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Using fire to manage species composition in *Heteropogon contortus* (black speargrass) pastures 2*. Enhancing the effects of fire with grazing management

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Abstract. Burning in spring can increase the proportion of the desirable species *Heteropogon contortus* (black speargrass) when pastures remain ungrazed following burning and to a lesser extent when the pasture is grazed. Consequently, an experiment examined the effects on pasture composition of annual spring burning followed by grazing deferment for 0, 2, 4, or 6 months or for 0 months but at half the stocking rate of the other 4 treatments.

Either deferring grazing for 4 or 6 months or halving the stocking rate after burning in spring resulted in an increase in the proportion of *H. contortus*. Burning reduced the undesirable *Aristida* spp. as a pasture component and this effect occurred independently of grazing treatment.

The development of 2 cohorts of *H. contortus* seedlings was monitored for 18 months. Seedlings were selectively grazed but developed rapidly with few differences between treatments. Differences in seedling survival between years reflected differences in rainfall after establishment.

Results indicate that burning in spring to increase the proportion of *H. contortus* will be more effective if followed by 4–6 months rest or by reduced grazing pressure.

Additional keywords: *Aristida* spp., burning, pasture composition, seedling development.

Introduction

Burning a *Heteropogon contortus* (black speargrass) pasture once in either late summer or spring increased the proportion of *H. contortus* and decreased that of *Aristida* spp. when followed by exclosure but not when followed by grazing (Paton and Rickert 1989). Similarly, burning in spring for 3 years in the absence of grazing increased the proportion of *H. contortus* and reduced that of *Aristida* spp. (Orr *et al*. 1991).

More recently, the yield of *H. contortus* has been shown to be influenced by an interaction between burning and grazing (Orr *et al*. 1997). Cattle selectively grazed *H. contortus* that had been burnt in spring in preference to *H. contortus* that had not been burnt. These considerations indicated the need for a grazing management strategy that would allow burning to increase the proportion of *H. contortus* but not remove grazing for prolonged periods of time.

This paper reports a study of the effects of 5 grazing treatments following annual burning in spring of a *H. contortus* pasture and follows on from the earlier experiment reported by Orr *et al*. (1997). The current experiment examines the effects of these treatments at the plant community and individual plant scales.

Methods

Site

This study was conducted at Brian Pastures Research Station, Gayndah, between 1989 and 1994. Details of the site and its grazing and burning history are described in Orr *et al*. (1997).

Treatments

Following burning every spring over the 5 years, grazing was deferred for 0, 2, 4, or 6 months or for 0 months but with half the stocking rate of the other 4 treatments. This latter treatment is hereafter referred to as the half stocking treatment.

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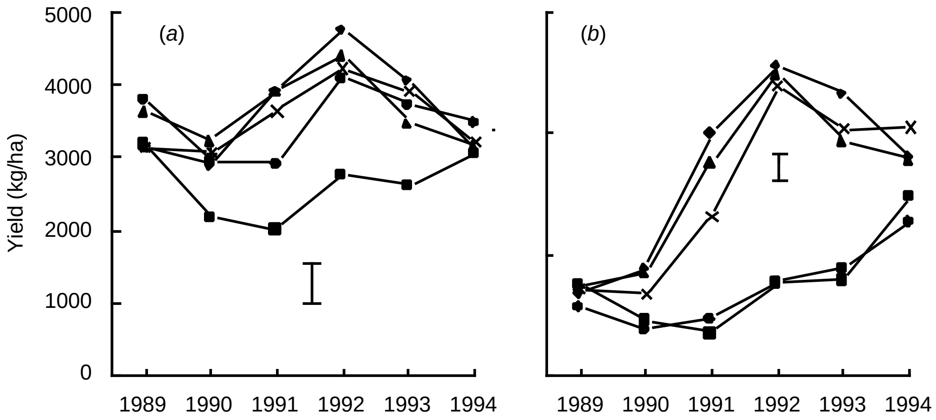

Fig. 1. Changes in the yield (kg/ha) of (*a*) total pasture and (*b*) *H. contortus* under 5 grazing treatments between 1989 and 1993 with subsequent complete exclosure from grazing for the 1994 summer in *H. contortus* pasture: (■) 0 months, (●) 2 months, (▲) 4 months, (◆) 6 months, and (×) half stocking. Vertical bars are l.s.d. ($P = 0{\cdot}05$).

The experiment was a completely randomised design with 5 grazing treatments and 2 replications.

The experimental area of 18·0 ha was fenced from a commercially grazed paddock in February 1989 and livestock were removed. Paddock sizes were 1·5 ha for the 0, 2, 4, and 6 months deferment treatments and 3·0 ha for the half stocking rate treatment. Treatments were burnt for the first time in spring 1989 and grazed, according to treatment, by a single yearling steer of approximately 200 kg liveweight.

In all years, the experiment was burnt following the first substantial rainfall (>25 mm) between August and October. Burning occurred on 15 September 1989, 11 October 1990, 21 October 1991, 21 October 1992, and 7 September 1993.

Measurements

Changes at plant community scale

We measured the yield and botanical composition annually at the end of the summer growing period. Each autumn between 1989 and 1994, 6 trained operators assessed a total of 108 quadrats in each paddock by using the Botanal procedure (Tothill *et al*. 1992). At each recording, the grasses *H. contortus*, *Bothriochloa bladhii*, and *Aristida* spp. were recorded individually. (Individual species of *Aristida* spp. were recorded in the field but grouped into *Aristida* spp. for analysis, despite *A. ramosa* being dominant.) Some species, e.g. *B. decipiens* and *Chloris divaricata*, were recorded individually, whereas others were grouped, e.g. native legumes.

Total basal area and the contribution of perennial grasses to total basal area were measured in December 1993 in the 0 months, 6 months, and half stocking rate treatments. A point frame, with 5 points spaced 10 cm apart, was used to record 'strikes' on all plants from 200 locations (i.e. 1000 points) in each paddock.

Changes at individual plant scale

We monitored the development of *H. contortus* seedlings emerging over the 1990–91 and 1991–92 summers. (Few seedlings emerged following the first burn in spring 1989, as reported earlier; Orr *et al*. 1997.) Two weeks after the first rainfall that resulted in seedling emergence in November 1990 and November 1991, 6 permanent quadrats (0·5 by 0·5 m) containing seedlings were located based on stratified seedling density in each paddock.

Seedling survival was measured by using a pantograph (Williams 1970) at 2-monthly intervals during the first summer and less frequently during the subsequent year. At the same time, seedlings were recorded as grazed or ungrazed. At the end of the second summer, the basal diameter of these *H. contortus* plants was measured. Where plants were not circular, diameter was measured in 2 directions to determine a mean diameter.

Statistical analysis

The effects of treatments and years on the yield and frequency of pasture components were tested using analysis of variance. Preliminary testing indicated that a transformation was necessary for the minor species but not for the major species. Analysis of variance of basal area was performed on square root transformed data.

The effects of grazing treatments on seedling development were tested by analysis of variance using data transformations as required. For survival within and between years, seedling counts were converted to a percentage and the data analysed for each sampling occasion by using analysis of variance following an angular transformation. Analysis of plant diameter classes was performed using a Chi-square test.

Results

Rainfall

Rainfall varied from below to above the long-term mean for all seasons over the duration of the experiment (see Table 1 in Orr *et al*. 1997).

Changes at the plant community scale

Species yield

Between 1989 and 1994, total pasture yield averaged 3390 kg/ha (range 2020–4770 kg/ha) and was differentially influenced ($P < 0{\cdot}05$) by both grazing treatment and year as measured by a treatment×year interaction (Fig. 1*a*). Total yields were generally higher in the 4 and 6 months and half stocking rate treatments than in the 0 months treatment. Between 1990 and 1993, yield measurements reflected the combined effects of burning treatment and differential removal by grazing. To assess cumulative effects of treatments, all paddocks remained ungrazed following burning in spring 1993 until final yield measurements in May 1994.

The mean yield of *H. contortus* was 1270 kg/ha (350–2560 kg/ha) and was differentially influenced ($P < 0{\cdot}05$) by both grazing treatment and year as measured by a treatment×year interaction (Fig. 1*b*). After 1990, yields of *H. contortus* segregated into 2 groups: one containing the 4 and 6 months and half stocking rate treatments, and the other group containing the 0 and 2 months treatments. This pattern was still evident in 1994 following complete rest from grazing after burning in spring 1993.

The mean yield of *Aristida* spp. was 645 kg/ha (75–1630 kg/ha) and declined with time. The mean yield of *B. bladhii* was 725 kg/ha (60–2025 kg/ha) and increased from 1989 until 1992 and then slightly declined. Yields of both *Aristida* spp. and *B. bladhii* differed ($P < 0{\cdot}05$) between years but the effects of grazing treatments were not significant ($P > 0{\cdot}05$) (Fig. 2).

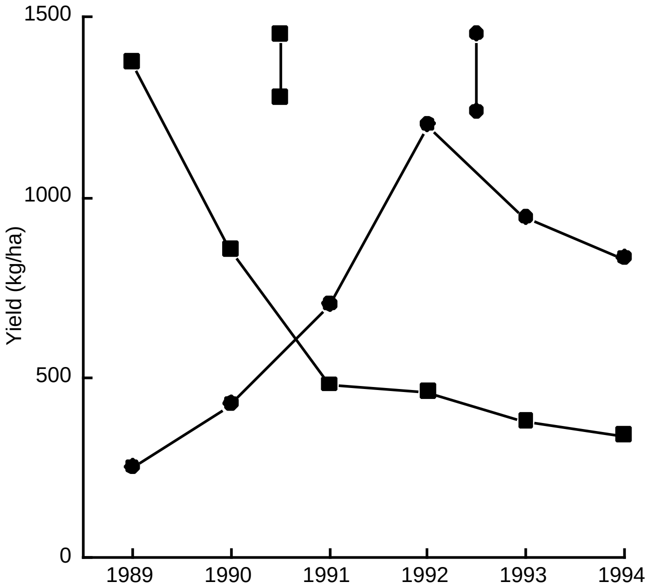

Fig. 2. Changes in the yield (kg/ha) of *Aristida* spp. (■) and *B. bladhii* (●) in *H. contortus* pasture between 1989 and 1994 (data averaged over grazing treatments). Vertical bars are l.s.d. ($P = 0{\cdot}05$).

The yields of minor pasture components varied between years ($P < 0{\cdot}05$) (Table 1) but grazing treatments were not significant ($P > 0{\cdot}05$). Nevertheless, there was a trend for the yields of *B. decipiens*, *C. divaricata*, and *Eragrostis* spp. to decline with the increasing number of times that the pasture was burnt. *Themeda triandra* occurred as isolated plants in one replicate of the half stocking rate treatment and these plants increased in yield each year to 1992. Yields of *Chloris* spp., *Dichanthium sericeum, Sporobolus* spp., *Tragus australianus*, native grasses, and sedges were all <5 kg/ha.

Table 1. Yield (kg/ha) of minor species, averaged over five grazing deferment treatments, between 1989 and 1994

Analyses performed on log (x+1) transformed data

Species	1989	1990	1991	1992	1993	1994	Sign.
Bothriochloa decipiens	405	90	230	175	150	65	*
Chloris divaricata	170	295	100	25	40	10	*
Eragrostis spp.	220	140	160	70	65	20	*
Themeda triandra	0	5	7	12	6	6	*
Other grasses	90	65	70	52	120	65	*
Other forbs	25	65	60	60	30	15	*

$P < 0{\cdot}05$.

Species frequency

The mean frequency of *H. contortus* was 63% (45–82%) and was influenced ($P < 0{\cdot}05$) by both grazing treatment and year of measurement (Fig. 3). The frequencies of *H. contortus* measured in the 0 and 2 month treatments were lower than in all other treatments. This trend was still apparent in 1994.

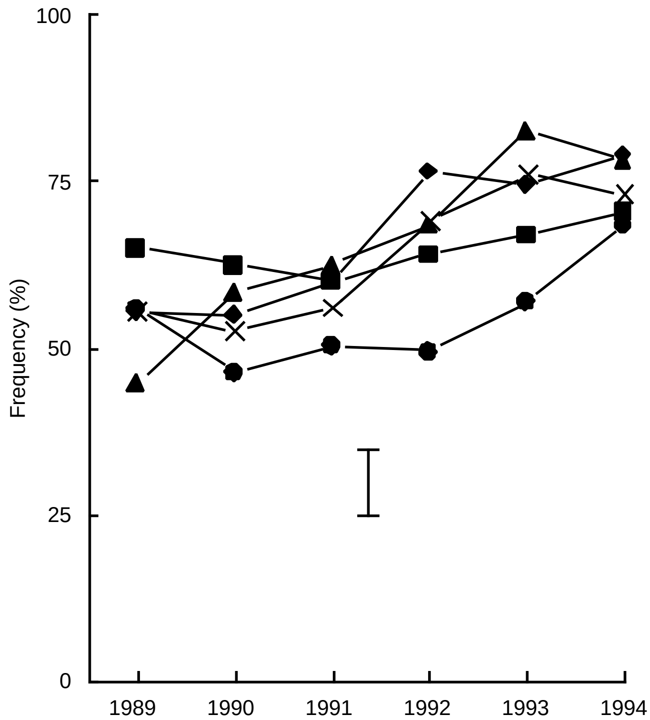

Fig. 3. Changes in the frequency (%) of *H. contortus* under 5 grazing treatments between 1989 and 1993 with subsequent complete exclosure from grazing for the 1994 summer in *H. contortus* pasture: (■) 0 months, (●) 2 months, (▲) 4 months, (◆) 6 months, and (×) half stocking. Vertical bar is l.s.d. ($P = 0{\cdot}05$).

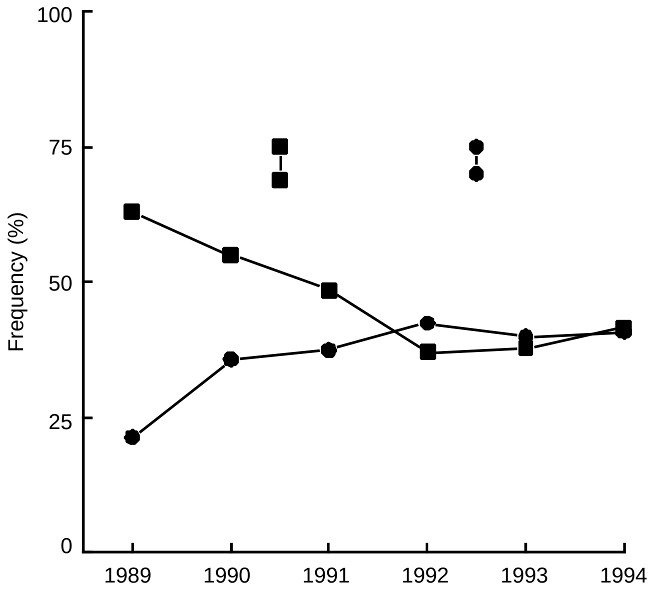

Fig. 4. Changes in the frequencies (%) of *Aristida* spp. (■) and *B. bladhii* (●) in *H. contortus* pasture between 1989 and 1994 (data averaged over grazing treatments). Vertical bars are l.s.d. ($P = 0{\cdot}05$).

The mean frequency of *Aristida* spp. was 47% (18–66%) and declined with time. The mean frequency of *B. bladhii* was 36% (11–59%) and increased after 1989. Frequencies of both *Aristida* spp. and *B. bladhii* differed ($P < 0{\cdot}05$) between years but the effects of grazing treatments were not significant ($P > 0{\cdot}05$) (Fig. 4).

Table 2. Changes in the frequency (%) of minor species, averaged over five grazing deferment treatments, between 1989 and 1994

Analyses performed on arcsine transformed data

Species	1989	1990	1991	1992	1993	1994	Sign.
Bothriochloa decipiens	40	15	30	25	25	15	*
Chloris divaricata	31	48	32	7	14	5	*
Chloris spp.	<1	<1	<1	<1	<1	<1	n.s.
Dichanthium sericeum	<1	8	1	1	1	2	*
Eragrostis spp.	40	38	43	27	26	19	*
Sporobolus spp.	5	13	13	3	3	1	*
Themeda triandra	0	1	1	1	1	1	*
Tragus australianus	1	<1	<1	2	0	<1	n.s.
Other grasses	25	24	27	18	20	17	*
Other forbs	62	89	72	62	40	49	*
Native legumes	6	31	22	30	22	21	*
Sedge	8	9	14	21	17	23	*

* $P < 0{\cdot}05$; n.s., not significant.

The frequencies of minor pasture components were also influenced by year ($P < 0{\cdot}05$; Table 2) but not by grazing treatments ($P > 0{\cdot}05$). However, the frequencies of *B. decipiens*, *C. divaricata*, and *Eragrostis* spp. tended to decline as the numbers of burns increased. The frequency of the native legume component varied from a low of 6% in 1989 to a high of 31% in 1990.

Basal area

Basal area of *H. contortus* in 1993 was doubled ($P < 0{\cdot}05$) in the 6 months and half stocking rate treatments compared with the 0 months treatment (Fig. 5) and increased to be >50% of the total basal area. Total *Aristida* spp. and *B. bladhii* basal areas were similar between treatments.

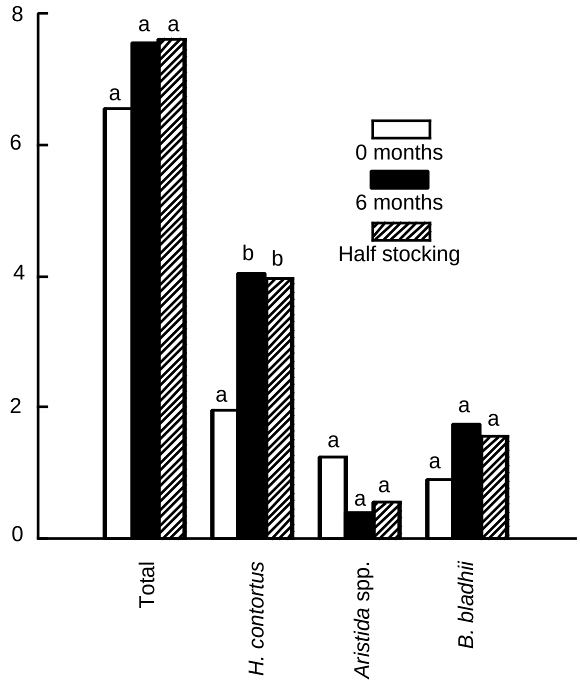

Fig. 5. Basal area (%) in December 1993 of total pasture, *H. contortus*, *Aristida* spp., and *B. bladhii* under 3 grazing treatments in *H. contortus* pasture. Treatments followed by the same letter are not significantly different ($P > 0{\cdot}05$). Analysis performed on square root transformed data.

Changes at the individual plant scale

Seedling growth and development

The highest densities of *H. contortus* seedlings occurred each November with few new seedlings appearing later in the summer (Fig. 6). Because most seedlings appeared in November, the following results are for the November cohorts only. The development of the January and March cohorts was similar to that for the November cohorts (data not presented).

Seedling densities in November 1990 were similar between grazing treatments (Fig. 7). In November 1991, seedling densities were higher ($P < 0{\cdot}05$) for the 4 and 6 months treatments than for the 0 and 2 months treatments.

The proportion of seedlings grazed differed ($P < 0{\cdot}05$) between treatments, particularly during the 1990–91 summer when more seedlings were grazed in the 0 months treatment (Fig. 8). By August 1991, virtually all seedlings from November 1990 had been grazed. By August 1992, most seedlings from November 1991 in the 0 months and 2 months treatments had been grazed, contrasting with the 4 and 6 months and half stocking rate treatments.

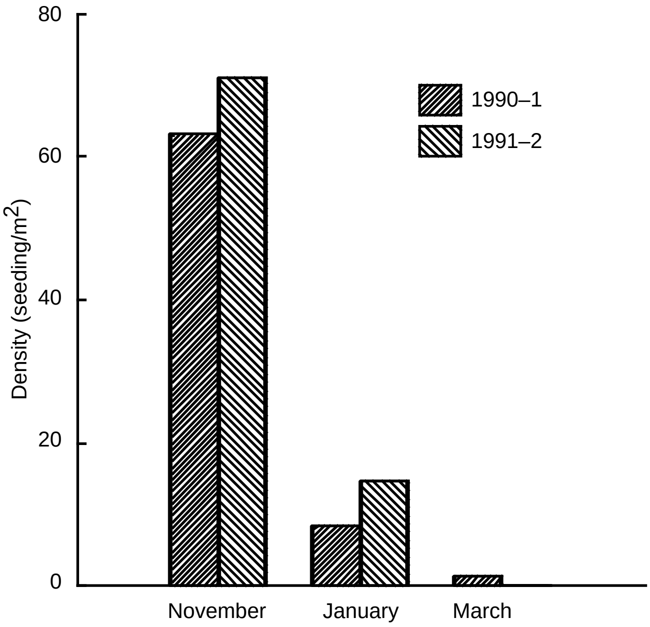

Fig. 6. Density of *H. contortus* seedling recruitment (no./m^2) at 2-monthly intervals over the 1990–91 and 1991–92 summers.

Seedling survival in both 1990–91 and 1991–92 was similar between grazing treatments. Despite this, differences ($P < 0 \cdot 05$) in seedling densities apparent in November 1991 (Fig. 7) had been eliminated by May 1993. After 2 months of growth, seedling survival differed significantly ($P < 0 \cdot 05$) between years (Fig. 9) and this difference was maintained for subsequent growth.

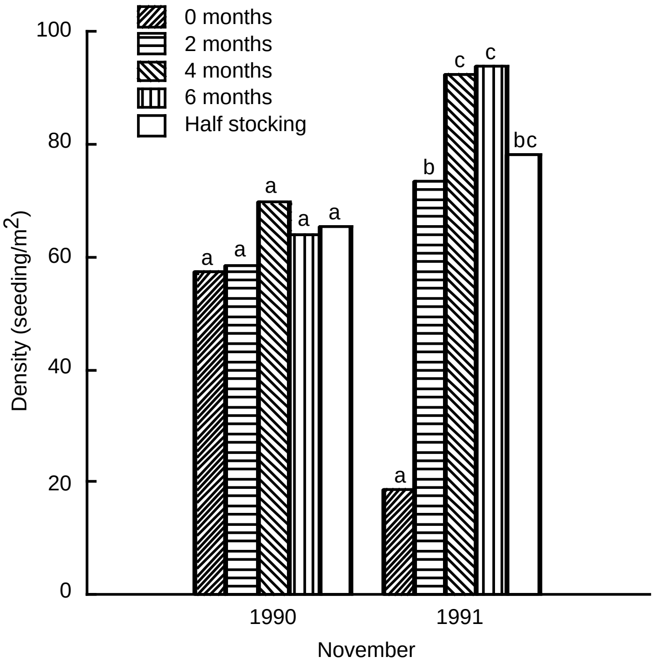

Fig. 7. Density of *H. contortus* seedling recruitment (no./m^2) under 5 grazing treatments in November 1990 and November 1991. Treatments followed by the same letter are not significantly different at $P = 0 \cdot 05$.

After the second summer of growth, both the number of seedlings and their size distributions differed ($P < 0 \cdot 05$) between treatments (Table 3). The largest proportion of seedlings in the 2 largest diameter classes occurred in the 0 and 2 months grazing treatments.

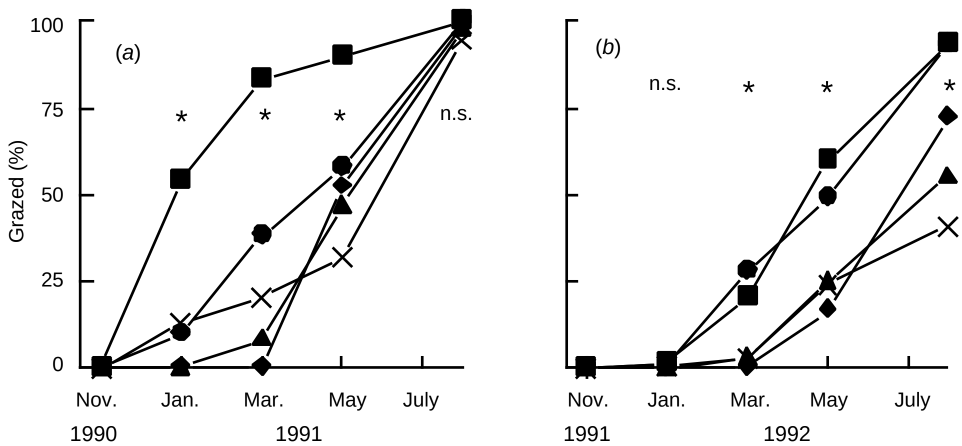

Fig. 8. Changes in the grazing status (% grazed) of *H. contortus* seedlings over the (*a*) 1990–91 and (*b*) 1991–92 seasons under 5 grazing treatments in *H. contortus* pasture: (■) 0 months, (●) 2 months, (▲) 4 months, (◆) 6 months, and (×) half stocking. Significant differences are indicated (*$P < 0 \cdot 05$; n.s., not significant). Analyses performed on arcsine transformed data.

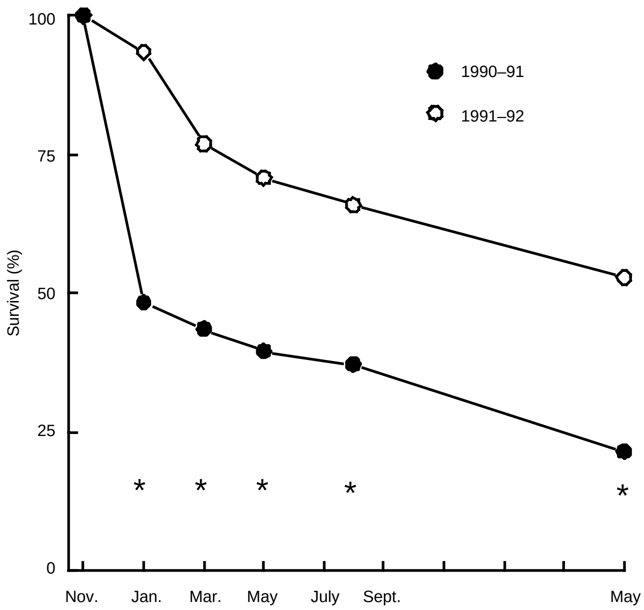

Fig. 9. Survival (%) of November seedling cohorts of *H. contortus* over 18 months for the 1990–91 and 1991–92 summers. Significant differences ($^*P < 0{\cdot}05$) are indicated.

Table 3. Distribution of plant sizes (% of total) between four plant size (tussock diameter) classes and total number of plants (no./1·5 m^2) for the November 1990 seedlings in May 1992 and the November 1991 seedlings in May 1993

Grazing treatment	Size class (cm) <1	1–<2	2–<3	3–<4	Total number of plants
		1990 seedlings in 1992			
0 months	12	47	29	12	24·5
2 months	31	50	19	0	13·0
4 months	46	44	7	3	26·5
6 months	40	57	3	0	18·5
Half stocking	33	62	5	0	20·0
		1991 seedlings in 1993			
0 months	28	32	30	10	20·0
2 months	34	31	23	12	55·5
4 months	60	33	7	0	64·0
6 months	63	28	9	0	60·0
Half stocking	53	30	17	0	70·5

Discussion

Changes at the plant community scale

Burning in spring for 5 successive years, together with reduced grazing pressure, resulted in increased yields of both total pasture and *H. contortus*. Grazing treatments did not influence the occurrence of the other grasses and forbs, although there was a marked decline in the contribution of *Aristida* spp., attributed to annual burning (Orr *et al*. 1997).

Reducing or deferring grazing following spring burning allows new tillers of *H. contortus* to develop following rainfall (Mott *et al*. 1992). Furthermore, consistent differences in *H. contortus* yield between the 2 and 4 months deferred grazing treatments in our experiment support the conclusion that grazing during the early phase of the wet season can be detrimental to plant development (Mott *et al*. 1992). However, our experiment could not define precisely the length of this critical period because animals in our experiment removed different amounts of plant material.

The basal area of *H. contortus* in spring 1993 was less where pastures had been grazed at the normal stocking rate immediately after burning, suggesting that basal area of *H. contortus* is a sensitive measure of important changes in pasture composition in these pastures. Similarly, grazing treatment differences in yield and frequency of *H. contortus* remained following complete exclosure of cattle for the 1993–94 summer, suggesting that these are also sensitive measures of pasture composition. Total pasture species, *Aristida* spp., and *B. bladhii* basal area remained unaffected by grazing treatment. These values for perennial grass basal area are similar to those reported (Orr *et al*. 1991) at a nearby site.

In 1989, *Themeda triandra* was present as isolated plants in one replicate of the half stocking rate treatment. These plants, together with new plants, increased in yield each year and contributed to the increased occurrence of *T. triandra* in this paddock. This result indicates that spring burning together with reduced grazing pressure, when established plants are present, can promote *T. triandra*. Nevertheless, burning in autumn may be even more effective because protection of the tiller bud primordia in autumn is more efficient than that in *H. contortus*, whereas this situation is reversed in spring (Walker *et al*. 1983).

The overall reduction of *Aristida* spp. with burning is consistent with other results (Tothill 1983; Paton and Rickert 1989; Orr *et al*. 1997). However, *B. bladhii*, unlike *H. contortus*, was not affected by grazing, supporting the earlier suggestion (Orr *et al*. 1997) that, although *B. bladhii* is selectively grazed, it is less heavily selected than *H. contortus*.

The occurrence of *B. decipiens*, *C. divaricata*, and *Eragrostis* spp. tended to decline with time in these pastures that were burnt each year. All 3 species are reported to increase when the occurrence of preferred species is reduced (Shaw 1957; Tothill and Hacker 1973; Orr and Paton 1993) so that grazing management that includes spring burning may reduce the occurrence of these less desirable species. The frequency of native legumes differed between years and the increase after 1989 may reflect the reduction in grazing pressure experienced in our study compared with that prior to the commencement of our study.

Changes at the individual plant scale

Seedling emergence of *H. contortus* measured in November was lower than the 300 seedlings/m^2 measured in a pasture with a history of recent burning (Tothill 1969). In our study, most seedlings emerged in November, with much lower emergence later in the summer, and this pattern is consistent with other seedling emergence data in *H. contortus* pastures (Wandera 1993) and in other tropical grasslands (Torssell and McKeon 1976; McIvor and Gardener 1991). In those studies, the major seedling emergence occurred at the start of the summer growing season and was followed by further, but much lower, emergence later in the wet season. Differences in the density of *H. contortus* seedlings in November 1991 probably reflect differences in seed production in the previous autumn. *H. contortus* is a short day plant (Tothill and Knox 1968), with the major flowering period occurring in March. Thus, the heavier grazing pressure on *H. contortus*, as occurred in our 0 and 2 month treatments, may reduce seed set in autumn and seedling recruitment in the following spring.

Stocking rates used in our study were not high enough for animals to remove seedlings (Paton and Rickert 1989). In both years, *H. contortus* seedling survival remained unaffected by the wide range of grazing treatments. Despite this, differences in seedling densities that were apparent between the early (0 and 2 month) and the deferred (4 and 6 month) grazing treatments in November 1991 were not evident in May 1993. This suggests that competition between seedlings and mature plants in the 4 and 6 month treatments may have lead to differential death of seedlings.

Differences in seedling survival between years probably resulted from differences in rainfall during the first 2 months of growth. However, comparing survival in our study with that for a range of introduced grasses and legumes in a similar environment (Cook and Dolby 1981; Cook 1984; Cook and Ratcliff 1992) suggests that *H. contortus* seedlings possess a high level of drought tolerance compared with some introduced species. Drought tolerance in *H. contortus* seedlings would be an advantage, particularly in the southern speargrass region where the summer growth season is less well defined than further north and can be influenced by periods of intense moisture stress within the summer wet season (Tothill 1966). If seedlings from the opening summer rainfall perished due to moisture stress, then the major contribution to seedling recruitment would be from those seedlings that emerged later in the summer.

When *H. contortus* seedlings were grazed soon after burning, those seedlings tended to have larger diameter than seedlings that were rested. This suggests that early defoliation may promote tillering, although the mechanism for this effect is not clear from our study. Grazing of the surrounding mature plants could reduce leaf area and transpiration and so alter the quality of radiation reaching the developing seedling and thus influence tiller recruitment (Briske and Silvertown 1993). Murphy and Briske (1992) reject the concept of apical dominance as overly restrictive in explaining tillering in grasses.

Using fire to reduce the proportion of *Aristida* spp. followed by reduced/deferred grazing to increase that of *H. contortus* can be compared with another study to control *Aristida* spp. (Lodge and Whalley 1985). Instead of using fire, these authors used heavy grazing during summer to reduce *Aristida* spp. followed by deferred grazing in the winter to increase the proportion of the preferred *Danthonia linkii*.

Results from our study provide supporting evidence for the transitions between states outlined in a ‘state and transition’ model for southern black speargrass (Orr *et al*. 1994). According to this model, transitions from the ‘unpalatable tall grass’ (includes *Aristida* spp.), ‘palatable short grass’ (includes *C. divaricata* and *Eragrostis* spp.), and ‘forb/annual grass’ states to the ‘palatable tall grasses’ state (includes *H. contortus* and *T. triandra*) can be achieved through the use of fire and reduced grazing pressure.

Implications for grazing management

Results from this study indicate that the proportion of *H. contortus* can be substantially increased by burning in spring followed by deferred or reduced grazing pressure. However, deferred or reduced grazing pressure requires careful consideration, e.g. provision of alternative forage sources or restructuring to larger property sizes so that stocking rates can be effectively reduced while still providing an economic return for graziers.

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References

Briske, D. D., and Silvertown, J. W. (1993). Plant demography and grassland community balance: the contribution of population regulation mechanism. *In* ‘Proceedings XVIIth International Grassland Congress, Palmerston North’. pp. 291–7.

Cook, S. J. (1984). Establishment of four pasture grasses and Siratro from seed oversown into dense and open speargrass pastures. *Australian Journal of Agriculture and Animal Husbandry* **24**, 360–9.

Cook, S. J., and Dolby, G. R. (1981). Establishment of buffel grass, green panic and Siratro from seed broadcast into a speargrass pasture in southern Queensland. *Australian Journal of Agricultural Research* **32**, 749–59.

Cook, S. J., and Ratcliff, D. (1992). Effects of tree clearing and seedbeds on the establishment, growth and population dynamics of siratro, green panic and signal grass oversown into a speargrass pasture in south-east Queensland. *Tropical Grasslands* **21**, 171–80.

Lodge, G. M., and Whalley, R. D. B.(1985). The manipulation of species composition of natural pastures by grazing management on the Northern Slopes of New South Wales. *Australian Rangeland Journal* **7**, 6–16.

McIvor, J. G., and Gardener, C. J. (1991). Soil seed densities and emergence patterns in pastures in the seasonally dry tropics of north-eastern Australia. *Australian Journal of Ecology* **16**, 159–69.

Mott, J. J., Ludlow, M. M., Richards, J. H., and Parsons, A. D. (1992). Effects of moisture supply in the dry season and subsequent defoliation on persistence of the savanna grasses *Themeda triandra, Heteropogon contortus* and *Panicum maximum*. *Australian Journal of Agricultural Research* **43**, 241–60.

Murphy, J. S., and Briske, D. D. (1992). Regulation of tillering by apical dominance: chronology, interpretive value, and current perspective. *Journal of Range Management* **45**, 419–29.

Orr, D. M., McKeon, G. M., and Day, K. A. (1991). Burning and exclosure can rehabilitate degraded black speargrass (*Heteropogon contortus*) pastures. *Tropical Grasslands* **25**, 333–6.

Orr, D. M., and Paton, C. J.(1993). Impact of grazing pressure on the plant population dynamics of *Heteropogon contortus* (black speargrass) in subtropical Queensland. *In* 'Proceedings XVIIth International Grassland Congress, Palmerston North'. pp. 1908–10.

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., Paton, C. J., and McIntyre, S. (1994). State and transition models for rangelands 10. A state and transition model for the southern black speargrass zone of Queensland. *Tropical Grasslands* **28**, 266–9.

Paton, C. J., and Rickert, K. G. (1989). Burning, then resting, reduces wiregrass (*Aristida* spp.). *Tropical Grasslands* **23**, 211–18.

Shaw, N. H. (1957). Bunch speargrass dominance in burnt pastures in south-eastern Queensland. *Australian Journal of Agricultural Research* **8**, 325–34.

Torssell, B. W. R., and McKeon, G. M. (1976). Germination effects on pasture composition in a dry monsoonal climate. *Journal of Applied Ecology* **13**, 593–603.

Tothill, J. C. (1966). Phenological variation in *Heteropogon contortus* and its relation to climate. *Australian Journal of Botany* **14**, 35–47.

Tothill, J. C. (1969). Soil temperatures and seed burial in relation to the performance of *Heteropogon contortus* and *Themeda australis* in burnt native woodland pastures in eastern Queensland. *Australian Journal of Botany* **17**, 269–75.

Tothill, J. C. (1983). Fire in black speargrass (*Heteropogon contortus*) pastures—a ten year comparison of burnt and unburnt treatments. *In* 'The 2nd Queensland Fire Research Workshop Working Papers'. (Ed. B. R. Roberts.) (Darling Downs Institute: Toowoomba, Qld.)

Tothill, J. C., and Hacker, J. B. (1973). 'The Grasses of Southern Queensland.' (University of Queensland Press: St Lucia.)

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

Tothill, J. C., and Knox, R. B. (1968). Reproduction in *Heteropogon contortus* 1. Photoperiodic effects on flowering and sex expression. *Australian Journal of Agricultural Research* **19**, 869–78.

Walker, J., Malafant, K., and Edwards, J. (1983). The effects of fire on a *Themeda–Heteropogon* grassland near Rockhampton. *In* 'The 2nd Queensland Fire Research Workshop' Working Papers'. (Ed. B. R. Roberts.) (Darling Downs Institute: Toowoomba, Qld.)

Wandera, F. P. (1993). Patches in a *Heteropogon contortus* dominated grassland in southeast Queensland—their characteristics, probable causes, implications and potential for rehabilitation. PhD Thesis, University of Queensland.

Williams, O. B. (1970). Population dynamics of two perennial grasses in Australian semi-arid grassland. *Journal of Ecology* **56**, 869–75.

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