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Using fire to manage species composition in *Heteropogon contortus* (black speargrass) pastures
1. Burning regimes

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Abstract. A reduction in the proportion of the desirable grass *Heteropogon contortus* (black speargrass) and an increase in the undesirable *Aristida* spp. (wiregrasses) are evident in commercially grazed pastures. This paper evaluates the effectiveness of spring burning regimes over a period of 4 years (1989–92) in reversing this form of pasture degradation.

Burning increased the proportion of *H. contortus* when pastures remained ungrazed but not when pastures were grazed, because cattle selectively grazed *H. contortus* after burning. Burning reduced the proportion of *Aristida* spp. and other undesirable grasses such as *Bothriochloa decipiens* and *Chloris divaricata*. A strong 'year of burning' effect was evident.

Burning increased recruitment of *H. contortus* which, in turn, increased plant density and later basal area. Burning reduced the basal area of *Aristida* spp. initially by reducing tussock size and later by reducing tussock numbers.

Results indicate that spring burning can restore pasture composition and that burning in at least 2 successive years appears to be necessary. Light stocking rates should be adopted so that the proportion of *H. contortus* can be maintained and so that pastures can be burnt when and if required.

Additional keywords: *Aristida* spp., basal area, pasture composition, seedling recruitment.

Introduction

In Queensland, *Heteropogon contortus* (black speargrass) pastures occupy 23 million ha and support 3–4 million beef cattle. Since the 1960s stocking rates have increased substantially in these pastures (see Fig. 2, Tothill and Gillies 1992), probably because of economic pressures on producers, increases in the price for beef, particularly prior to the beef price slump in 1974, the introduction of *Bos indicus* cattle, and the use of diet supplements.

Increasing stocking rates combined with drought, particularly during the 1980s, resulted in increased grazing pressures and reduced opportunities to burn these pastures. Such grazing management is consistent with deleterious changes in pasture composition (Weston *et al*. 1981; Anderson *et al*. 1984; Tothill and Gillies 1992).

A state and transition model of vegetation change in southern *H. contortus* pastures (Orr *et al*. 1994) describes transitions between 4 vegetation states in relation to grazing pressure, fire, and seasonal rainfall. According to this model, the deleterious changes in composition reported are associated with a change from palatable, e.g. *H. contortus*, *Bothriochloa bladhii* (forest bluegrass), to unpalatable grasses, e.g. *Aristida* spp.

The presumed role of fire in promoting *H. contortus* has been reported extensively (Shaw 1957; Woodhouse 1964; Tothill and Shaw 1968; Tothill 1983; Walker *et al*. 1983). Tothill (1983) suggested that fire could be used to control pasture composition but few data exist. Subsequently, Paton and Rickert (1989) reported that neither a single fire in spring nor one in late summer followed by grazing reduced the incidence of *Aristida* spp. However, burning in spring for 3 years in

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the absence of grazing increased the proportion of *H. contortus* from 20 to 70% of total pasture yield, while the proportion of *Aristida* spp. fell from 70 to 16% (Orr *et al*. 1991).

Restoring pasture composition by excluding grazing cattle for 3 years is unacceptable to the industry because of lost animal production. The results of Orr *et al*. (1991) suggest that restoration requires some combination of repeated burning and grazing deferment. These considerations prompted the current research that was undertaken to understand further the plant processes involved in repeated burning and in grazing management following fire.

This paper reports a study of the effects of burning regimes on vegetation change in *H. contortus* pastures at community and individual plant scales (Harper 1978). An associated paper (Orr and Paton 1997) reports the effects of grazing management following fire on vegetation change.

Methods

Site

A study of burning regimes was conducted at Brian Pastures Research Station, Gayndah (250° 39′ S, 151° 45′ E), between 1989 and 1992. The site was on a uniform, prairie soil (Uf6, Northcote 1972). This area had a recent history of heavy grazing, being the preferred grazing area of cattle in a commercially grazed paddock stocked at 1 adult equivalent/2·8 ha. Ineffective fires, due to insufficient fuel, were attempted in October 1986 and October 1987.

Treatments

The experimental design was a randomised block split plot with 2 replications of 2 grazing (grazed or ungrazed) treatments each split into 8 burning treatments. Treatments were unburnt, burnt in 1 year, burnt in 2 years, or burnt in each of 3 years. Within these frequencies of burning, treatments were designed to test the effect of year of burning. Accordingly, treatments burnt in 1 year were burnt in the first, second, or third year and treatments burnt in 2 years were burnt in the first and second, first and third, or second and third years. Burning was usually conducted following the first substantial rainfall (>25 mm) between August and October and occurred on 20 September 1989, 12 October 1990, and 28 October 1991.

The experimental area of 2·5 ha was fenced in October 1988 from a commercially grazed paddock and livestock were removed. Plots were 25 by 25 m separated by a 5-m mown border and burning treatments within each grazing treatment were randomised between these plots. Grazing was achieved by allowing steers from the adjacent, commercially grazed paddock equal access to all grazed plots.

Cattle were excluded from the grazed plots over the 1988–89 summer to accumulate fuel and were then allowed access following the first fire in spring 1989. Cattle concentrated their grazing on burnt plots so that, by the third year, much less fuel was available to burn, particularly in those plots that were burnt each year.

Measurements

Changes at plant community scale

Yield and botanical composition were measured annually at the end of the summer growing period. Each autumn between 1989 and 1992, 4 trained operators assessed a total of 48 quadrats in each plot by using the Botanal procedure (Tothill *et al*. 1992). At each time, the grasses *H. contortus*, *B. bladhii*, and *Aristida* spp. were recorded individually. (Individual species of *Aristida* spp. were recorded in the field but grouped into *Aristida* spp. for analysis.) Some species, e.g. *B. decipiens* and *Chloris divaricata*, were recorded individually, whereas others were grouped, e.g. native legumes.

Changes at plant individual scale

Permanent quadrats were established to measure populations of *H. contortus* and *Aristida* spp. Six quadrats, each 0·5 by 0·5 m, were located in each of the ungrazed and grazed replicates of the treatments that were either unburnt or burnt in all 3 years. In October 1988, the position and size of all *H. contortus* and *Aristida* spp. tussocks in these quadrats were recorded using a pantograph (Williams 1970). Basal area of *H. contortus* and of *Aristida* spp. was calculated from the number and diameter of tussocks. Subsequent recordings were made annually in autumn until 1992.

Tussocks of both *H. contortus* and *Aristida* spp. tend to break down into separate segments with increasing age. Where this had occurred in October 1988, we recorded each segment and regarded it as part of one plant, and at subsequent recordings, that plant was considered to be alive if one or more segments of that tussock remained.

The utilisation of *H. contortus* and *Aristida* spp. plants was determined in the permanent quadrats by using the method described by Orr (1980). Utilisation of individual plants was assessed as 1 (ungrazed), 2 (light), 3 (medium), or 4 (heavy) for each plant in each quadrat and then used to derive a mean value for each replicate.

Statistical analyses

An initial analysis of both species yield and frequency data using different burning frequencies (burnt 0, 1, 2, or 3 times) indicated significant differences between years in the effect of burning. Subsequently, total change in species yield and frequency data between 1989 and 1992 were analysed by using a 2^4 factorial design with 2 levels (plus or minus burning) of 3 factors (Years 1, 2, and 3) and 2 grazing levels using GENSTAT. Data presented are the 1992 species yields and frequencies. Although some third-order interactions were statistically significant, they were a minor component of the variability relative to main effects and second-order interactions.

For the permanent quadrats, treatment effects on *H. contortus* and *Aristida* spp. were tested by analysis of variance (following square root transformation) using individual values for each treatment. Values were derived as a mean value of the 6 permanent quadrats in each replicate.

Results

Initial pasture composition

Aristida spp. (mainly *A. ramosa*) were the major contributors to vegetation biomass in autumn 1989, with a mean yield of 1515 kg/ha and a frequency of occurrence of 59% (Table 1).

Table 1. Mean and range for yield (kg/ha) and frequency (%) of important species in a *H. contortus* pasture at Brian Pastures Research Station in autumn 1989

	Yield		Frequency	
	Mean	Range	Mean	Range
Total	4410	3310–6340	—	—
Heteropogon contortus	860	120–2280	54	19–77
Aristida spp.	1515	175–4460	59	23–92
Bothriochloa bladhii	525	25–1700	28	6–60
B. decipiens	830	245–1490	58	83–25
Other forbs	65	5–195	82	63–98
Chloris divaricata	205	0–580	29	0–67
Other grasses	285	50–650	41	25–67
Eragrostis spp.	125	10–350	23	4–67
Native legumes	<5	0–15	20	0–42

Rainfall

Rainfall varied from below to above the seasonal mean in different years (Table 2).

Table 2. Seasonal rainfall (mm) between 1989 and 1994 in relation to the long-term mean for Brian Pastures Research Station

Summer rainfall includes the December rainfall for the previous year

	Summer (Dec.–Feb.)	Autumn (Mar.–May)	Winter (June–Aug.)	Spring (Sept.–Nov.)
1989	302·2	166·6	134·6	175·8
1990	140·8	308·6	54·2	126·6
1991	253·0	104·0	34·2	114·2
1992	429·3	219·1	41·0	175·2
1993[A]	316·8	67·0	85·1	188·6
1994[A]	235·3	188·0		
Long-term mean	287·3	201·7	105·4	123·8

[A] Additional rainfall data included for completeness (see Orr and Paton 1997).

Changes at the plant community scale

Species yield

The mean total pasture yield across all treatments in 1992 was 6730 kg/ha (range 2500–10415 kg/ha) and was influenced ($P < 0{\cdot}01$) by an interaction of grazing×burning in Year 2 (Fig. 1*a*). Total yields increased in treatments both unburnt and burnt in Year 2 when grazing was excluded. Total yields were reduced in the burnt in Year 2, grazed treatments.

The mean yield of *H. contortus* was 2680 kg/ha (375–6500 kg/ha) and was influenced ($P < 0{\cdot}001$) by an interaction of grazing×burning in Year 2. In all treatments, grazing reduced yield and nullified any benefit from burning (Fig. 1*b*). In the absence of grazing, yields were higher after burning in Year 2 but were not affected by burning in Years 1 or 3.

The mean yield of *Aristida* spp. was 1420 kg/ha (15–5160 kg/ha) and was reduced ($P < 0{\cdot}01$) by burning in Years 1 and 2 but not in Year 3 (Fig. 1*c*). These changes occurred independently of grazing treatment. The mean yield of *B. bladhii* was 1390 kg/ha (115–3650 kg/ha); yield increased ($P = 0{\cdot}059$) more in the treatments that were unburnt (1100 kg/ha) than in those that were burnt (640 kg/ha) in Year 2, and this occurred independently of grazing treatment.

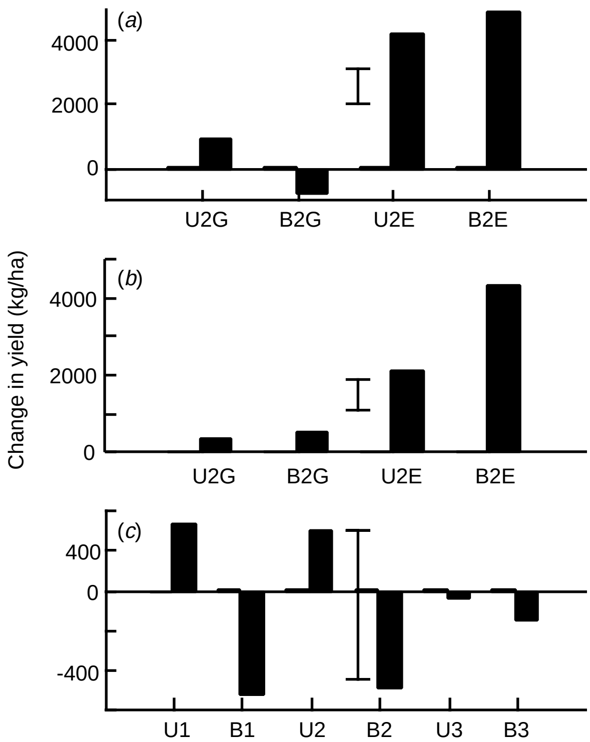

Fig. 1. Changes in the yields (kg/ha) of (*a*) total, (*b*) *H. contortus*, and (*c*) *Aristida* spp. in *H. contortus* pasture under 4 burning regimes between 1989 and 1992. Unburnt (U), burnt (B), exclosed (E), grazed (G); number refers to year of burn. Vertical bars are l.s.d. ($P = 0{\cdot}05$).

The mean yield of *B. decipiens* was 675 kg/ha (100–1500 kg/ha) and burning in Year 2 reduced ($P < 0{\cdot}05$) the yield independently of grazing treatment (Fig. 2*a*). The mean yield of the ‘other forbs’ component was 85 kg/ha (0–380 kg/ha) and was influenced ($P < 0{\cdot}01$) by an interaction of grazing × burning in Year 2 (Fig. 2*b*). Yields of ‘other forbs’ increased under unburnt in Year 2, ungrazed and burnt in Year 2, grazed treatments but were reduced by burnt in Year 2, ungrazed treatments.

The mean yield of *C. divaricata* was 75 kg/ha (0–570 kg/ha) and was reduced ($P < 0{\cdot}05$) by an interaction of grazing × burning in Year 3 (Fig. 2*c*). Burnt in Year 3, ungrazed treatments reduced *C. divaricata* yields more than under burnt in Year 3, grazed treatments. The yields of the ‘other grasses’

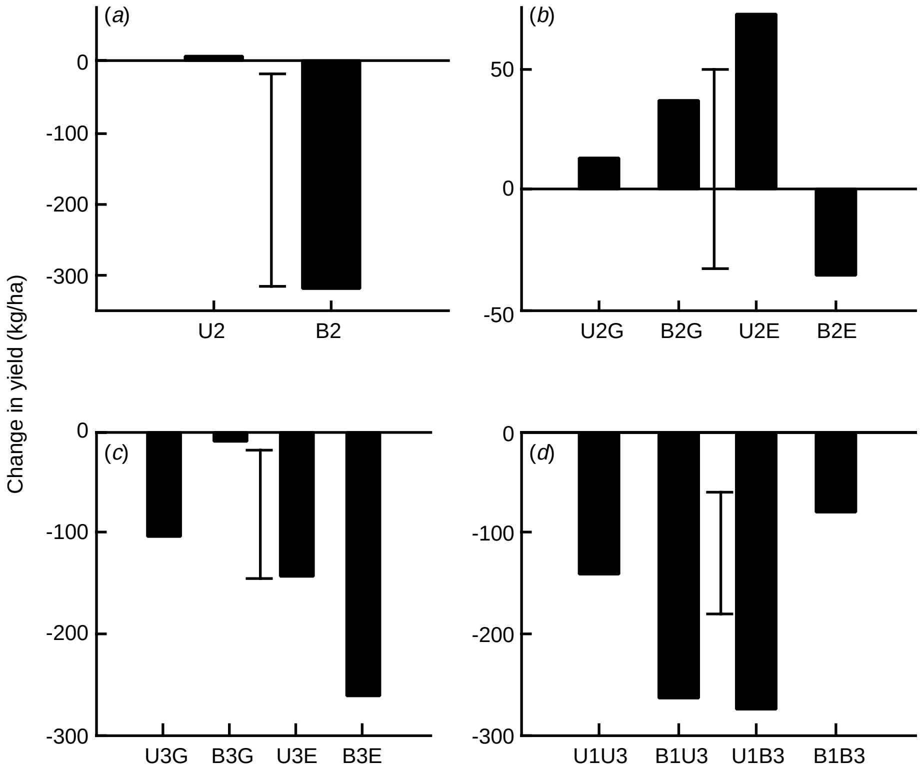

Fig. 2. Changes in the yields (kg/ha) of (*a*) *B. decipiens*, (*b*) other forbs, (*c*) *C. divaricata*, and (*d*) other grasses in *H. contortus* pasture under 4 burning regimes between 1989 and 1992. Unburnt (U), burnt (B), exclosed (E), grazed (G); number refers to year of burn. Vertical bars are l.s.d. ($P = 0{\cdot}05$).

component averaged 100 kg/ha (0–560 kg/ha) and were reduced significantly ($P < 0{\cdot}05$) by a burning in Year 1×burning in Year 3 interaction (Fig. 2*d*).

Mean yields of 75 kg/ha (0–570 kg/ha) for *Eragrostis* spp. and 10 kg/ha (0–75 kg/ha) for native legumes were unaffected by burning and grazing treatments.

Species frequency

The mean frequency of *H. contortus* in 1992 was 67% (range 17–96%) and increased ($P < 0{\cdot}01$) with burning in Year 2 and in Year 3 but not in Year 1 (Fig. 3*a*). This increase was independent of grazing treatment.

The mean frequency of *Aristida* spp. was 51% (4–98%) and was reduced ($P < 0{\cdot}01$) by burning in Years 1 and 2 but not in Year 3 (Fig. 3*b*) and was independent of grazing treatment.

The mean frequency of *B. bladhii* was 40% (17–71%) and increased ($P < 0{\cdot}05$) more when ungrazed than when grazed (Fig. 3*c*). Frequency was also increased more ($P < 0{\cdot}01$) in the unburnt than in the burnt in Year 2 treatment (Fig. 3*d*).

The mean frequency of *B. decipiens* was 35% (10–73%) and the reduction in frequency was greater ($P < 0{\cdot}05$) when ungrazed (32%) than when grazed (13%). The mean frequencies of *C. divaricata*, 'other forbs', and 'other grasses' components were 11% (0–46%), 67% (31–94%), and 13% (4–29%) and the analyses of variance indicated that these frequencies were influenced ($P < 0{\cdot}05$) by third-order interactions. The mean frequencies of 13% (0–42%) for *Eragrostis* spp. and 40% (10–67%) for native legumes were unaffected by burning and grazing treatments.

Changes at individual plant scale

H. contortus plants remained ungrazed over the 1988–89 summer because cattle had been excluded to accumulate fuel for the first fire in spring 1989. Following fire, burnt *H. contortus* plants were selectively grazed compared with unburnt plants (Table 3). Despite this selective grazing, the effect of grazing on seedling recruitment, plant density, and basal area was not significant. Few plants of *Aristida* spp. were grazed.

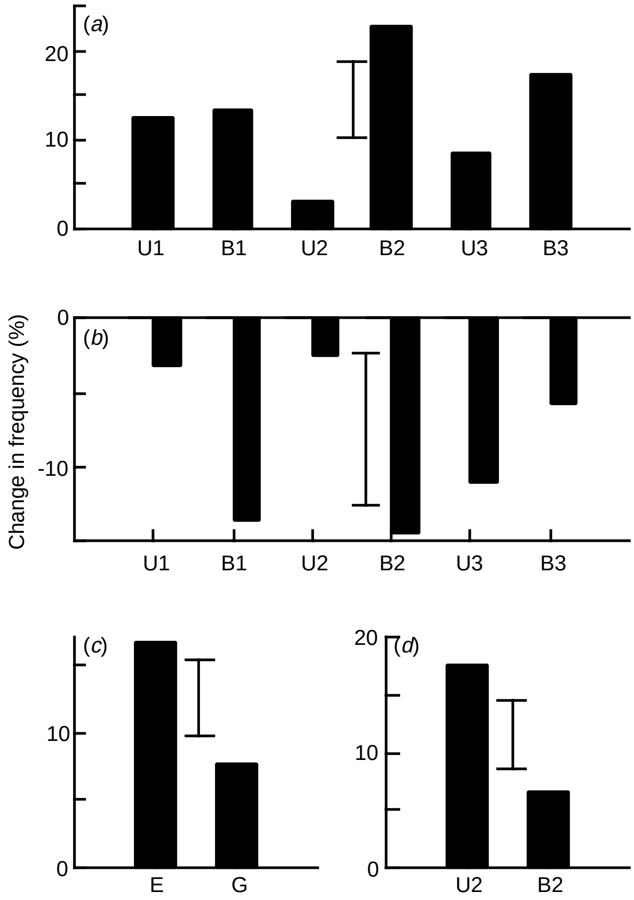

Fig. 3. Changes in the frequency (%) of (*a*) *H. contortus*, (*b*) *Aristida* spp., and *B. bladhii* in response to (*c*) grazing and (*d*) burning in *H. contortus* pasture under 4 burning regimes between 1989 and 1992. Unburnt (U), burnt (B), exclosed (E), grazed (G); number refers to year of burn. Vertical bar is l.s.d. ($P = 0{\cdot}05$).

The density of *H. contortus* increased ($P < 0{\cdot}05$) in the burnt treatment during the 1990–91 summer following burning in the second year (Table 3), whereas the density of *Aristida* spp. was lower ($P < 0{\cdot}05$) in the burnt treatment in 1992 following burning in the third year (Table 4).

The increase in *H. contortus* density between 1990 and 1992 resulted from higher ($P < 0{\cdot}05$) seedling recruitment under burning, particularly following burning in the second year but also in the third year (Table 3). In contrast, few seedlings of *Aristida* spp. were encountered.

Basal area of *H. contortus* in 1992 was higher ($P < 0{\cdot}05$) following burning in the third year compared with the unburnt treatment (Table 3). After burning in the first year, the basal area of *Aristida* spp. fell ($P < 0{\cdot}05$) to remain less than the unburnt treatment for the rest of the study (Table 4).

Table 3. Utilisation rating (1, nil; 2, light; 3, medium; 4, heavy), plant density (plants/m^2), seedling recruitment (number/m^2) and basal area (%) of *H. contortus* in unburnt and burnt treatments for the years 1989–92

Data are mean values for ungrazed and grazed treatments. Analysis of density, seedling recruitment, and basal area performed on $(x{+}0{\cdot}5)^{0{\cdot}5}$ transformed data

	1989	1990	1991	1992
		Utilisation		
Unburnt	—	1·9	1·8	1·4
Burnt	—	2·7	3·2	2·5
Signif.		n.s.	*	n.s.
		Density		
Unburnt	21·9	22·9	21·4	20·5
Burnt	19·9	22·6	44·9	41·2
Signif.	n.s.	n.s.	*	*
		Recruitment		
Unburnt	2·1	1·1	0·1	0·2
Burnt	0·8	3·9	21·5	7·9
Signif.	n.s.	n.s.	**	*
		Basal area		
Unburnt	1·53	2·11	1·43	1·59
Burnt	1·46	2·37	2·24	2·55
Signif.	n.s.	n.s.	n.s.	*

$*P < 0{\cdot}05; **P < 0{\cdot}01$; n.s., not significant.

Table 4. Changes in the plant density (plants/m^2) and basal area (%) of *Aristida* spp. in unburnt and burnt treatments between 1989 and 1992

Data are mean values for ungrazed and grazed treatments. Analysis performed on $(x{+}0{\cdot}5)^{0{\cdot}5}$ transformed data

	1989	1990	1991	1992
		Density		
Unburnt	15·1	15·6	15·9	15·8
Burnt	11·9	11·4	11·2	9·8
Signif.	n.s.	n.s.	n.s.	*
		Basal area		
Unburnt	3·85	3·52	2·95	2·67
Burnt	3·29	1·06	0·53	0·48
Signif.	n.s.	*	*	*

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

Discussion

Effects of burning and grazing

Both burning and grazing influenced pasture composition. Burning increased the yield of *H. contortus* in exclosure but not under grazing because cattle selectively grazed *H. contortus* in the burnt plots. Despite this grazing, seedling recruitment, plant density, and basal area of *H. contortus* were similar under exclosure and grazing. This interaction between burning and grazing as it affects the yield of *H. contortus* is new and further studies of this interaction are discussed in Orr and Paton (1997).

In exclosure, burning in the second year had a major influence on *H. contortus*. Yields in the third year were higher when treatments had been burnt than where they had not been burnt in the second year. Burning in Year 3 did not influence yields, probably because the yield in the unburnt treatment was the growth accumulated over 2 summers, whereas the yield in the burnt treatment represented growth over 1 summer. Reasons for the effectiveness of burning in Year 2 are not readily apparent but may be associated with a seasonal growth effect and particular plant growth mechanisms as discussed below.

Burning reduced the occurrence of *Aristida* spp. independently of grazing treatment. The maximum yield of 3650 kg/ha for *Aristida* spp. in 1992 in the unburnt, grazed treatment reflects the ability of *Aristida* spp. to increase in grazed and unburnt pastures. The large reduction in *Aristida* spp. following burning in the first and second years indicates that *Aristida* spp. (especially *A. ramosa*) are susceptible to fire.

The overall changes in the proportions of *H. contortus* and *Aristida* spp. are consistent with other burning studies conducted in these pastures (Tothill 1983; Paton and Rickert 1989; Orr *et al*. 1991).

Relatively high yields of *B. bladhii* in 1992 (maximum 3650 kg/ha) are indicative of the relatively heavy texture of the soil (Tothill and Hacker 1973) on which this experiment was conducted. In our study, *B. bladhii* increased from 1989 to 1992 but this increase was smaller under burning than non burning. Grazing also reduced its yield, supporting indications (Orr and Paton 1997; R. E. Hendricksen, unpubl. data) that this species is selectively grazed, but since the reduction in yield of *B. bladhii* was less than that of *H. contortus*, *B. bladhii* is perhaps less palatable than *H. contortus*. Shaw (1957) reported that *B. bladhii* was resistant to fire.

The yield of *B. decipiens* was reduced by burning independently of grazing treatment, whereas *C. divaricata* was reduced by burning in exclosure. However, a reduction in *C. divaricata* occurred independently of grazing treatment following burning in spring in an associated study (Orr and Paton 1997). Reasons for these differing results are not readily apparent from the data. The abundance of *B. decipiens* (Shaw 1957; Tothill and Hacker 1973) and *C. divaricata* (Orr and Paton 1993) in these pastures often increases as a result of heavy grazing of the grass species preferred by livestock.

Burning had little effect on the other minor species, possibly because at such low frequency of occurrence our sampling intensity may have been inadequate to detect changes. Tothill (1983) found a reduced occurrence of forbs and other grasses following fire on a light-textured soil elsewhere in the southern speargrass region.

Plant mechanisms

Spring burning promoted recruitment of *H. contortus* and through this process increased plant frequency, density, and basal area. The diameters of seedlings recruited in burnt treatments were larger than those in unburnt treatments, probably because, as found by Campbell (1995), seedlings emerge earlier in spring when pastures are burnt than when they are not burnt. There was no evidence that burning increased the diameter of those individual plants present at the start of the study.

The mechanism by which burning stimulates recruitment in *H. contortus* is not clear. Woodhouse (1964) suggested that, in the southern speargrass region, burning 'may result in a relatively greater production of seed of *H. contortus* at the next heading'. In contrast, spring burning of *H. contortus* in the Northern Territory (Lazarides *et al*. 1965) advanced the timing of floral development but did not change inflorescence density. At a site adjacent to our study, Campbell (1995) showed that spring burning promoted recruitment by promoting seed germination but not seed production. In the current study, fire did not increase the frequency of *H. contortus* until the second and third years. This finding suggests that the soil seed bank at the time of the first fire may have been insufficient to allow the expression of the effect of burning on seedling recruitment. Recruitment of *H. contortus* in 1992 was smaller than that in 1991. Burning in spring 1991 occurred on 28 October following 66 mm of rainfall in the previous 10 days. It was considered that this late burning may have destroyed some emerging seedlings and resulted in the reduced seedling density in 1991 compared with 1990. However, Campbell (1995) showed that seedling emergence is controlled by the effect of burning that causes otherwise dormant seed to germinate. The recruitment measured in our study was higher than that measured in autumn at 4 stocking rates in unburnt pasture (Orr and Paton 1993) elsewhere in the southern region.

In contrast, the basal area of *Aristida* spp. declined following burning in the first year and occurred independently of plant density, which did not decline until after burning in the third year. This result occurred probably because burning reduced the number and size of segments within plants rather than causing the death of whole plants. Burning also reduces plant density in other *Aristida* spp. (Mullham 1985). Although Brown

(1986) reported that burning killed 70% of mature *A. armata* plants, this effect was more than offset by large seedling recruitment in the subsequent summer.

Burning regimes

Despite the finding that the effect of burning differed between years, it is possible to draw some general conclusions on burning regimes. Burning in at least 2 successive years would seem necessary to increase substantially the proportion of *H. contortus* where pastures initially contain a high proportion of *Aristida* spp. (It is unclear whether the effect of 2 consecutive burns is cumulative.) Burning in a third successive year may be necessary to reduce the density of *Aristida* spp. Although the role of fire is important, our results indicate that the particular conditions at the time of burning may be more important.

Implications for grazing management

Results from this study suggest that at least 2 successive spring fires, together with reduced grazing pressure (Orr and Paton 1997), can restore *H. contortus* dominance and control *Aristida* spp., *B. decipiens*, and *C. divaricata*. In contrast, Tothill (1983) reported that annual burning is undesirable because it reduces biodiversity and increases soil erosion. However, the total biomass in our pasture was initially only 20% *H. contortus*, whereas Tothill's comments refer to pastures with initially 50% of the total biomass. Thus, biannual burning is necessary to increase the contribution of *H. contortus*, but once achieved, less regular burning should be adequate.

Graziers should reduce stocking rates for 2 reasons. Firstly, pasture composition measured at the commencement of this study indicates that high stocking rates can result in an increase in the proportion of species such as *Aristida* spp. Secondly, light stocking rates will ensure that fuel is available *if* a fire is considered necessary. Burrows *et al*. (1990) suggest that 800–1000 kg/ha is the minimum yield for burning and Campbell (1995) reports that fire intensity *per se* is not an important factor in controlling *Aristida* spp. However, reducing stocking rates requires careful consideration, e.g. alternative forage sources or larger property sizes so that stocking rates can be reduced and still provide an economic return for graziers.

The fact that burning can be used to manipulate pasture composition raises 2 questions. Firstly, what proportions of these species are desirable in these pastures? Secondly, as posed by Orr *et al*. (1994), what is the relative animal productivity from pastures of different species compositions?

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