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Impacts of grazing management options on pasture and animal productivity in a *Heteropogon contortus* (black speargrass) pasture in central Queensland. 4. Animal production

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Abstract. Steer liveweight gains were measured in an extensive grazing study conducted in a *Heteropogon contortus* (black speargrass) pasture in central Queensland between 1988 and 2001. Treatments included a range of stocking rates in native pastures, legume-oversown native pasture and animal diet supplement/spring-burning pastures. Seasonal rainfall throughout this study was below the long-term mean. Mean annual pasture utilisation ranged from 13 to 61%. Annual liveweight gains per head in native pasture were highly variable among years and ranged from a low of 43 kg/steer at 2 ha/steer to a high of 182 kg/steer at 8 ha/steer. Annual liveweight gains were consistently highest at light stocking and decreased with increasing stocking rate. Annual liveweight gain per hectare increased linearly with stocking rate. These stocking rate trends were also evident in legume-oversown pastures although both the intercept and slope of the regressions for legume-oversown pastures were higher than that for native pasture. The highest annual liveweight gain for legume-oversown pasture was 221 kg/steer at 4 ha/steer. After 13 years, annual liveweight gain per unit area occurred at the heaviest stocking rate despite deleterious changes in the pasture. Across all years, the annual liveweight advantage for legume-oversown pastures was 37 kg/steer. Compared with native pasture, changes in annual liveweight gain with burning were variable. It was concluded that cattle productivity is sustainable when stocking rates are maintained at 4 ha/steer or lighter (equivalent to a utilisation rate around 30%). Although steer liveweight gain occurred at all stocking rates and economic returns were highest at heaviest stocking rates, stocking rates heavier than 4 ha/steer are unsustainable because of their long-term impact on pasture productivity.

Additional keywords: burning, economic evaluation, legume oversowing, steer age effects, steer liveweight gain, stocking rate.

Introduction

In earlier papers, Orr *et al*. (2010*a*, 2010*b*) reported the impacts of stocking rate, legume oversowing and supplements/burning treatments on pasture yield, composition and plant dynamics in a *Heteropogon contortus* pasture in central Queensland. Increasing stocking rate reduced total pasture yield, reduced *H. contortus* density and increased the occurrence of a range of 'increaser' species. Oversowing legumes into the pasture increased the presence particularly of *Stylosanthes scabra* cv. Seca, which had increased to a density of 140 plants/m^2 and contributed 50% of total pasture yield in 2001 at the end of the study. Stocking rate was more influential than pasture type in contributing to these pasture changes.

The sustainable management of native pastures represents a major challenge to grazing land managers. Although *H. contortus* pastures cover 23 million hectares in Queensland, there have been few studies of animal production from these native pastures *per se* because most early studies in Queensland (Hacker *et al*. 1982), focussed on the replacement of these native pastures with introduced grasses and legumes. However, the complete replacement of native with exotic species has usually been uneconomic although one option has been to augment these native pastures with low fertility-demanding legumes such as *Stylosanthes* species. For example, Middleton *et al*. (1993) demonstrated that such pasture development in central Queensland resulted in an annual liveweight gain of 40–70 kg/head per year over that from native pasture. McLennan *et al*. (1987) reported a mean annual liveweight gain of 102 kg/head across a range of native and sown pastures at a range of sites within the *H. contortus* pasture community while Miller and Stockwell (1991) reported animal liveweight gains of 120 kg/head per year for southern *H. contortus* pastures. This paper reports liveweight gains and economic performance of steers in relation to stocking rates in native pasture, native pasture with legume oversown and native pasture with animal diet supplement/burnt treatments between 1988 and 2001.

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Materials and methods

Grazing study

A study was conducted between 1988 and 2001 in a *H. contortus* pasture at Galloway Plains, Calliope (24°10′S, 150°57′E) in central Queensland. The original design was a randomised block with two replications of 11 treatments: five stocking rates (8, 5, 4, 3 and 2 ha/steer) in native pasture and three stocking rates (4, 3 and 2 ha/steer) in both native pasture oversown with introduced legumes with dietary phosphorus (P) supplement and native pasture with dry season protein supplement provided to the steers (Table 1). The two predominant soil types were a low fertility duplex (Dy3) and a grey clay (Ug5) with the study designed so that one replicate block was located on each of these two dominant soil types. Five *Bos indicus* crossbred steers grazed each treatment with paddock sizes from 10 to 40 ha to achieve the designated stocking rates although six steers were included in Drafts 5 (1992–93), 8 (1995–96), 12 (1999–2000) and 13 (2000–01) in order to accelerate stocking rate effects. Steers were replaced annually. The legumes *S. scabra* cv. Seca, *S. hamata* cv. Verano and *Chamaecrista rotundifolia* cv. Wynn were surface sown in October 1987 and *C. rotundifolia* cv. Wynn was resown into cultivated strips in August 1988.

Table 1. Experimental design for stocking rate and pasture type treatments at Galloway Plains between 1988 and 2001

Stocking rate (ha/steer)	Native pasture	Native pasture with legume	Native pasture with dry season supplement/burning
8	+[A]	–	
5	+	–	+[B]
4	+	+	+
3	+	+	+
2	+	+	+

[A]Treatment conducted between 1988 and 1996.
[B]Treatment conducted between 1996 and 2001.

In 1992, the dry season supplement treatments were replaced by spring-burning treatments because there were no long-term liveweight advantages to the supplement treatments. However, by 1996, below average rainfall combined with reduced pasture yields, particularly at 2 and 3 ha/steer, reduced the opportunity to burn. Consequently, in 1996, the 8 ha/steer native pasture treatment (Treatment 1, Table 1) was reassigned to evaluate the impact of spring burning at the stocking rate of 5 ha/steer (Treatment 13, Table 1). Further details are provided in Orr *et al*. (2010*a*).

Animal selection and management

Thirteen drafts of *Bos indicus* crossbred steers were sourced commercially from northern or central Queensland and grazed the study between 1988 and 2001 (Table 2). For each draft, steers were allocated to each paddock based on random stratified initial fasted liveweight. Steers grazed the treatment paddocks for periods varying between 35 and 58 weeks.

For Draft 5 (1992–93), the three heaviest steers were removed from each paddock in June 1993 because seasonal conditions were extremely dry. For Draft 8 (1995–96), the steers were of much lower initial liveweight so that one steer from the previous draft was retained in each paddock for ~6 months. For Draft 11 (1998–99), only four steers grazed each paddock in order to determine whether the liveweight advantage to steers grazing legume-oversown treatments was cumulative over 2 consecutive years. To achieve this comparison, two steers from the previous draft (Draft 10) with ~500 kg/head liveweight were retained while two replacement steers of initial liveweight 250 kg/head were added to each paddock. The two large steers retained from Draft 10 were selected on the basis of a liveweight close to the mean liveweight for each paddock.

Table 2. Animals per paddock, initial liveweight, start and end date for each draft of steers between 1988 and 2000 at Galloway Plains

Year	Draft	Animals per paddock	Initial liveweight (kg)	Start date	End date
1988	1	5	278	14 September 1988	21 June 1989
1989	2	5	291	13 July 1989	4 April 1990
1990	3	6	324	17 July 1990	19 June 1991
1991	4	5	282	9 July 1991	15 July 1992
1992	5	6[A]	259	29 July 1992	8 September 1993
1993	6	5	277	16 September 1993	12 October 1994
1994	7	5	276	30 November 1994	2 August 1995
1995	8	6[B]	172	9 August 1995	23 August 1996
1996	9	5	272	23 October 1996	8 October 1997
1997	10	5	329	15 October 1997	2 September 1998
1998	11	4[C]	323	2 September 1998	5 August 1999
1999	12	6[D]	252	29 July 1999	3 August 2000
2000	13	6[D]	297	26 July 2000	6 June 2001

[A]Heaviest three animals removed in June 1993 due to dry conditions.
[B]One extra animal per paddock retained until March 1996 due to low initial liveweight of Draft 8.
[C]Two animals of 500 kg from Draft 10 and two animals of 250 kg liveweight.
[D]One extra animal per paddock for the entire draft.

Steers were weighed following overnight fasting at the beginning and end of each draft. Between these fasted recordings, steers were weighed without overnight fasting at 4-weekly intervals for Drafts 1–6 but this interval was extended to 6-weekly intervals for all subsequent drafts.

Supplementary feeding

No dry season supplement was fed to animals in Draft 1. Cottonseed meal containing ~40% crude protein was fed at the equivalent of 0.5 kg/steer per day once per week to supplement treatments steers for Drafts 2, 3 and 4 between 25 August 1989 and 3 November 1989, 13 August 1990 and 27 December 1990 and 20 September 1991 and 17 December 1991 respectively. Steers grazing the legume-oversown treatments were fed P as Fermaphos during the wet season (Table 3) while no P was fed to steers grazing either the native pasture or supplement/burning treatments.

Statistical analyses

The grazing experiment was a randomised complete block design consisting of two replicates of 11 treatments. The treatments were arranged as a factorial structure comprising five stocking rates and three pasture types with four treatment combinations missing during 1988 and 1996 and four stocking rates and three pasture types with one treatment combination missing during 1997 and 2001. Given the lack of balance in the treatment structure, the data was analysed using ANOVA with an appropriate nested factorial structure in GENSTAT (Release 6.1, VSN International, Oxford). All measurements were analysed separately for each year.

Economic analyses

An economic evaluation of the native pasture and oversown native pasture was conducted using a standard discounted cash flow (DCF) investment analysis. The DCF analysis estimates the net present value (NPV) or lump present value equivalent of the incremental net cash flow stream over an investment period. It arises directly as a result of estimating the difference in the annual cash flow pattern for the property, with and without any proposed changes. The net present value is calculated as:

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t} \quad (1)$$

where n = number of periods in the investment, r = the discount rate, t = the time of the cash flow and C_t = cash flow at time t.

The analysis was based on the following assumptions: animal liveweight gain was the mean annual liveweight gain per steer for each treatment; a 1000-ha paddock over a 13-year time scale, opportunity cost of livestock capital costs of 10% and a discount rate of 6% applying over the period and purchase and sale prices based on those paid at Gracemere (Rockhampton) sale yards on 24 July 2009.

Table 3. Phosphorus supplement fed to steers in different steer drafts together with start and finish date between 1988 and 2000 at Galloway Plains

Draft	Amount (g/steer.day)	Start	Finish
1	6	13 January 1989	20 June 1989
2	5.9	3 November 1989	3 July 1990
3	6	18 January 1991	10 May 1991
4	5	12 December 1991	26 May 1992
5	5	26 October 1992	15 May 1993
6	9	20 October 1993	23 May 1994
7	Nil	–	–
8	6	13 November 1995	21 June 1996
9	6	25 November 1996	7 April 1997
10	6	15 December 1997	6 July 1998
11	6	25 January 1999	8 June 1999
12	Nil	–	–
13	4	22 January 2001	28 May 2001

Results

Rainfall

Trends in the 5-year moving average summer (October–March) rainfall for Calliope Station (20 km from the Galloway Plains) indicate that the experiment was conducted through the driest period of the last 100 years in this district. Summer rainfall in some years e.g. 1990–91 and 1996–97, approached the long-term mean rainfall while other years e.g. 1992–93 and 1994–95, were very much below the long-term mean. Further details are provided in Orr *et al.* (2010*a*).

Pasture utilisation

Mean annual pasture utilisation increased with increasing stocking rate in the five native pasture treatments from 13% at 8 ha/steer to 61% at 2 ha/steer. Utilisation varied widely between 10% at 8 ha/steer in 1988–89 and 96% at 2 ha/steer in 1997–98. Utilisation was consistently higher on the duplex soil than on the clay reflecting lower pasture yields on the duplex soil. Further details are provided in Orr *et al.* (2010*a*).

Liveweight gain relationships

Averaged across all years, annual liveweight gain per steer decreased linearly with increasing stocking rate in both native pasture ($R^2 = 0.78$; $n = 5$) and legume-oversown ($R^2 = 0.99$; $n = 3$) treatments (Fig. 1*a*). Similarly averaged, liveweight gain per hectare increased linearly with increasing stocking rate for both native pasture (R^2 = 0.88; n = 5) and legume-oversown pasture (R^2 = 0.95; n = 3) (Fig. 1*b*). For both liveweight gain relationships, the intercept and slope of the regression lines for legume-oversown pasture were both higher than that for native pasture.

Impact of stocking rate in native pasture

Annual liveweight gain (kg/steer) in native pasture varied widely with stocking rate and seasonal rainfall notwithstanding grazing periods which ranged from 35 weeks for Draft 7 (1994–95) and 58 weeks for Draft 5 (1992–93) (Table 2). Annual liveweight gain (kg/steer) ranged from a minimum of 43 kg/steer at 2 ha/steer in Draft 5 (1992–93 with 58 weeks of grazing and a low rainfall year) to 182 kg/steer at 8 ha/steer in Draft 8 (1995–96 with 54 weeks of grazing and a high rainfall year) (Fig. 2). Within each draft, there was a consistent

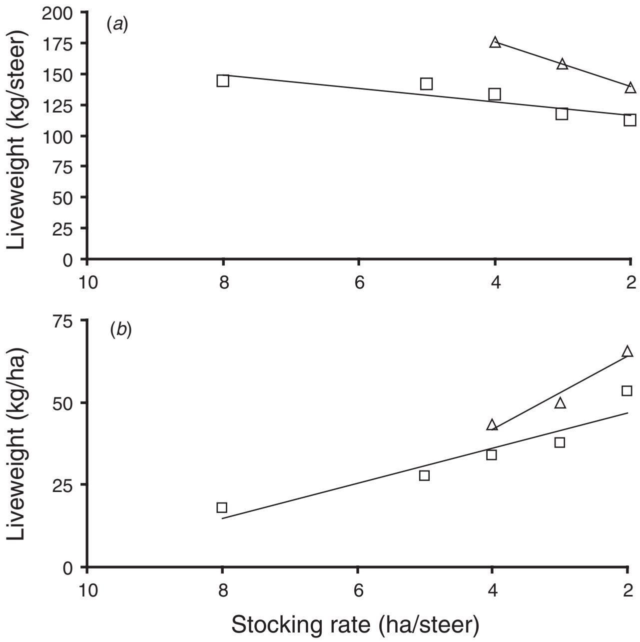

Fig. 1. Relationship between annual liveweight gain in native pasture (□) and legume (△) in relation to (*a*) per animal (kg/steer) and (*b*) per hectare (kg/ha) at Galloway Plains. Equations: liveweight gain per steer in native pasture, $y = 5.49x + 105.29$ ($R^2 = 0.78$), in legume-oversown pasture, $y = 18.26x + 102.84$ ($R^2 = 0.99$) liveweight gain per hectare in native pasture, $y = -5.34x + 57.55$ ($R^2 = 0.88$), in legume-oversown pasture, $y = -11.17x + 86.43$ ($R^2 = 0.95$).

pattern for annual liveweight gain to be highest at the lightest stocking rate and decrease with increasing stocking rate from 8 ha/steer (5 ha/steer 1996–97) to 2 ha/steer. Differences in liveweight gain within years were significant ($P < 0.05$) for the 1990–91 to 1992–93, 1995–96 and the 1999–2000 and 2000–01 draft of steers.

Impact of legume oversowing

A pasture type × stocking rate interaction on animal liveweight was significant ($P < 0.05$) only for Draft 12 (1999–2000). However, the main effect of pasture type was significant ($P < 0.05$) in all 13 drafts while the main effect of stocking rate was significant ($P < 0.05$) in 8 of the 13 drafts. Annual liveweight gain was consistently higher (20–60 kg/head) in the legume-oversown pasture compared with that in the native pasture and supplement/burning treatments and there were no differences ($P > 0.05$) between these latter two pasture types (Fig. 3). As with native pasture, annual liveweight gain decreased with increasing stocking rate (data not presented).

Steer age effects

The overall liveweight gains for the young steers were higher than those for the old steers for Draft 11 (1998–99) (Fig. 4). Young steers in the legume-oversown treatments gained more weight and were heavier ($P < 0.05$) than those in native pasture by the twelfth week of these treatments and this increased liveweight advantage was maintained throughout the remaining period of this draft. In contrast, the liveweight gains of older steers in legume-oversown treatments were similar to that in the native pasture except for the last two weighings when steers in the legume-oversown treatments were heavier ($P < 0.05$) than steers in the native pasture treatments. The liveweight advantage over the 1998–99 season for young steers in legume-oversown treatments was 92 kg/steer over native pasture compared with only 30 kg/steer for the older steers.

Liveweight advantage to legumes

The extent of the annual liveweight advantage to legume-oversown pasture (up to 60 kg/steer in 1998–99 compared with the other two pasture types) varied between years although there was an overall trend for this liveweight advantage to increase with increasing legume composition (Fig. 5). The major period of this liveweight advantage occurred during the autumn and early winter period. During the relative drought year of 1993–94, steers grazing legume-oversown pastures managed to largely maintain liveweight during the winter–spring period whereas steers grazing native pastures and supplement/burning pastures lost weight (Fig. 6*a*). During the generally favourable

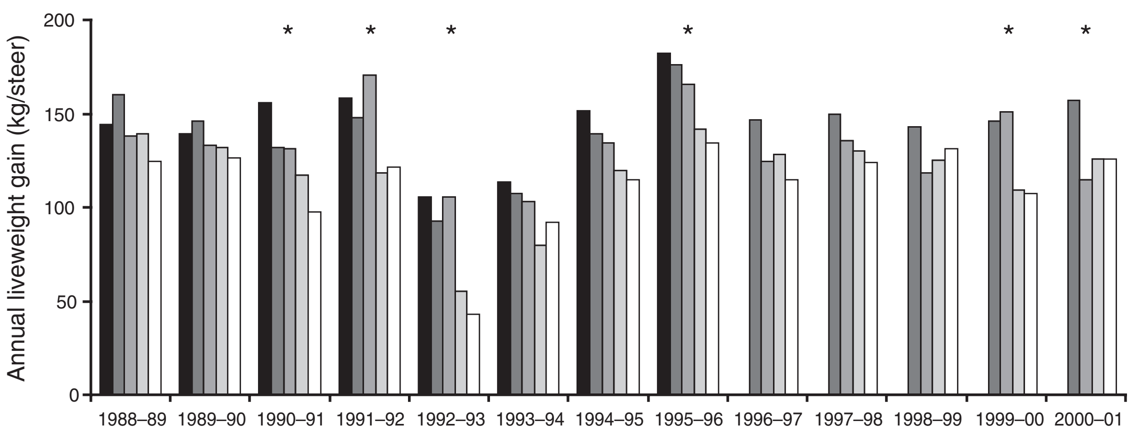

Fig. 2. Liveweight gain (kg/head) of steers grazing native pasture at five stocking rates (8 ha/steer black, 5 dark grey; 4 mid-grey; 3 light grey; 2 white) between 1988 and 1996 and four stocking rates between 1988 and 2001 at Galloway Plains. Within years, asterisks indicate differences ($P < 0.05$) between treatments.

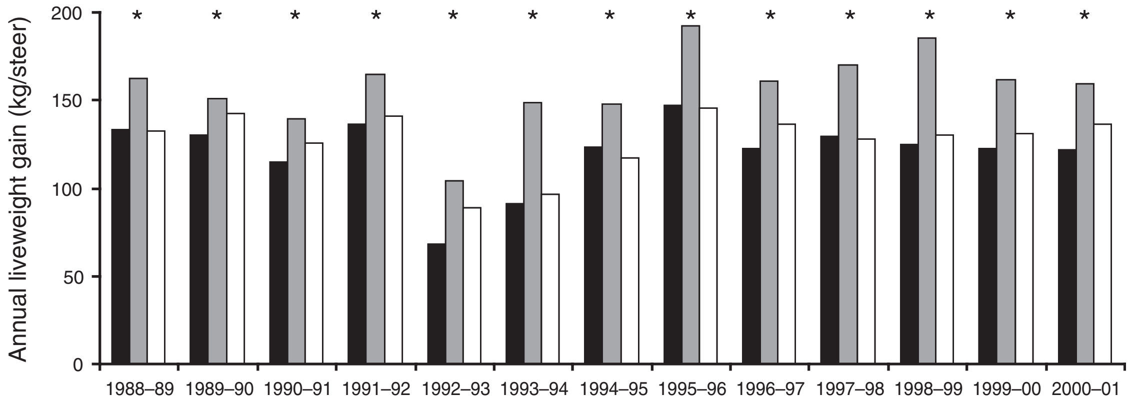

Fig. 3. Liveweight gain (kg/head) of steers grazing three pasture types (native pasture black; legume-oversown grey; supplement/burnt white) (data averaged over three stocking rates) between 1988 and 2001 at Galloway Plains. Within years, asterisks indicate differences ($P < 0.05$) between treatments.

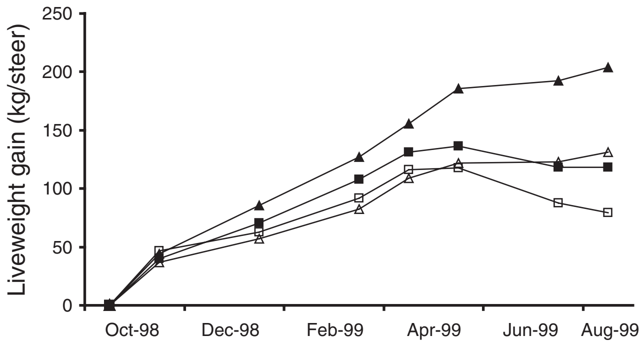

Fig. 4. Liveweight gain (kg/head) of two age groups of steers grazing native pasture (large □, small ■) and legume-oversown pastures (large △, small ▲) (averaged over three stocking rates) for the 1998–99 draft at Galloway Plains.

rainfall year of 1995–96, all steers continued to gain weight throughout the year although the liveweight advantage of legume-oversown pastures was evident in spring and this advantage continued to increase during the autumn–winter period (Fig. 6*b*).

Impact of burning

The pattern of liveweight gain differed substantially between the 1992 and 1999 burns. The impact of grazing at 4, 3 and 2 ha/steer on total pasture yield during drought allowed spring burning in only these 2 years (Orr *et al*. 2010*a*). By April 1993, following burning in September 1992, steers grazing the burnt pasture had similar liveweight to those grazing legume-oversown pastures and both groups of steers were heavier ($P < 0.05$) than those grazing unburnt native pasture (Fig. 7*a*). This liveweight advantage to burning compared with native pasture continued through May 1993 but by June the liveweight of steers grazing the burnt pasture was intermediate between that of the legume-oversown and native pasture steers. No comparison was made beyond June 1993 because the three heaviest steers were removed in June due to drought. Following the burn in October 1999, there were no differences ($P > 0.05$) in steer liveweight between the burnt and unburnt

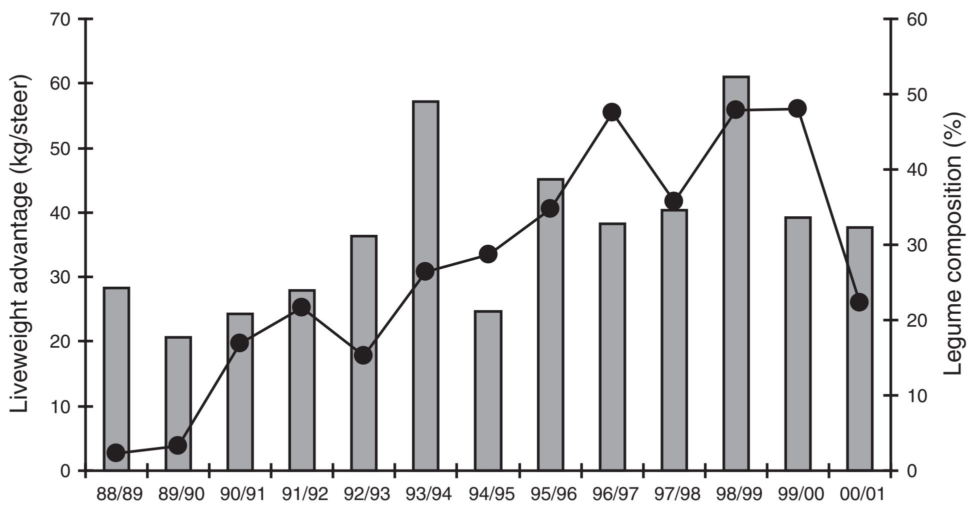

Fig. 5. Liveweight advantage (bars) to steers (kg/steer) grazing legume-oversown native pasture in relation to legume composition (%) (●) in the pasture at Galloway Plains between 1989 and 2001.

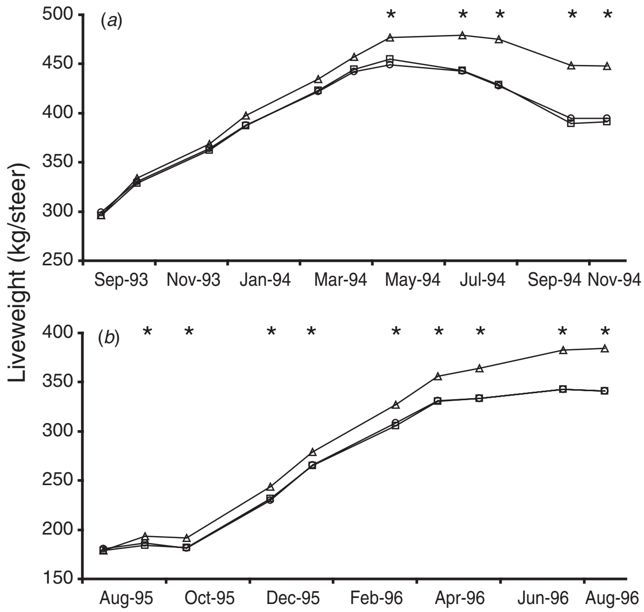

Fig. 6. Unfasted liveweight change (kg/head) of steers grazing three pasture types (averaged over three stocking rates) (□ native pasture, △ legume oversown, ○ supplement/burnt) for the (*a*) 1993–94 and (*b*) 1995–96 steer drafts at Galloway Plains. Within sampling dates, asterisks indicate differences ($P < 0.05$) between treatments.

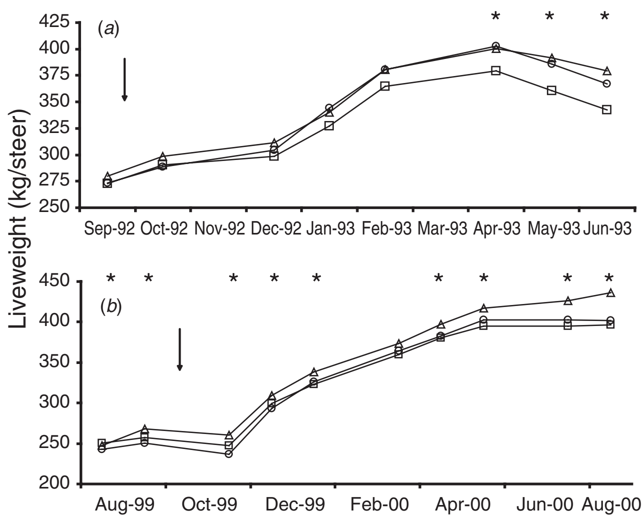

Fig. 7. Unfasted liveweight change (kg/head) of steers grazing three pasture types (averaged over three stocking rates) (□ native pasture; △ legume oversown; ○ supplement/burnt) for the (*a*) 1992–93 and (*b*) 1999–2000 steer drafts at Galloway Plains. Within sampling dates, asterisks indicate differences ($P < 0.05$) between treatments. (Arrows indicate time of spring burning.)

native pasture while steers grazing legume-oversown pasture were consistently heavier ($P < 0.05$) than those in both native pasture and in the burnt pasture except in March 2000 (Fig. 7*b*).

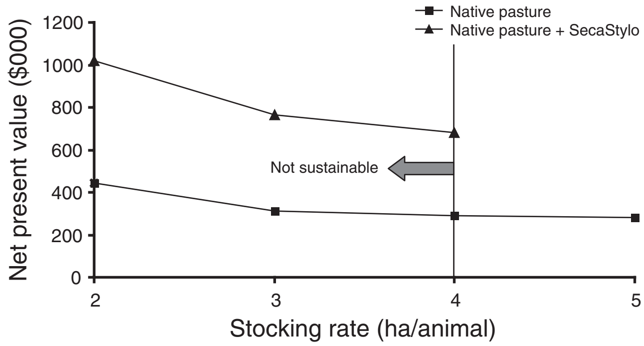

Fig. 8. An economic analysis of grazing at Galloway Plains using net present value.

Economic analyses

Legume-oversown pasture achieved higher economic returns than native pasture across all treatments (Fig. 8). Highest economic returns were achieved at the highest stocking rate of 2 ha/steer with oversown legume while for native pasture, economic returns were highest at 2 ha/steer. There were only marginal differences between economic returns 3, 4 and 5 ha/steer which indicate that stocking rate could reasonably be reduced without reducing economic returns. However, this analysis takes no account of the negative impacts of heavy stocking rates on soil and pasture condition (Fig. 8).

Discussion

Impacts of stocking rate and pasture type

Increasing stocking rate from 8 ha/steer to 2 ha/steer in native pasture progressively reduced annual liveweight gain per steer but increased annual liveweight gain per hectare. Reduced liveweight gain with increasing stocking rate is consistent with the reduction in both total pasture yields (Orr *et al*. 2010*a*) and the contribution to steer diets of *H. contortus* (Hendricksen *et al*. 2010). These stocking rate trends were also evident in legume-oversown pastures although both the intercept and slope of the regression for legume-oversown pastures were higher than that for native pasture. These overall patterns of liveweight gains with stocking rate are consistent with that in most managed pastures (Jones and Sandland 1974). Spring burning had an inconsistent effect on liveweight gain compared with unburnt native pasture.

After 13 drafts of steers during generally dry years, the highest annual liveweight gain per hectare continued to occur at the 2 ha/steer stocking rate indicating some degree of resilience within the pasture system. Despite this apparent resilience, increasing indications of declining resource condition e.g. increasing occurrence of 'increaser' species, reduced landscape function (Orr *et al*. 2010*a*) and reduced *H. contortus* density (Orr *et al*. 2010*b*) suggest that this heavy stocking rate will eventually be unable to maintain this level of animal production and so result in reduced carrying capacity. Few comparable data on pasture resilience in northern Australia are available. However, O'Reagain *et al*. (2009) reported that, after 10 years of grazing near Charters Towers, the heaviest grazing strategy continued to produce the highest animal production per hectare although this result could be maintained only by drought feeding in the drier years. After 8 years, this heavy stocking rate was reduced and subsequent animal performance was lower than might have been expected leading O'Reagain *et al*. (2009) to suggest a decline in the productive potential of this treatment.

A feature of the liveweight responses at Galloway Plains was the large variation among years that was apparent at all stocking rates and in all three pasture types. For example, annual liveweight gain in native pasture ranged from a minimum of 43 kg/steer at 2 ha/steer ('dry' year in 1992–93) to a maximum of 182 kg/steer at 8 ha/steer ('wet' year in 1995–96) while for legume-oversown pastures the range was 75 kg/steer at 2 ha/steer and 221 kg/steer at 4 ha/steer. Such large variations are common in commercial production (Bortolussi *et al*. 2005). Similar large variations have also been demonstrated in other grazing studies in *H. contortus* pastures (Middleton *et al*. 1993; Jones 1997; Hasker 2000; MacLeod and Cook 2004) and other pasture communities in northern Australia (O'Reagain *et al*. 2009). This variation is usually explained by variation in both total annual rainfall and its seasonal distribution and, in commercial systems, by these factors combined with management regimes (Bortolussi *et al*. 2005). Jones (2003) derived a linear relationship between annual liveweight gain and the number of 'green days' as an indication of rainfall distribution but was unable to demonstrate any relationship between liveweight gain and total annual rainfall. More recently, Hill *et al*. (2009) have demonstrated the importance of pasture attributes such as green leaf mass and proportion of green leaf as indicators of potential growth rates of grazing animals.

Steer liveweight gains in our study were higher than that for similar aged steers in northern *H. contortus* pastures near Townsville in both native pasture (Jones 1997) and legume-oversown native pastures (Jones 2003). However, the 2–8 ha/steer stocking rates we used were lighter than the 1.1–3.3 ha/steer used near Townsville. Liveweight gains in our study were similar to those in both native pasture and legume-oversown native pasture in central Queensland (Middleton *et al*. 1993) but were less than that recorded in legume-oversown native pasture stocked at 1.7 ha/steer at Glenwood in southern *H. contortus* pastures (MacLeod and Cook 2004). This overall trend of increasing annual liveweight gains from north to south in *H. contortus* pastures is consistent with the general patterns of liveweight gain described by Miller and Stockwell (1991) who attributed this trend to relatively more fertile soils in the south compared with those in the north. A further factor contributing to this trend is the higher number of 'green days' throughout the year due to the more even distribution of annual rainfall in the south compared with that in the north. This geographic trend is consistent with the results of Bortolussi *et al*. (2005).

Liveweight advantage to legume oversowing

The annual liveweight advantage to legume-oversown pasture over native pasture averaged 37 kg/steer over 13 years. This advantage is higher than the 22 kg/steer annual advantage for steers grazing legume (five species) oversown *H. contortus* pasture between 1989 and 1995 during protracted drought at Glenwood in southern inland Queensland (MacLeod and Cook 2004). Nevertheless, the 37 kg/steer liveweight advantage was similar to the 35 kg/steer advantage recorded between 1984 and 1989 in southern coastal *H. contortus* region which had been oversown with *Cassia rotundifolia* cv. Wynn (Partridge and Wright 1992). This 37 kg/steer advantage at Galloway Plains was at the low end of the 40–70 kg/steer range measured elsewhere in central Queensland (Middleton *et al*. 1993) and the 30–60 kg/steer quoted by Coates *et al*. (1997) for northern Australia. However, the 70 kg/steer figure reported by Middleton *et al*. (1993) was recorded from a pasture where superphosphate fertiliser had been applied to the pasture, whereas steers in our study were fed a P supplement directly in their diet.

An apparent liveweight advantage to steers grazing legume-oversown pastures in the initial year (legume composition <1% of total yield) was an artefact resulting from the soil disturbance associated with the resowing of *C. rotundifolia* cv. Wynn into cultivated strips in August 1988. Such soil disturbance stimulates the mineralisation of soil nitrogen which is taken up by plants and is reflected in increased liveweight gain in subsequent years following the soil disturbance. Nevertheless, there was a consistent trend for the liveweight advantage to legume oversowing to increase with time and this increase was associated with increasing legume composition in the pasture between 1988 (<1% yield; 3 plants/m^2 density) and 2001 (50% yield; 75 plants/m^2) (Orr *et al*. 2010*a*). Despite this increasing legume composition in the pasture, the diet composition in autumn between 1992 and 2000 failed to reflect this increase of *S. scabra* measured in the pasture (Hendricksen *et al*. 2010). The precise point at which the legume composition begins to influence liveweight gain was not clear although 10% legume composition may be a minimum. MacLeod and Cook (2004) suggested that liveweight gain advantages due to legume oversowing occurred when legume composition comprised 5% of total pasture yield.

Steer age effects

Large differences were apparent in the rate of liveweight gain between young and old steers grazing the same treatments during the same season. This finding is similar to that for other mixed aged steers grazing both native and legume-oversown *H. contortus* pastures near Townsville (Jones and Coates 1992; Jones 1997). This result indicates that the liveweight advantage achieved by legume oversowing should be cumulative for the life of steers. However, results from Galloway Plains indicate that the extent of this liveweight advantage on oversown pastures will be greatest for young steers.

Impacts of burning on animal production

Our study produced conflicting results on the impact of burning on annual liveweight gain and this finding is consistent with similar equivocal results on the impact of burning on animal liveweight gain elsewhere in *H. contortus* pastures (Anderson *et al*. 1987). Generally, pasture burning involves the conflicting impacts of reduced pasture yield and improved diet quality. Although Draft 5 (1992–93) did display a substantial liveweight response during summer, equivalent to that from legume oversowing, this response had been reduced by the 1993 winter when steer liveweight in the burning treatment was intermediate between that in the legume-oversown and native pasture treatments. In contrast, Draft 12 (1999–2000) failed to display any liveweight response over that from unburnt native pasture. Spring burning substantially reduced total pasture yields in spring 1992, autumn 1993 and autumn 2000 compared with those in both native pasture and legume-oversown pastures. Thus, this reduced total pasture yield in autumn 1993 probably explains why the initial liveweight advantage in burnt compared with unburnt native pasture had been reduced by the 1993 winter. This reduced pasture yield was probably further exacerbated by reduced pasture quality resulting from the very low seasonal rainfall at that time. Clearly, more research is necessary to further understand the conflicting impacts of spring burning on liveweight gain as measured at Galloway Plains.

This study has reinforced the fact that increasing stocking rate reduces liveweight gain on a per steer basis but increases liveweight gain on a per unit area basis. Oversowing legumes increases liveweight gain over that in native pasture at the same stocking rate and most of this advantage occurs during the autumn–winter period. Young animals gain weight at a faster rate than older animals grazing the same treatments. Spring burning has an inconsistent impact on steer liveweight gain. Although steers continue to achieve highest liveweight production per unit area at the heaviest stocking rate, reduced pasture yield and composition, accelerated soil loss and loss in landscape function suggest that such animal productivity is not sustainable in the long term.

General conclusions

Overall results from this Galloway Plains grazing study indicates that cattle production is sustainable when native pasture is grazed continuously at 4 ha/steer and this equates to 30% pasture utilisation. Increasing stocking rates above 4 ha/steer or 30% utilisation, in the long term, results in deleterious changes in the pasture resource such that cattle production will eventually become unsustainable. One feature of our results is the time lag between the imposition of the grazing treatments and the vegetation response. The composition of *S. scabra* cv. Seca in oversown pasture increases with time and results in some deleterious changes in pasture composition. Spring burning promotes the establishment of *H. contortus* but only at light stocking rates. The unsustainable nature of grazing at 2 and 3 ha/steer in all three pasture types is highlighted by reduced total yields, deleterious changes in pasture composition, accelerated soil loss and reduced landscape function (Orr *et al*. 2010*a*, 2010*b*).

Highest annual liveweight gain per steer occurs at the lightest stocking rate although annual liveweight gain per hectare occurs at the highest stocking rate. Annual liveweight gain is highly variable between years. Oversowing legumes results in additional liveweight over native pasture at the same stocking rate and this advantage averaged 37 kg/steer over the 13 years of our study. The impact of spring burning on liveweight is highly variable. Fistulated steers preferentially grazed *H. contortus* and also select *Chrysopogon fallax*, Seca stylo, forbs and sedge species when these species were available in the pasture but avoided *Bothriochloa bladhii* despite it contributing up to 50% of total pasture yield (Hendricksen *et al*. 2010).

The economic analysis presented here fails to account for the negative impacts of heavy stocking rates (Orr *et al*. 2010*a*, 2010*b*) which will eventually impact negatively on soil and pasture resource. Therefore, it is concluded that long-term sustainable cattle production in these central Queensland *H. contortus* pastures can be achieved using stocking rates of no higher than 4 ha/steer or 30% utilisation in either native pasture or legume-oversown native pasture.

The conundrum for policy makers and extension officers is the quantity of income graziers forgo in the short to medium term in order to achieve sustainable outcomes. In the case of legume oversowing at Galloway Plains, the decision to reduce stocking rate from 2 ha/steer to 4 ha/steer for 13 years would have left the producer A$335 000 worse off. For native pasture, the decision to reduce stock numbers from 2 to 4 ha/steer would have left the grazier A$150 000 worse off. In each instance a rational grazier seeking to maximise profits would be unlikely to reduce stock numbers to 4 ha/steer unless the forgone income streams could be recouped elsewhere in the business via technological advancements or business refinements.

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