April 2003–March 2004) and long-term mean monthly rainfall at: (a) Rockhampton; (b) Injune; (c) Nebo; (d) Charleville; (e) Charters Towers; and (f) Theodore. (Note differences in scales).

Basal area of perennial grasses

Total basal area of perennial grasses in autumn 2003 was 4.7% at both Nebo and Injune, 5.1% at Rockhampton and 6.4% at Theodore (no measurements were possible at Charters Towers or Charleville) (Figure 2). Changes in perennial grass basal area at all sites between 2003 and autumn 2004 were small. Perennial grass basal area at Charters Towers and Charleville in autumn 2004 was much lower than at any of the other 4 locations.

At Injune, Nebo, Charleville and Charters Towers, the contribution of desirable perennial grasses to total basal area was low (<10%) (Figure 2). Of particular interest was the virtual absence of desirable perennial grasses at Charleville, the dominance of undesirable *Chloris* spp. and *Bothriochloa decipiens* at Injune and also the undesirable *Aristida leptopoda* and *Panicum* spp. at Nebo. *B. pertusa* was the dominant undesirable perennial grass at Charters Towers. (The allocation of individual species to desirable, undesirable and other categories at each location is presented in Table 2).

At Rockhampton, there was a large increase in perennial grass basal area between 2003 and 2004 for the treatment exclosed from grazing for 12 months, but this effect was not apparent on any of the other treatments (Figure 3). This large increase was due to an increase in the basal area of *Heteropogon contortus*, in response to the above-average rainfall at that site in December 2003 and January 2004.

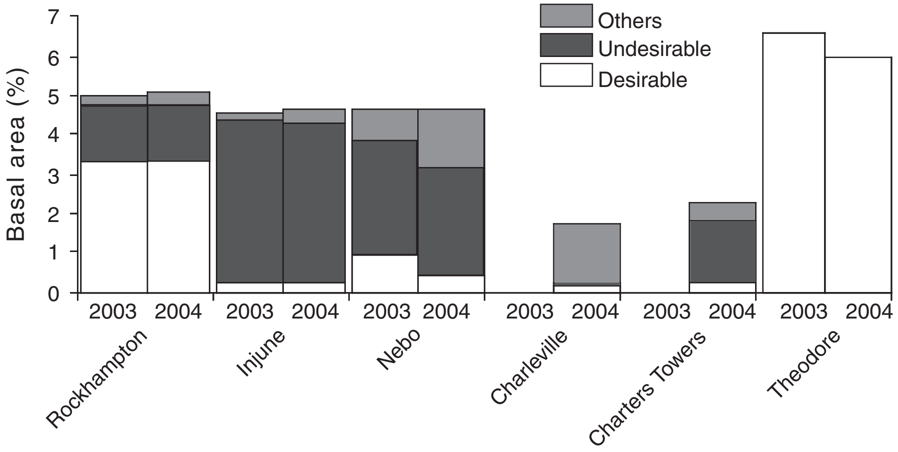

Figure 2. Total basal area (%) of perennial grasses pooled across 4 treatments at 6 locations in 2003 and 2004, indicating the contribution of desirable, undesirable and other perennial grasses to total basal area. (No measurements were possible at Charleville and Charters Towers in 2003). (Species allocated to each classification are detailed in Table 2.)

Table 2. The distribution of individual species between the desirable, undesirable and other categories at each of 6 locations. (Species are listed in order of decreasing contribution to basal area in each category at each location). (Other species are those perennial grass species which are neither desirable nor undesirable.)

Location	Desirable	Undesirable	Other
Rockhampton	*Heteropogon contortus, Bothriochloa bladhii, Panicum* spp.	*Aristida* spp., *Bothriochloa decipiens, B. pertusa*	*Chrysopogon fallax, Cymbopogon* spp.
Injune	*Dichanthium sericeum, Bothriochloa bladhii, Heteropogon contortus, Cenchrus ciliaris*	*Chloris* spp., *Bothriochloa decipiens, Aristida* spp., *Eragrostis* spp., *Tripogon loliiformis*	*Enneapogon* spp., *Chrysopogon fallax*
Nebo	*Dichanthium sericeum, Paspalidium* spp., *Eulalia* spp., *Eriochloa* spp., *Heteropogon contortus*	*Aristida leptopoda, Panicum* spp., *Bothriochloa pertusa, Sporobolus* spp.	
Charleville	*Cenchrus ciliaris, Thyridolepis mitchelliana*	*Aristida* spp., *Eragrostis* spp.	*Eriachne* spp.
Charters Towers	*Heteropogon contortus, Panicum* spp.	*Bothriochloa pertusa, Aristida* spp.	*Chrysopogon fallax*
Theodore	*Cenchrus ciliaris, Dichanthium sericeum*		

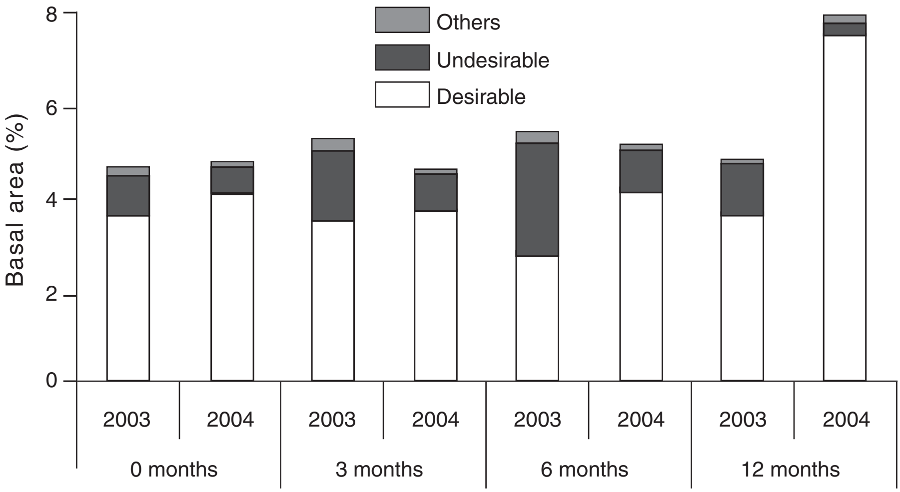

Figure 3. Contribution of desirable, undesirable and other perennial grasses to perennial grass basal area (%) following 4 durations of spelling in 2003 and 2004 at Rockhampton. (Species allocated to each classification are detailed in Table 2).

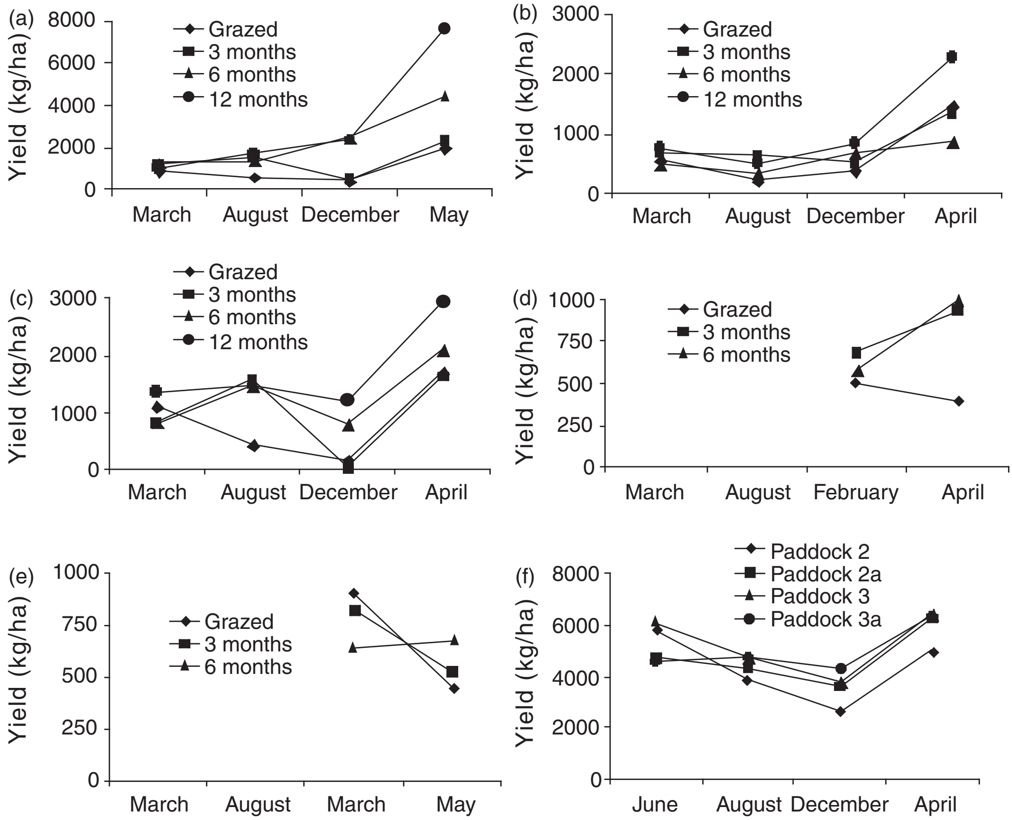

Figure 4. Changes in total pasture yields at: (a) Rockhampton; (b) Injune; (c) Nebo; (d) Charleville; (e) Charters Towers; and (f) Theodore following 4 durations of spelling between autumn 2003 and autumn 2004. (Note differences in scales).

Total pasture yields

By autumn 2004, the highest total pasture yields occurred at the longest period of exclosure (Figure 4). The effects of 6- and 12-month exclosure treatments were most obvious at Rockhampton and Nebo in December when compared with the yields in the grazed and 3-month exclosure treatments. At Theodore, total pasture yields were similar at the 4 sites. At the 4 locations where yield was measured in December 2003, pasture yield increased between then and April–May 2004, reflecting the impact of summer rainfall on pasture growth.

Species composition

A large increase in the perennial grass basal area and total yield at Rockhampton was reflected in a similar large increase in the contribution of the desirable *H. contortus* (Figure 5). However, yields of the undesirable *Aristida* spp. were generally higher in 2004 than in 2003. At both Nebo and Injune, much of the increase in total yield reflected increasing yields of undesirable species. At Nebo, the undesirable *Aristida leptopoda* and *Panicum* spp. (*P. decompositum* and *P. queenslandicum*) and at Injune the undesirable *Bothriochloa decipiens* and *Chloris* spp. (*C. divaricata*) were the major contributors to total yields and also to perennial grass basal area.

Nitrogen yields

Nitrogen concentrations in autumn 2004 ranged from 0.39% at Theodore to 0.76% at Nebo (Figure 6). Within each location, there was little consistent variation between treatments. At Rockhampton, nitrogen concentration was lower for the 12-month exclosure than for the other 3 sites. Nitrogen yields (*i.e.*, nitrogen concentration × total pasture yield) ranged from 4 kg/ha at Charters Towers to 24 kg/ha at Theodore (Figure 7). There was a clear trend for nitrogen yields to be highest in the 12-month exclosure treatments.

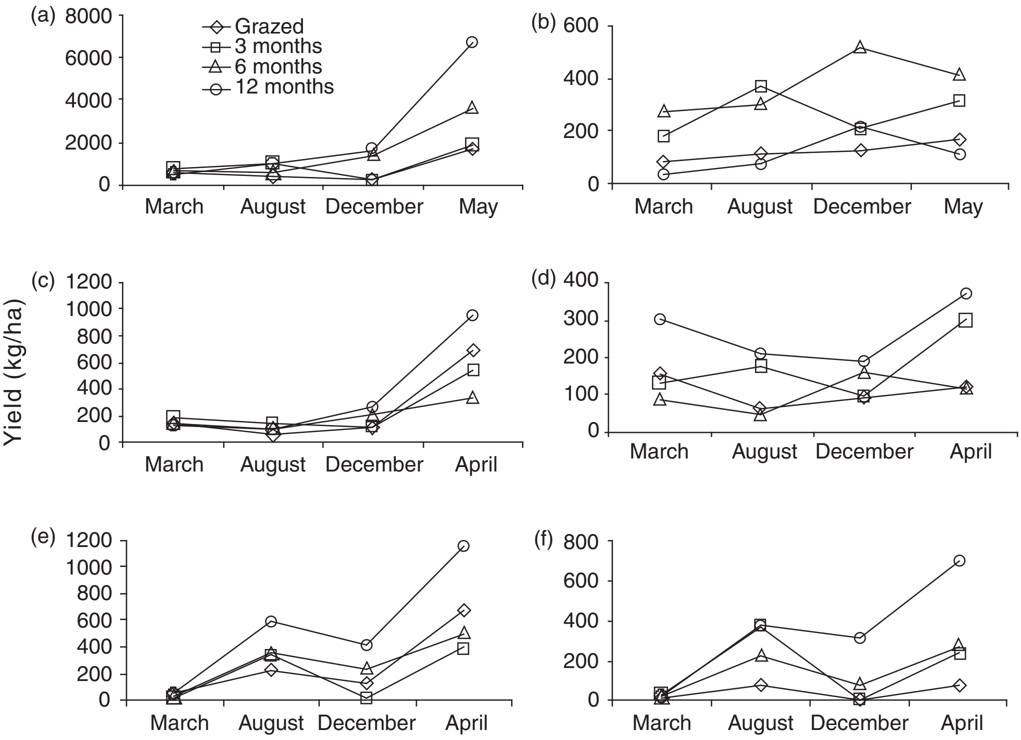

Figure 5. Changes in DM yields of: (a) *H. contortus* and (b) *Aristida* spp. at Rockhampton; (c) *Chloris* spp. and (d) *B. decipiens* at Injune; and (e) *Aristida* spp. and (f) *Panicum* spp. at Nebo between autumn 2003 and autumn 2004. (Note differences in scales).

Discussion

Good pasture condition is represented by high yields and basal area of desirable perennial grasses. This study has reinforced the findings of Tothill and Gillies (1992), that many of our grazing lands are degraded and the measures examined in this study will do little to reverse this situation. This result indicates that pasture condition will not improve following drought simply by excluding livestock for short periods, especially during winter, and particularly when rainfall is only average or below.

The one notable exception to this generalisation of poor pasture recovery was the response of *H. contortus* in the 12-month exclosure treatment at Rockhampton. This response was mediated through above average rainfall during December 2003 and January 2004, which resulted in a large increase in basal area of *H. contortus* through large increases in the size of existing tussocks rather than from seedling recruitment. Pastures at Theodore were in good condition at the commencement of this study — high perennial grass basal area and high pasture yield of *Cenchrus ciliaris* — and these pastures remained in good condition despite only 'average' rainfall over the 2003–04 summer. Nevertheless, the presence of isolated plants of *Dichanthium sericeum* in these pastures indicated some replacement by native species which are less nutrient-demanding than *C. ciliaris.* Similar changes are a feature of these pastures with increasing time from the initial development of the *Acacia harpophylla* (brigalow) scrub (Burrows 2000). A significant feature of the pasture at Theodore was the similar changes in pasture yield across the 4 treatments. This is a feature of the time controlled grazing system, where animals graze paddocks at high stocking pressures for short periods and the animal rotation through the paddocks maintains a relatively uniform pasture yield amongst the paddocks.

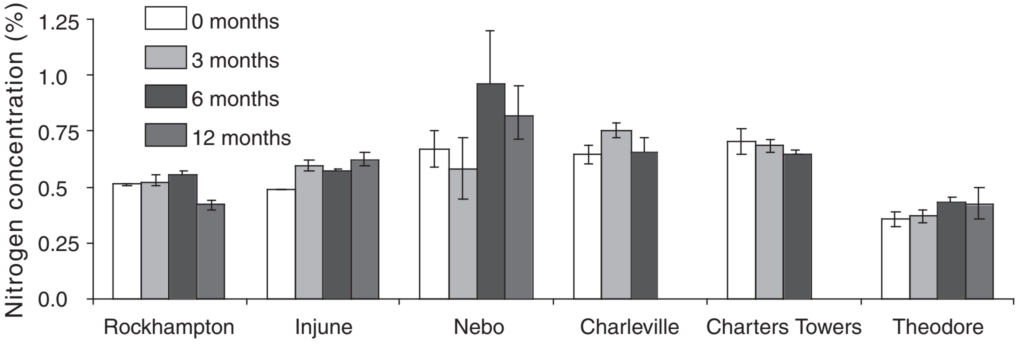

Figure 6. Nitrogen concentration in pasture following 4 durations of spelling at 6 locations in autumn 2004. (Vertical bars are the standard error of the mean).

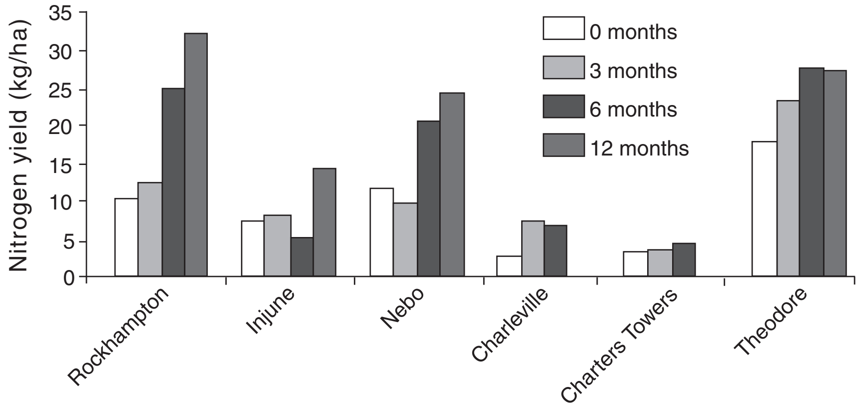

Figure 7. Nitrogen yield from pasture following 4 durations of spelling at 6 locations in autumn 2004.

The total pasture yield and perennial grass basal area at the Rockhampton location in response to 2 consecutive months of above long-term mean rainfall suggest that large increases in yield and basal area may require above long-term mean rainfall. While most of the other 5 locations received above long-term mean rainfall in at least one summer month, there was little increase in total pasture yield or perennial grass basal area. These data suggest that above long-term mean rainfall in at least 2 months during summer may be required to achieve large-scale increases in total yield and perennial grass basal area. However, this suggestion is at variance with the conclusion from the ECOGRAZE project at Charters Towers (Ash *et al*. 2002), that grazing management, not climate, is the most important determinant of pasture condition. Reasons for these contrasting responses are not readily apparent.

The poor pasture responses in the current study also contrast with the marked recovery (grass basal area, proportion of desirable species) reported on a fertile soil over 3 years of generally favourable rainfall conditions at Charters Towers (McIvor 2001). However, in that study, some experimental plots that were initially in poor condition (low pasture yields rather than poor species composition) had not recovered after 3 years. McIvor (2001) concluded that unfavourable rainfall conditions would probably depress subsequent pasture performance on less fertile soils than the responses reported in that study. The poor response recorded in this paper supports McIvor's conclusion.

Perennial grass basal area at Injune, Nebo, Charleville and Charters Towers was moderate for these vegetation types, despite long periods of drought and associated heavy grazing. However, these locations displayed poor floristic composition as indicated by the low contribution of desirable grasses. Desirable grasses were virtually absent at Charleville, while undesirable species dominated pastures at both Injune and Nebo and the Charters Towers location was dominated by the undesirable *Bothriochloa pertusa*. Poor pasture composition at both Charleville and Charters Towers is consistent with the 7th and 8th 'degradation events', respectively, as described by McKeon *et al.* (2004). A further concern from the current study is that undesirable species, *Bothriochloa decipiens* and *Chloris* spp. at Injune, *Aristida leptopoda* and *Panicum* spp. at Nebo and *Bothriochloa pertusa* at Charters Towers, were the species displaying the greatest increase in yield following spelling.

Rehabilitating pasture at sites currently dominated by undesirable species to a situation where composition is dominated by desirable species requires large shifts in species occurrences. Limited data are available on recovering pasture condition throughout northern Australia (Whalley 1993; Filet 1993). Orr (1981) recorded large increases in the abundance of *Dichanthium sericeum* in *Astrebla* (Mitchell grass) grassland following a series of years with above average summer rainfall. The increases probably resulted from the sequence of improved seed set, resulting seedling recruitment and subsequent plant growth during this series of 'wet' summers. Similarly, Orr and Evenson (1991) recorded an increase in basal area of *Astrebla* spp. from 1.5 to 3.8% during 2 consecutive summers of above average rainfall, despite 40–50% utilisation by sheep over the intervening dry season. This rapid increase in basal area occurred through extensive tillering of existing *Astrebla* spp. tussocks.

Furthermore, Orr *et al*. (1997) and Orr and Paton (1997) demonstrated the role of strategic burning in reducing the dominance of the undesirable *Aristida* spp. in *H. contortus* pastures and how this burning interacted with management practices. In that research, spring burning increased the contribution of the desirable *H. contortus*, while either exclosure from grazing or substantially reduced grazing pressure over the summer growth period enhanced this effect. An important factor was seedling recruitment of *H. contortus,* which resulted from high seed production in the previous autumn. Clearly, further research is necessary to identify management practices that can be used to reduce undesirable perennial grasses in *Dichanthium sericeum* grassland, *Aristida-Bothriochloa* and *Acacia aneura* woodland pasture communities.

One limitation of the current study was that the 3- and 6-month exclosure treatments occurred during winter, when plant growth is limited by lack of rainfall and by reduced temperature. The improvements in vegetation composition following tactical summer spelling at Gayndah (Orr and Paton 1997) and early wet season spelling at Charters Towers (Ash *et al*. 2002) occurred in response to livestock exclosure during summer. These results suggest that excluding livestock for the purpose of improving pasture composition will be most effective during summer when plants are actively growing. If so, our results from 6-month exclosure, where the livestock exclosure occurred during winter, might not reflect the responses if exclusion had been in summer and rainfall had been adequate. In southern Africa, Tainton (1999) indicated that resting in summer can improve pasture composition by increasing both the number and size of desirable species by promoting seed production and seedling development and by promoting tillering of desirable species.

An important finding from this project has been the reduction in nitrogen yield with increased grazing pressure, a result which occurred across all locations. This finding supports the suggestion by Ash and McIvor (1995) that nitrogen uptake is reduced with heavy pasture utilisation, such as occurs during drought. These results (combined with soil moisture data not presented here) can now be utilised in the GRASP model simulation of the impact of high stocking rates on pasture productivity in northern Australia, extending the range of land types to which this model applies. The mechanistic basis for lower nitrogen uptake under grazing is likely to be a function of reduced root density; however, there have been few studies to support this hypothesis (*e.g.* Crider 1955).

Conclusions

This study indicates that short-term exclosure from grazing does not lead to a rapid recovery in pasture condition, particularly in the absence of above average rainfall. Furthermore, this study indicates that the pasture communities at some of the project locations are in poor condition. Further research, conducted over a series of years, is required to develop an understanding of 'triggers' for vegetation change in northern Australian pasture communities.

Acknowledgements

The cooperation of the following producers who made land available for this study is greatly appreciated: Shane and Shan Joyce, 'Dukes Plain', Theodore; Pat and Norma Galvin, 'Archer', Bajool; Keith and Annabel Chandler, 'Glentulloch', Injune; Scot Stewart, 'Oxford Downs', Nebo; and Rob and Sue Bennetto, 'Virginia Park', Charters Towers. We are grateful to Trevor Hall, Terry Hilder, Peter Connelly and Brigid Nelson, Department of Primary Industries and Fisheries for managing the sites at Injune, Nebo, Charleville and Charters Towers, respectively. We are grateful to Dr Greg McKeon for ongoing discussions throughout the conduct of this study and the preparation of this manuscript. This project was supported by Meat and Livestock Australia

References

Ash, A.J. and McIvor, J.G. (1995) Land condition in the tropical tallgrass pasture lands. 2. Effects on herbage quality and nutrient uptake. *The Rangeland Journal*, **17**, 86–98.

Ash, A.J., O'Reagain, P.J., McKeon, G.M. and Stafford Smith, M. (2000) Managing Climate Variability in Grazing Enterprises: A Case Study for Dalrymple Shire. In: Hammer, G.L., Nicholls, N. and Mitchell, C. (eds) *Applications of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems. The Australian Experience.* pp. 254–270. (Kluwer Academic Press: Netherlands).

Ash, A.J., Corfield, J.P. and Ksiksi, T. (2002) *The Ecograze Project: Developing guidelines to better manage grazing country*. (CSIRO Sustainable Ecosystems: Townsville).

Burrows, W.H. (2000) Successional change and brigalow pastures. In: Cook, B. (ed.) *Buffel Grass Symposium*. (Queensland Department of Primary Industries: Brisbane).

Crider, F.J. (1955) Root growth stoppage resulting from defoliation of grass. *Technical Bulletin Number* 1102. *United States Department of Agriculture.*

Filet, P.G. (1993) State and transition models for rangelands. 3. The impact of the state and transition model on grazing lands research, management and extension: A review. *Tropical Grasslands,* **28**, 214–222.

Hall, T.J. and Douglas, J.R. (2005) Cattle grazing management effects on pasture composition in semi-arid woodlands. *XX International Grassland Congress: Offered papers, Dublin.* p. 542.

McIvor, J.G. (2001) Pasture management in semi-arid tropical woodlands: regeneration of degraded pastures protected from grazing. *Australian Journal of Experimental Agriculture,* **41**, 487–496.

McKeon, G.M., Ash, A.J., Hall, W.B. and Stafford Smith, M. (2000) Simulation of grazing strategies for beef production in north-east Queensland. In: Hammer, G.L., Nicholls, N. and Mitchell, C. (eds) *Applications of Seasonal Climate Forecasting in Agricultural and Natural ecosystems. The Australian Experience*. pp. 227–252. (Kluwer Academic Press: Netherlands).

McKeon, G.M., Hall, W.B., Henry, B.K., Stone, G.S. and Watson, I.W. (2004) *Pasture degradation and recovery in Australia's rangelands: Learning from history*. (Queensland Department of Natural Resources, Mines and Energy: Brisbane).

Orr, D.M. (1981) Changes in the quantitative floristics in some *Astrebla* spp. (Mitchell grass) communities in south-western Queensland in relation to trends in seasonal rainfall. *Australian Journal of Botany,* **29**, 533–545.

Orr, D.M. and Evenson, C.J. (1991) Effects of sheep grazing *Astrebla* grasslands in central western Queensland. 3. Dynamics of *Astrebla* spp. under grazing and exclosure between 1975 and 1986. *The Rangeland Journal,* **13**, 36–46.

Orr, D.M., Paton, C.J. and Lisle, A.T. (1997) Using fire to manage species composition in *Heteropogon contortus* (black speargrass) pastures. 1. Burning regimes. *Australian Journal of Agricultural Research,* **48**, 795–802.

Orr, D.M. and Paton, C.J. (1997) Using fire to manage species composition in *Heteropogon contortus* (black speargrass) pastures. 2. Enhancing the effects of fire with grazing management. *Australian Journal of Agricultural Research,* **48**, 803–810.

Stone, G., Crimp, S., Day, K., Hall, W., Henry, B., McKeon, G., Owens, J., Power, S., Syktus, J. and Watson, I. (2003) Preventing the 9th Degradation episode in Australia's grazing lands. In: Stone, R. and Partridge, I. J. (eds) *Science for Drought, Proceedings of the National Drought Forum, Brisbane, April 2003*. pp. 62–73. (Queensland Department of Primary Industries: Brisbane).

Tainton, N.M. (1999) *Veld management in South Africa.* p. 184. (University of Natal Press: Pietermaritzburg).

Tothill, J.C. and Gillies, C. (1992) The pasture lands of northern Australia. Their condition, productivity and sustainability. *Occasional Publication* No. 5. *Tropical Grassland Society of Australia, Brisbane*.

Tothill, J.C., Hargreaves, J.N.C., Jones, R.M. and McDonald, C.K. (1992) BOTANAL — A comprehensive sampling and computing procedure for estimating pasture yield and composition. 1. Field sampling. *Technical Memorandum* No. 78. *Division of Tropical Crops and Pastures, CSIRO, Australia.*

Whalley, R.D.B. (1993) State and transition models for rangelands. 1. Successional theory and vegetation change. *Tropical Grasslands*, **28**, 195–205.

(Received for publication November 30, 2005; accepted August 29, 2006)