Development options in *Heteropogon contortus* grasslands in south-east Queensland: tree killing, legume oversowing and pasture replacement.

1. Pasture production and composition

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Abstract

This paper reports changes in pasture production and composition in response to development options in a black speargrass (*Heteropogon contortus*) community. The study commenced in 1972 in south-east Queensland and measured the effects of tree killing, siratro oversowing, pasture replacement and stocking rate. During Phase I (1972–77), summer rainfall was mostly above average, while in Phase II (1979–86) summer rainfall was mostly below average.

Killing of trees effectively doubled pasture production with little change in species composition, whereas oversowing with siratro (*Macroptilium atropurpureum*) brought dramatic changes in pasture composition. In the wetter years of Phase I, siratro increased to around 50% of pasture yield, with a corresponding decrease in speargrass and other native grasses, but in the drier years of Phase II, siratro decreased to <10%. Replacement of the native pasture with a buffel grass (*Cenchrus ciliaris*) — siratro mixture showed a similar pattern of siratro growth to the oversown pastures but buffel grass tended to dominate and increased to >90% of available pasture during the drier years in Phase II. In years with good soil moisture in winter–spring, massive seasonal increases of nitrophilous species (*e.g.* *Digitaria ciliaris*, *Conyza bonariensis*) occurred as a result of the increased fertility from the siratro. This indicates a potential for other more productive species to exploit this environmental niche.

Pasture utilisation rates remained <30% during Phase I but increased to 50% or more at higher stocking rates in Phase II. In oversown pastures, this led to an increase in the proportion of *Aristida* species from <2% in Phase I to >10% in Phase II, reaching 25% by the final year (1986). The implications of these findings for pasture management are discussed.

Introduction

A large part of the subhumid zone of north-eastern Australia is vegetated by open eucalypt forests and woodlands, which are characterised by a natural grassy understory (Moore 1970; Weston et al. 1981). The black speargrass (*Heteropogon contortus*) region, as originally defined by Shaw and Bisset (1955), was estimated at approximately 17.5 Mha between latitudes 27°S and 19°S. However, Weston et al. (1981) have mapped the region to include a total area of 25 Mha. Black speargrass is found predominantly in areas receiving 650–1000 mm rainfall (Tothill 1970). The dynamics of the speargrass community were reviewed by Grice and McIntyre (1995).

The southern, subtropical part of the black speargrass region is substantially defined by the basins containing the catchments of the Brisbane, Burnett and Boyne Rivers. The southern part differs from the central and northern parts in the occurrence of some winter rain, which reduces the severity of the dry season, and cooler night temperatures during the dry season.

Early development of the region consisted of improved distribution of watering points, fencing and reduction of tree densities by ring-barking. While ring-barking increased herbage production, low quality of the herbage still limited animal performance. During the dry season, protein concentration could decrease to <5% and even as low as 1% (Christian and Shaw 1951; Shaw and Bisset 1955). A further problem was the lack of persistence of speargrass under heavy
grazing (Miles 1949; Bisset 1962). As a result, the country was used mostly for cattle breeding enterprises and rarely for fattening.

However, pasture quality could be improved by introducing legumes into the native pasture. Studies by Shaw in central Queensland showed that Townsville stylo (Stylosanthes humilis) could be successfully introduced into speargrass country (Hacker et al. 1982). However, establishment of Townsville stylo had been unsuccessful in the southern region. Studies by Mannetje (1967) indicated that siratro (Macroptilium atropurpureum cv. Siratro) had potential as a suitable legume for this region. To overcome the lack of persistence by speargrass, introducing a more persistent and productive grass such as buffel grass (Cenchrus ciliaris) was a possible development option.

From this background, an attempt was made to evaluate the major development options for stable and sustainable livestock production on black speargrass country in southern Queensland. The project examined the following 3 basic options:
1. killing or removal of trees,
2. oversowing siratro into native pastures, and
3. replacing native pasture with sown pastures of grass + siratro.
A range of stocking rates was studied for each development option.

This paper presents the impacts of these pasture development options on pasture production and composition. Impacts on animal production are presented in Tothill et al. (2008).

Materials and methods

Site

The 270 ha experiment was located on the former CSIRO Narayen Research Station (25°41’S, 150°52’E) in south-east Queensland. The dominant vegetation was silver-leaf ironbark (Eucalyptus melanophloia) overstory, with a density of 150–200 trees/ha. The community was very uniform except for intrusions of E. tereticornis (blue gum) and E. tessellaris (Moreton Bay ash) in the lower drainage lines. The herbaceous understory was dominated by black speargrass. A detailed description and map of the vegetation of Narayen Research Station are given in Coaldrake et al. (1972).

The soil was a weakly acid (pH 6.2 in water), yellow-red podzolic (paleustalf or albic luvisol) or yellow chromosol (Isbell 1993), derived from freshly weathered granite (adamellite) with a 25–60 cm coarse sand A horizon. Soil P was in the range 15–20 ppm (bicarbonate P).

The average annual rainfall of approximately 700 mm is summer-dominant (December–March). Low rainfall and low minimum temperatures (including frosts) severely reduce plant growth in winter. Detailed meteorological information is available in Cook and Russell (1983).

The site had been part of a large pastoral holding prior to 1965 and there had been no development. Breeding cows had grazed the area at industry rates, believed to be around 6 ha/hd, for approximately 100 years.

Treatments

The experiment was established during 1971–72. In the initial phase (1972–77), there were 24 paddocks representing 12 treatments in 2 replications (Table 1). The experiment was a completely randomised design of 4 main treatments and 7, varyingly allocated, stocking rate subtreatments. With the irregular outline of silver-leaf ironbark woodland through the overall area, the layout of the experiment was also irregular, with all paddocks encompassing largely the same range of slope in the rolling topography. Paddock size was determined by the stocking rate with 4 animals per paddock. Phase II (1979–1986) comprised the main treatments from Phase I, but at a reduced number of stocking rates, augmented with new treatments which will be described in a later publication.

The main treatments in Phases I and II were:
C — native pasture, natural woodland with trees intact (Control),
N — native pasture with trees killed,
NS — native pasture with trees killed, oversown with siratro and P fertiliser applied, and
BS — trees cleared, ground cultivated, buffel grass + siratro mixture sown and P fertiliser applied.

The control (C) plots of unaltered woodland were set up as complete small catchments and were jointly used for this experiment and a complementary hydrological study (Prebble and Stirk 1988).

On N and NS treatments, the trees were killed by stem injection of ‘Tordon’ (picloram) immediately before sod-seeding siratro at 2.2 kg/ha in the
Development options in speargrass lands

NS treatment in January 1972. For the BS treatment, tree clearing, windrowing and burning had been carried out in the late dry season of 1971, with seed-bed cultivation and seed drilling carried out in January 1972.

In NS and BS treatments, 200 kg/ha of single superphosphate (9.6%P) plus molybdenum at 300 g/ha was applied at sowing of the pastures. Subsequently, 100 kg/ha of triple superphosphate (19%P) was applied biennially by aerial application. In Phase II, triple superphosphate was applied triennially.

Stocking rates (Table 1) were based on levels used commercially on black speargrass pastures in the area. For the treatments containing siratro, rates were based on levels indicated by the initial trial experiences of Mannetje and Shaw (1967) at Brian Pastures, where siratro and buffel grass were clearly outstanding, and subsequently of Mannetje (1968) at Narayen, where early trial results confirmed siratro and buffel grass as the most promising legume and grass species. Pilot trials (Tothill 1970) confirmed the suitability of siratro for direct sod-seeding into native pasture under trees, which had been killed with arboricide. As buffel grass fails to establish well from sod-seeding, it was drilled into a cultivated seed-bed, which necessitated the removal of trees.

### Table 1. Main treatments and stocking rates for Phase I (1972–77) and Phase II (1979–86) of the experiment.

<table>
<thead>
<tr>
<th>Stocking rate (ha/hd)</th>
<th>Phase I</th>
<th>Phase II</th>
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</thead>
<tbody>
<tr>
<td>(hd/ha)</td>
<td>Control (C)</td>
<td>Control (C)</td>
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<tr>
<td></td>
<td>Native, trees killed (N)</td>
<td>Native, trees killed (N)</td>
</tr>
<tr>
<td></td>
<td>Native, trees killed, + siratro + P (NS)</td>
<td>Native, trees killed, + siratro + P (NS)</td>
</tr>
<tr>
<td></td>
<td>Buffel-siratro + P, trees cleared (BS)</td>
<td>Buffel-siratro + P, trees cleared (BS)</td>
</tr>
<tr>
<td>C_0.18</td>
<td>N_0.29</td>
<td>NS_0.41</td>
</tr>
<tr>
<td>N_0.18</td>
<td></td>
<td></td>
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<tr>
<td>5.7 0.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.4 0.29</td>
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<td></td>
</tr>
<tr>
<td>2.4 0.41</td>
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<tr>
<td>1.7 0.58</td>
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<td></td>
</tr>
<tr>
<td>1.4 0.75</td>
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<td></td>
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<tr>
<td>1.1 0.93</td>
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<tr>
<td>0.9 1.11</td>
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</tr>
</tbody>
</table>

Measurements

The whole experimental area was overlain by a sampling grid of 30 × 30 m for the improved pastures (NS and BS) and 30 × 60 m for the unimproved (C and N) pastures, giving 2300 sampling sites, with a minimum of 50 per paddock. Pasture and vegetation information was collected from these sites. Each grid point could be related to topographic positions and any other spatial characteristics of the area. While the overall grid was fixed by permanent markers on fences, individual grid points were not permanently marked.

In the year between Phase I and Phase II (May 1977–May 1978) of the experiment, the dead trees were cleared for safety reasons during the dry season to minimise ground disturbance. This, and the need for a year to equilibrate the treatments where stocking rates were changing, meant that 1977–78 was excluded from analyses.

Pasture species

The choice of siratro as the legume and buffel grass cv. Biloela as the introduced species was based on the experience of Mannetje and Shaw (1967) at Brian Pastures, where siratro and buffel grass were clearly outstanding, and subsequently of Mannetje (1968) at Narayen, where early trial results confirmed siratro and buffel grass as the most promising legume and grass species. Pilot trials (Tothill 1970) confirmed the suitability of siratro for direct sod-seeding into native pasture under trees, which had been killed with arboricide. As buffel grass fails to establish well from sod-seeding, it was drilled into a cultivated seed-bed, which necessitated the removal of trees.

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and Hargreaves 1979), using a 50 × 50 cm quadrat. Two estimates were made simultaneously: one on the basis of individual species and the other on the basis of 3 individual species (buffel, speargrass and siratro) and grouped pasture component entities of ‘other grasses’, ‘other legumes’ and forbs, which were further partitioned into green and dry portions. It was recognised that the dry-weight-rank multipliers may have been inappropriate for use with these portions, but this method did provide a relative measure of the green and dry proportions, which appeared to relate well to reality. Pasture presentation yields were estimated using the comparative yield method of Haydock and Shaw (1975). Separate calibrations were made for each pasture type, i.e., N, NS and BS. The above methods are defined in the Botanal package (Tothill et al. 1992). To account for pasture already consumed by animals, intake (biomass attributable to the grazed herbage) was estimated from animal liveweights and liveweight gain using the formula of Minson and McDonald (1987). Intake was apportioned into green and dry components based on preliminary diet selection studies by R. McLean (personal communication). Utilisation (%) was calculated by expressing annual intake as a proportion of total growth (end of season yield + intake in the growing season). It was assumed that all growth from the previous growing season decomposed by the end of the current season.

The presence of speargrass, buffel grass and siratro was recorded simultaneously with pasture composition data to provide frequency data for these key species. The frequency of a species was defined as the percentage of quadrats within a treatment where the species was present.

A visual estimate of ground cover was done simultaneously with pasture estimates, on the basis of projected foliar and litter cover within each quadrat. This was considered a useful indicator of degradation or sustainability, and an important parameter in rainfall runoff considerations.

Temperature data were recorded daily at the official weather station for Narayen, located 3–4 km north–west of the experimental site. Rainfall was recorded daily at the experimental site. Characteristics of rainfall variability and temporal distribution at Narayen and the nearby area are given in Prebble (1981).

**Statistical analyses**

The data analysed for pasture production were green and total (green + dead) DM yields of buffel grass, speargrass, siratro, other grasses and forbs and total green DM. When comparing main treatments and other parameters over all years of Phases I and II, peak yields were used. To relate pasture production to animal performance (see Tothill et al. 2008), the data for Phase I were averaged over seasonal categories used in analysing the animal production data. These were: whole year (all harvests for each year), winter/dry season (June to September–October), spring–summer/wet season (October–November to February–March) and autumn (March to May). Additionally, peak yield in March–April was used when comparing years across Phases I and II. These periods differed slightly according to the start and finish of the rains in different years. For the analysis of stocking rate and seasonal effects, the information used was that taken over the whole year (from 8 sampling times per year in Phase I, and peak yield only in Phase II). The analyses were carried out using GENSTAT © 1980 Lawes Agricultural Trust (Rothamstead Experimental Station) using a completely randomised design with 2 replications.

For pasture composition, except for total values, the same parameters were analysed as for pasture production.

**Results**

**Climate**

Annual and spring–summer (October–March) rainfalls for 1972–1986 are given in Figure 1. In Phase I, 4 of the 5 years had median annual rainfall (691 mm, 1885–1998) or above, with 3 of the 5 years having above median spring–summer rainfall (488 mm). In contrast, in Phase II, only 3 of the 8 years had above median annual or spring–summer rainfall. Further, 5 of the 8 years had spring–summer rainfall below decile 3 (401 mm).

Mean monthly minimum temperatures ranged from 6.5°C in July to 19.6°C in January (Figure 2a), while mean monthly maximum temperatures ranged from 20.3°C to 32.0°C, and grass minimum temperatures from 2.2°C to 17.7°C. Similar numbers of frosts were recorded in Phase I (32/year) and Phase II (27/year).
Figure 1. Actual (bars) rainfall during the study period (1972–1986) and long-term (1885–1998) median rainfall (line): (a) annual; (b) spring–summer (October–March).
(Figure 2b). The highest number of heavy frosts (grass minimum <−2.2°C) occurred in the winter of the drought year 1982, with none in the following winter when rainfall was well above average.

**Main treatments: the four land development systems**

While these may be considered individually as pasture treatments, when taken as pairs of treatments, they represent important developmental sequences, such as the effect of clearing trees (Treatments C vs N), the effect of oversowing siratro into native pasture (Treatments N vs NS) and the comparison of oversown native pasture with fully sown replacement pasture (Treatments NS vs BS).

**Pasture production.** The yields of both dead and green herbage, plus an estimate of livestock intake, were substantially different between main treatments both within and between Phases I and II (Figure 3a). In Phase I, in both Treatments C and N, there was almost as much dead material as green material, but in Treatments NS and BS there was much more green than dead. However, in Phase II, there was much more green material than dead on all treatments, reflecting higher grazing pressures as a result of the generally lower rainfall. In Phase I, green yield increased over the main treatments C, N, NS and BS. Peak green yields in autumn were significantly higher in Treatment N than in Treatment C over Phase I (P<0.001) and Phase II (P<0.05) (Figure 3b). Peak green yields were lower in all treatments in Phase II than in Phase I, but at much lower production levels.

Towards the end of Phase II, the BS treatment was severely stressed by drought and high stocking rates (Figure 3b). Annual peak green yields of the main treatments in the worst year of Phase I (1975) were only slightly lower than those in the best years of Phase II (1981 and 1982). Differences in green yields between the main treatments were smaller in the dry years of Phase II than in Phase I, but at much lower production levels.

Seasonal values for winter (June to Sept–Oct), spring–summer (Oct–Nov to Feb–Mar), and autumn (Feb–Mar to May), averaged over the 5 years of Phase I, for total green and dead yields of the main treatments are given in Figure 3c, along with calculated intakes of green and dead forage. For winter, green yields were generally low, with much higher yields of dead material in all treatments. Winter greenness was lowest in the NS treatment.

**Intake.** The estimated animal intakes increased markedly as the level of pasture development increased in both Phases I and II (Figure 3a). Utilisation rates in Phase I were lower than in the drier years of Phase II, particularly at the higher stocking rates (Table 2).

**Ground cover.** Table 3 shows that ground cover increased significantly (P<0.05) with increasing pasture development over Phase I, with Treatments NS and BS having over 90% ground cover of plant and litter material. However, cover was lower in Phase II (about 80%) owing to a combination of dry conditions, poorer growth and higher stocking rates, with negligible differences between treatments.

<table>
<thead>
<tr>
<th>Table 2. Percent utilisation (estimated animal intake) for each main treatment × stocking rate combination, averaged over Phase I (1972–77) and Phase II (1979–86).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ha/ha</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td><strong>Phase I</strong></td>
</tr>
<tr>
<td>5.7</td>
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<tr>
<td>3.4</td>
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<tr>
<td>2.4</td>
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<tr>
<td>1.7</td>
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<tr>
<td>1.4</td>
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<tr>
<td>1.1</td>
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<tr>
<td>0.9</td>
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<tr>
<td><strong>Phase II</strong></td>
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<tr>
<td>5.7</td>
</tr>
<tr>
<td>2.4</td>
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<tr>
<td>1.4</td>
</tr>
<tr>
<td>0.9</td>
</tr>
</tbody>
</table>
Figure 2. (a) Mean monthly maximum, minimum and grass minimum temperatures during the study period (1972–86); (b) Number of heavy (grass minimum $\leq -2.2^\circ C$) and light (grass minimum $\leq 0.0^\circ C$) frosts over the experimental period.
Figure 3. Main treatment [native pasture + trees (C); native pasture, trees killed (N); native pasture, trees killed + siratro + P (NS); trees cleared + buffel-siratro pasture + P (BS)] effects for Phases I (1972–77) and II (1979–86). Values for (a) and (c) are averages for all harvests taken within the year or season, and those for (b) are for time of peak yield in autumn. Mean I and Mean II represent the means across Phases I and II, respectively. (a) green and dead presentation yields and estimated green and dead animal intakes, averaged over Phases I and II; (b) total green yields for individual years, averaged over stocking rates; (c) green and dead yields and estimated green and dead animal intakes for treatments by seasons (Phase I only).
Pasture composition. For treatment C, while there was considerable year-to-year variation in yield over both Phases I and II (Figure 4a), the relative proportions of speargrass, other grasses and forbs remained remarkably constant (Figure 5a). Year 1974–75 had the lowest speargrass yield in Phase I (640 kg/ha), equivalent to the medium production years 1980–81 and 1983–84 in Phase II, while the lowest speargrass yields in Phase II were 300–400 kg/ha (1979–80, 1984–85 and 1985–86).

In Phase I, yields of speargrass and other grasses in treatment N were approximately 1.7 times (P<0.05) and those of forbs nearly 3 times (P<0.01) those in Treatment C (Figures 4a, 4b); however, pasture composition was similar for the two treatments (Figures 5a, 5b). For Phase II, speargrass yields were similar in Treatments C and N, while yields of other grasses (P<0.05) and forbs (P<0.01) were significantly higher in Treatment N (Figures 4a, 4b). However, only forbs were significantly higher (P<0.05) in composition (Figures 5a, 5b). There was large year-to-year variation in yields with 1973–74 and 1981–82 showing much higher yields of the 3 components than other years in both Treatments C and N.

In Treatment NS (Figure 4c), yields of speargrass were lower, and those of other grasses (P<0.05) and forbs (P<0.001) significantly lower than in Treatment N (Figure 4b) for both Phases I and II. However, while the proportion of these 3 components was significantly lower (P<0.05) in NS than N in Phase I, there was no significant difference in Phase II (Figure 5b, 5c).

In Phase I, there was a clear decline in the proportion of speargrass and other grasses in the years 1973–74 and 1974–75, with a small resurgence in 1976–77. The reduction of speargrass and other grasses coincided with the dominance of siratro in 1974–75 (1000 kg/ha, 70% of the pasture). The drought years of Phase II led to a decline in speargrass yield similar to that in Treatment N (Figure 4c), probably due to higher stocking pressures, but percent composition increased owing to the decline in siratro (Figure 5c). Both total yields and relative yields of all components were highly variable, reflecting largely the climatic variation of predominantly below average rainfall years interspersed with a few good years. However, the trend overall was for a substantial reduction in siratro from 54% in Phase I to 13% in Phase II, though this component increased to 21% in the above average rainfall year 1981–82.

There was a strong trend towards dominance by buffel grass (Figures 4d, 5d) in the BS treatment, with siratro declining over both Phases I and II. In contrast to the NS treatment, in 1981–82 there was little increase in siratro in Treatment BS. By the end of Phase II, the BS pastures were almost totally buffel grass (Figure 5d).

Individual species. Individual species (contributing >1% of pasture composition), which had previously been lumped within the pasture components of ‘other grasses’ and ‘forbs’ (Figures 6 and 7 for Phases I and II, respectively) showed considerable year-to-year variation. Over Phase I, killing the trees on native speargrass pasture tended to increase Sporobolus elongatus and decrease Eragrostis

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**Table 3.** Percent cover (plant + litter) for each main treatment × stocking rate combination, averaged over Phase I (1972–77) and Phase II (1979–86). Values in the same row followed by a different letter are significantly different (P<0.05).

<table>
<thead>
<tr>
<th>Ha/hd</th>
<th>Hd/ha</th>
<th>Control (C)</th>
<th>Native (N)</th>
<th>Native + siratro (NS)</th>
<th>Buffel + siratro (BS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase I</td>
<td></td>
<td>(%)</td>
<td></td>
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</tr>
<tr>
<td>5.7</td>
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<td>91b</td>
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<tr>
<td>Mean</td>
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<td>88b</td>
<td>94bc</td>
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<td>Phase II</td>
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Figure 4. Peak green yields for speargrass, buffel grass, siratro, other grasses and forbs and estimated total green intakes by year, and overall means, for the main treatments over Phases I and II: (a) native pasture + trees (C); (b) native pasture, trees killed (N); (c) native pasture, trees killed + siratro + P (NS); (d) trees cleared + buffel-siratro pasture + P (BS). NB: note different scales on Y-axes of graphs.
Figure 5. Proportions of the various components of the pasture in autumn each year, and overall means, for the main treatments over Phases I and II: (a) native pasture + trees (C); (b) native pasture, trees killed (N); (c) native pasture, trees killed + siratro + P (NS); (d) trees cleared + buffel-siratro pasture + P (BS).
spp. (Figure 6a). The introduction of siratro into native pasture without trees (NS) resulted in considerable reductions in the weeping forms of Aristida spp., Cymbopogon refractus, S. elongatus and to a lesser extent, the erect forms of Aristida spp. and Eragrostis spp. There was, however, a considerable increase in the nitrophilous annual Digitaria ciliaris (Figure 6a). The sown buffel grass-siratro pasture prevented the survival or re-entry of many grass species. In Phase II, there was a notable increase in the erect Aristida spp. (Figure 7) and to a lesser extent B. decipiens and C. refractus in N and particularly the NS treatments, and a decrease in B. bladhii and Eragrostis spp. in N and NS and S. elongatus in Treatment N. In the NS treatment, Aristida spp. increased from <2% in Phase I to >10% in Phase II and were >25% in 1986. While there were increases in Aristida spp. from Phase I to Phase II in Treatments C and N also, the changes were of a smaller magnitude (Figures 6a, 7a). The unpalatable Arundinella nepalensis was the main increaser in Treatment BS but was still a minor component.

In Phase I, the predominant forbs in Treatment C were Glycine spp., Chrysanthemum apiculatum and Vernonia cinerea (Figure 6b). With tree clearing, Conyza bonariensis rapidly increased in both Treatments N and NS and was the only forb of significance in BS. C. apiculatum was reduced to negligible levels in NS, while there was a massive build-up of Cirsium vulgare in the final 2 years of Phase I (Figure 6b). In Phase II (Figure 7b), C. bonariensis became the predominant forb throughout all treatments, though Glycine spp. and Aster spp. remained substantial in Treatments C and N, with Aster spp. making a brief but substantial appearance in BS in 1985. In the NS treatment, Sida spp. and Portulaca spp. became prominent, with C. vulgare persisting.

Frequency. Speargrass frequency remained almost constant over Treatments C, N and NS between Phases I and II (Figure 8), as did that of buffel grass in Treatment BS. Between treatments, speargrass frequency declined from Treatment N to NS in Phase I but not Phase II. Speargrass in Treatment NS followed the same dip in frequency in 1975, as was seen in both green yield and dry matter composition.

Subtreatment effects — stocking rates

In the previous section dealing with the main treatment effects, stocking rates were averaged within main treatments, which meant that treatments were compared on the basis of different mean treatment stocking rates. In this section, stocking rate effects within main treatments and equivalent stocking rate effects between main treatments are examined.

Pasture production. Dead and green yields and animal intake estimates, averaged over the 5 and 8 years of Phases I and II, respectively, showed that stocking rate had little effect on pasture yield within main treatments in Phase I (Figure 9a). In Phase II, in the NS treatment, there was a larger difference between stocking rates than in Phase I, reflecting the significant climatic difference between the periods.

Intake. Estimated intake of green dry matter increased with stocking rate with the proportion of the total amount of green material eaten: the total green biomass produced (total green yield + green forage intake) ranging from 5% in Treatment N to 27% in Subtreatment NS at 0.93 hd/ha (NS0.93) in Phase I (Table 2). In Phase II, estimated intake represented a much greater proportion of the total biomass production than in Phase I. Similarly, estimated green intake was a much higher proportion, with Subtreatment NS at 1.11 hd/ha (NS1.11) having a utilisation rate of 64% of total green biomass and Treatment BS1.11 a rate of 48%, with some years exceeding 100%, i.e., all growth for the season was consumed.

Ground cover. In Phase I, stocking rate had little effect on cover (Table 3) with no significant difference between stocking rates within any main treatment. In Phase II, there was a substantial decrease in cover between NS0.75 and NS1.11.

Pasture composition. Speargrass yield was consistent over stocking rates within the sub-treatments of N and NS (Figure 9b). Other grasses and forbs decreased significantly (P < 0.05) in yield between Subtreatments N0.18 and N0.41. The overall levels of all 3 components in the sub-treatments of NS were significantly (P < 0.05) lower than those in N. Other grasses and forbs tended to increase with increasing stocking rate, but not significantly. In the NS sub-treatments, siratro yield was significantly reduced (P < 0.05) with increasing stocking rate. While overall yields in BS exceeded those in...
Figure 6. Proportions of individual species occurring at >1% within the pasture components for the main treatments [native pasture + trees (C); native pasture, trees killed (N); native pasture, trees killed + siratro + P (NS); trees cleared + buffel-siratro pasture + P (BS)], for individual years over Phase I (1972–77): (a) ‘other grass’ components: weeping Aristida spp. Aris(w), erect Aristida spp. Aris(e), B. bladhii (B.bld), B. decipiens (B.dec), C. refractus (C.ref), D. ciliaris (D.cil), Eragrostis spp. (Erag) and S. elongatus (S.elo); (b) ‘forb’ components: Glycine spp. (Glyc), Aster spp. (Aster), C. vulgare (Cirs), C. bonariensis (Conyz), C. apiculatum (Chrys), Vernonia cinerea (Vern), Sida spp. (Sida) and Portulaca spp. (Port).
Figure 7. Proportions of individual species occurring at >1% within the pasture components for the main treatments [native pasture + trees (C); native pasture, trees killed (N); native pasture, trees killed + siratro + P (NS); trees cleared + buffel-siratro pasture + P (BS)], for individual years over Phase II (1979–86): (a) ‘other grass’ components: weeping Aristida spp. Aris(w), erect Aristida spp. Aris(e), B. bladhii (B.bld), B. decipiens (B.dec), C. refractus (C.ref), D. ciliaris (D.cil), Eragrostis spp. (Erag) and S. elongatus (S.elo); (b) ‘forb’ components: Glycine spp. (Glyc), Aster spp. (Aster), C. vulgare (Cirs), C. bonariensis (Conyz), C. apiculatum (Chrys), Vernonia cinerea (Vern), Sida spp. (Sida) and Portulaca spp. (Port).
NS, differences were not significant. Buffel grass was virtually unaffected by increasing stocking rate and became dominant, excluding most of the other grass and forb components, with siratro yields similar to those in NS.

In Phase II, yields of speargrass, siratro, other grasses and forbs all decreased sharply (P<0.01) at the higher stocking rate of NS1.11.

Frequency. Stocking rate had no effect on speargrass frequency within Treatments C, N and NS in Phase I. Overall values for Treatment NS were significantly (P<0.05) lower than for C and N. In Treatment BS, buffel grass frequency remained very high throughout. Siratro declined slightly with increasing stocking rate in Treatment NS, but remained uniformly high in BS. In Phase II, frequency of speargrass and siratro tended to decline with increasing stocking rate in Treatment NS.

Seasonal effects. In Phase I only, effects of stocking rate on seasonal green yield were not significant (Figure 9c). Winter green yields were remarkably constant over stocking rates within main treatments, but there were quite marked differences between main treatments, with higher green yields in N and BS. Spring–summer yields tended to decrease with increasing stocking rates, especially in Treatments NS and BS.

Comparison of main effects at comparable stocking rates

As there was little effect of stocking rate on yield and composition, comparisons of main effects at the same stocking rate in Phase I are similar to those averaged over stocking rates.

The effect of tree clearing on native pasture (C vs N). This comparison between Treatments C (native pasture with trees) and N (native pasture without trees) is at the same stocking rate of 0.18 hd/ha (C0.18, N0.18) over Phase I and C0.18 and N at 0.41 hd/ha (N0.41) over Phase II.

In Phase I, overall pasture yields were significantly greater (P<0.05) for N0.18 than C0.18 for the 5-year means (Mean I, Figure 9a), as were yields of speargrass, other grasses and forbs (Figure 9b). For individual years, yields were always substantially greater for N0.18, being significantly so (P<0.001) for speargrass in 2 years out of 5, other grasses (P<0.05) in 4 years out of 5 and forbs (P<0.01) in all years. In Phase II, both the 8-year mean (Mean II, Figure 9a) and yields for individual years were always higher in Treatment N0.41 than C0.18 for all 3 pasture components. As with the main treatments, there was a slight drop in frequency of speargrass between Treatments

![Figure 8. Frequency of occurrence of speargrass or buffel grass and siratro for each main treatment × stocking rate combination, averaged over Phase I (1972–77) and Phase II (1979–86).](image-url)
Figure 9. Pasture yields and estimated animal intakes averaged over Phase I (1972–77) and Phase II (1979–86), for the stocking rate sub-treatments of the main treatments [native pasture + trees (C); native pasture, trees killed (N); native pasture, trees killed + siratro + P (NS); trees cleared + buffel-siratro pasture + P (BS)], at time of peak yield in autumn (a); (b) green yields for the main species: speargrass, buffel grass, other grasses, forbs and siratro, and green animal intake at time of peak yield in autumn; (c) green DM yields for winter, spring–summer and autumn, averaged over all harvests taken within the season, for Phase I only.
C.0.18 and N0.18, and a significant (P<0.05) difference in cover during Phase I (Table 3).

The effect of oversowing siratro into native pasture without trees (N vs NS). This comparison is between native pasture Subtreatments N (without) and NS (with) the oversown siratro plus P fertiliser at the equivalent stocking rates of 0.41 hd/ha (N0.41, NS0.41) during Phase I and Treatment N0.41 and Subtreatment NS at 0.75 hd/ha (NS0.75) during Phase II.

The 5-year mean values for green yields were substantially higher for NS0.41 than for N0.41 (Figure 9a). This was also the case for the majority of individual years. However, in the exceptional year 1974–75, the year following the siratro dominance, NS0.41 yielded significantly less (P<0.01) than N0.41.

Yield of speargrass was generally higher in N than NS, except for the initial year of 1972–73, when siratro was still establishing. Green yields of other grasses and forbs were significantly lower overall (P<0.05) in NS0.41 than N0.41, but there was considerable year-to-year variation. There was a significant (P<0.05) reduction in the frequency of speargrass between N0.41 and NS0.41, but a significant (P<0.05) increase in ground cover (Table 3).

In Phase II, the differences in yields between N0.41 and NS0.75 were smaller than in Phase I, owing to much lower rainfall and the higher stocking rate in the NS0.75 treatment. While siratro had been a major factor in increasing forage yields in Phase I, it played an almost negligible direct role in Phase II. In the middle years of Phase II, when rainfall was near normal, yields of speargrass and other grasses returned to their original levels in both treatments, and the differences between treatments were not significant. Other grasses and forbs did not exhibit a meaningful pattern or trend or any significant differences between treatments, and there was no significant difference in ground cover.

Comparison of native pasture oversown with siratro without trees, and replacement sown grass-siratro pasture (NS vs BS). A comparison of subtreatments of NS and BS pastures can be made over 3 equivalent stocking rates of 0.58, 0.75 and 0.93 hd/ha in Phase I, and at 1.1 hd/ha in Phase II (NS1.1 vs BS1.11).

There were substantial differences in yield between speargrass in NS and buffel grass in BS over all years (Figure 9b), but the differences were not significant. Buffel grass became progressively more dominant over the other components, whereas the speargrass pastures maintained a reasonable balance of components. The demise of siratro between Phases I and II occurred in both treatments. Total green yield was significantly higher (P<0.05) in BS pastures than in NS pastures over Phase I, while in Phase II it was apparent in only 4 out of 8 years, though the mean over all years in Phase II (Mean II) was greater. Siratro yields were similar in NS and BS during Phase I, while in Phase II, they were lower in BS, though not significantly so. Yields of other grasses and forbs were generally lower in BS than in Phase I.

Buffel grass maintained a substantially higher frequency % in BS than speargrass in NS. Frequency % of siratro was significantly higher (P<0.05) in BS than NS, with a significant stocking rate interaction (P<0.05) because of the decline of siratro with stocking rate in NS but not in BS. There were no significant differences in cover between NS and BS treatments at the same stocking rates (Table 3) in Phase I or II.

Discussion

This study has shown the benefits in pasture production and changes in pasture composition from undertaking various pasture development strategies in the southern speargrass region of Queensland. The 3 development options (killing trees; oversowing with siratro; and clearing and sowing a buffel grass-siratro mixture) represent a developmental sequence for black speargrass areas. The initial step in development, i.e., killing trees, effectively doubled pasture production with little change in pasture composition, whereas taking the further step and oversowing with siratro brought dramatic changes in pasture composition. In wetter years, siratro increased to around 50% of pasture dry matter, with a corresponding decrease in speargrass and other native grasses, but in drier years siratro decreased to <10%. In years with good winter–spring soil moisture, massive seasonal increases of nitrophilous species (e.g. Digitaria ciliaris and Conyza bonariensis) occurred as a result of the increased fertility from the siratro. This indicated a potential for other more productive species to exploit this environmental niche. Replacement of the native pasture with a buffel grass-siratro mixture
showed a similar pattern of siratro growth to the oversown pastures but, in the drier years, buffel grass increased to >90% of available pasture.

Comparisons between the 4 treatments C, N, NS and BS provided information on 3 important processes:
- the effect of trees on pasture production and composition of native pastures,
- the effect of legume introduction into native pastures, and
- the effect of replacing native pastures with fully sown improved grass-legume pastures.

**Climate**

While rainfall was well below long-term averages during Phase II of the experiment, when compared with the more recent 30-year period (1969–98), rainfall in the period 1979–86 was closer to normal with 4 out of 8 years below median annual (633 mm), 5 years below median spring–summer (414 mm) rainfall, and only 2 spring–summer periods with rainfall below decile 3 (382 mm). Hence, while the period was ‘below average’ in terms of long-term rainfall data, it was not ‘abnormal’ in relation to recent trends.

**Pasture production and composition**

*The tree effect.* Moisture was an important factor affecting production. In the control treatment (C), most of the year-to-year variation in herbage production can be related to rainfall and hence fluctuations in soil moisture availability. A large amount of dry senesced herbage was carried over from one year to the next, particularly in the better years of Phase I. The trees reduced the amount of green herbage growth following irregular small falls of rain, so both quantity and quality of the forage were relatively low. This was reflected in the very small proportion of total forage production accounted for by the calculated level of animal intake.

The marked (40–100%) increases in forage production when trees were killed were similar to the results of Scanlan and Burrows (1990) in central Queensland, and Gillard (1979), Winter *et al.* (1989) and McIvor and Gardiner (1995) on native pastures in northern Australia, but the lack of any significant change in composition was in contrast with the findings of McIvor and Gardiner (1995). There was considerable year-to-year variation in the response to tree killing, which seemed to reflect the differing patterns of rainfall and soil water availability within and between the normal wet seasons (Scanlan and McKeon 1993). The persistent increase in forage production in the killed treatment for the 14 years of the experiment contrasted with the findings of Kaur *et al.* (2005) on a similar land type in central Queensland, where production increases lasted for only 5–6 years. This suggested the system at their location might be nutrient-limited, whereas at our location it was mostly moisture-limited. While the significant (P<0.05) increase in pasture production led to significant (P<0.05) increases in animal production (Tothill *et al.* 2008), there can be negative consequences as tree clearing can lead to long-term problems with salinisation and woody regrowth in some situations (Anderson and Dowling 1987; Scanlan *et al.* 1992).

*The siratro effect.* When this study commenced, the oversowing of Townsville stylo into native pasture in the northern speargrass zone was widespread. However, efforts to establish Townsville stylo in the southern zone had been largely unsuccessful. Oversowing the alternative legume, siratro, into native pastures without trees produced a small increase in the peak yield of forage in the wetter Phase I and a small decrease in the drier Phase II. However, at the higher stocking rates imposed, there was also a much higher level of pasture utilisation (Tothill *et al.* 2008), as evidenced by the lower amounts of carry-over dry pasture from the winter, and lower levels of ground cover. The responses, as measured by total yield, green yield and speargrass yield, followed the pattern in rainfall. In comparing the oversown treatment with the C and N treatments, it should be noted that the oversown treatment received P fertiliser.

In the oversown treatment, siratro played a strong role in determining composition and, between Phase I and Phase II, changed from being a major component of the pasture to a relatively minor one. Mannetje and Butler (1991) and Jones *et al.* (2000) reported similar declines in siratro after the first few years. In spite of declining levels of siratro in the pastures, there was a substantial residual effect that contributed to enhanced livestock performance from these pastures for several years (Tothill *et al.* 2008). The benefits are not
necessarily specific to siratro, but would pertain to any productive adapted legume. More recently, shrubby stylo (*Stylosanthes scabra* cv. Seca) has been shown to be highly productive and persistent in central (Orr et al. 2001) and south-east (Jones et al. 2000) Queensland, as has Wynn cassia (*Chamaecrista rotundifolia* cv. Wynn) in south-east Queensland (Partridge and Wright 1992; Jones et al. 2000). These species have the ability to set seed at low yields and under heavy defoliation (McDonald and Jones 2002a; 2002b) and hence have better persistence than siratro in this region.

**The pasture replacement effect.** Replacement of the native speargrass pasture by sowing buffel grass and siratro, the most highly developed option tested, resulted in greater pasture production than introducing siratro into native pasture. The main element contributing to this higher production was the predominant role played by buffel grass. In winter, buffel grass became quite stemmy and less edible. As a result, there was carry-over of dry material into the next season, although these apparently dry stems produced some green shoots at the stem nodes following occasional winter rains. The buffel dominance may have been accentuated by the input of nitrogen by siratro during Phase I.

**Stocking rate effects.** In Phase I, stocking rate effects were relatively minor because rainfall was above average, even though the stocking rates for Treatments C and N were related to long-term industry levels. While the rates for Treatments NS and BS were based on research findings, mainly from the 1960s, it became apparent that they were somewhat conservative for years with this rainfall level. In Phase I, siratro decreased and other grasses increased in pasture composition with increasing stocking rate, while speargrass and other components remained remarkably constant over stocking rates within treatments. In Phase II, only Treatment NS contained a number of stocking rates and speargrass decreased and forbs increased with increasing stocking rate. In response to the drier conditions, stocking rate had a much greater effect than in Phase I, and in some years, rates were unsustainable. At the highest stocking rate of 1.1 ha/ha, utilisation rates far exceeded accepted levels of around 30% (e.g. McKeon et al. 1990) in both the NS and BS treatments (Table 2). The large difference between Phases I and II reflects not only the higher stocking rates but also the lower rainfalls in Phase II. Owing to wastage from trampling etc., actual pasture utilisation percentages would be considerably higher than these values based on estimated intake only. These results support the argument of Jones et al. (1995) that 5 years or less is usually inadequate to show lasting trends in pasture composition and/or persistence of sown species, especially if the period does not include periods of consecutive dry years. The results also highlight the risk in increasing stocking rates after a run of favourable years, as was done in both this experiment and that reported by Mannetje and Butler (1991). The different responses to stocking rate in Phases I and II indicate the importance of adjusting stocking rates to suit the seasonal conditions.

**Speargrass and siratro dynamics**

In 1974–75, yield and frequency of speargrass declined as a result of siratro dominance. In this situation, the decline in yield resulted from a combination of reduced plant numbers and a likely reduction in individual plant yield. However, in 1980, 1984 and 1986, when the yield of speargrass declined to very low levels, the frequency of speargrass actually remained high, indicating that the low yields were largely a reflection of low plant yields rather than low plant numbers. Similarly, Orr et al. (2001) reported the frequency of speargrass remained constant across stocking rates in central Queensland, while MacLeod and McIntyre (1997) reported a decrease in speargrass dominance (proportion of sites where speargrass had greater biomass than other species) rather than overall frequency. This highlights the resilience of speargrass under grazing. On the other hand, the substantial decline in siratro yield resulted from a combination of lower production per plant and low plant numbers. Prior to 1982, siratro frequency remained nearly as high as it had been throughout Phase I, even though yields were much lower, indicating that there was a strong residual siratro plant resource. This pasture could have been managed to retain the plants, even after the signals given by lower yields had been apparent for some time. Jones and Jones (2003) showed that autumn spelling of siratro-grass pastures increased both yield and frequency of siratro over set-stocked pasture up to 3-fold.
The failure of siratro to recover following the better rainfall in 1981–82 highlights the need for at least 2 good seasons for recovery; one year is needed for build up of soil seed reserves, and a second for seedling recruitment (Jones et al. 1993). In contrast, legumes such as shrubby stylo and Wynn cassia can persist under more difficult rainfall conditions (Jones et al. 2000; Orr et al. 2001; MacLeod and Cook 2004).

Individual species composition

Other grasses. Oversowing siratro into native pasture or sowing buffel grass into a fully cultivated seed-bed reduced substantially the contribution of other grasses. From 1972 to 1974, there was an almost continuous decline in other grasses, after which seasonal peaks developed. In the unsown native pastures, there was little change other than an increase of Cymbopogon in both the control (C) and the native with trees killed (N) treatments, a decrease in the more palatable Eragrostis spp., and an increase followed by a decrease of Sporobolus in N. Where siratro was oversown (NS), other native grasses declined markedly, but D. ciliaris increased considerably in Phase I, and B. decipiens in Phase II. Similar changes were reported by Tothill (1974) in studies at ‘Gigoomgan’ in south-east Queensland, where fertility-demanding and heavy grazing-tolerant grasses, such as Chloris divaricata, Cynodon dactylon and B. decipiens, increased significantly in fertilised, grazed native pasture treatments, even though the level of H. contortus remained quite stable. Orr et al. (2001) reported similar increases in C. divaricata under high stocking rates in central Queensland. The increase in erect Aristida spp. during Phase II reflected the increased utilisation rates during this phase and the subsequent decline in the proportion of siratro and other grasses more palatable than erect Aristida. The differing responses of weeping and erect Aristida species has been confirmed in a later analysis by McIntyre and Filet (1997), who categorised them as ‘fine-leaved’ and ‘coarse-stemmed’. This increase in erect/coarse Aristida with increased utilisation is consistent with many reports (e.g. Orr et al. 1994) and was known to some pasture managers as far back as the 1890s (Lilley 1975). Clearly, minimising over-utilisation will decrease the risk of increasing erect Aristida, and burning in spring followed by 4–6 months rest or reduced stocking rate can improve the proportion of desirable species (Orr and Paton 1997).

Forbs. Over the period 1972–77, the level of forbs in the native pasture remained fairly constant, while in the native pasture-siratro and buffel-siratro treatments there were seasonal peaks which increased to a maximum in 1976. These peaks were largely associated with a build up of cool-season species (Tothill and Berry 1981) such as Lepidium bonariense, Conyza bonariensis and Cirsium vulgare. These species built up over a period of 2 preceding years in which there had been vigorous establishment and growth of siratro accompanied by winter (dry season) rains. The availability of soil moisture and the fertility build up from the siratro, combined with temperatures too low for initiating growth in the tropical species, provided conditions suited to the growth of cool-season high-fertility forbs. Their prolific growth in 1976 suppressed early growth of the grasses, but livestock production was not affected (Tothill et al. 2008). However, in 1977, when soil moisture in winter was low, there was almost no occurrence of these species. In contrast, in the BS treatment, strong growth from buffel grass suppressed growth of forbs, even in winter. L. bonariense was a common cool-season component of this treatment when moisture was available, but was a minor proportion of the pasture. These cool-season plants provided a ‘green pick’ for animals during spring-early summer. The environmental niche exploited by these species indicated a potential opportunity for introducing more productive species that could take advantage of the increased fertility.

The extreme variation in the predominance of individual species of grasses and forbs between years highlights the danger of attributing species response to a particular management at the time of sampling, if the sampling is over a limited time period.

Development comparisons

The stocking rates quoted above are for animals of 180–500kg liveweight, with animals on the improved pastures being heavier, owing to higher liveweight gains (Tothill et al. 2008). To make meaningful comparisons across development options, the values need to be converted to ha/AE (Animal Equivalent, a 500 kg non-lactating animal). Although the rates given are believed
to be sustainable in the long term, based on pasture production and animal intake, stocking rate should be adjusted at least annually based on seasonal conditions.

Tree killing more or less doubled the dry matter yield of each component of the pasture, and, in turn, increased the carrying capacity from 5–6 ha/hd (8–9 ha/AE) to 2.5–3.5 ha/hd (3.5–5.0 ha/AE), at similar utilisation rates (Table 4). Although most tree killing would have been completed, or no longer be allowed, in most of the southern speargrass region, much of the beneficial effects would persist, unless negated by regrowth.

Oversowing of a suitable legume into speargrass pasture is advantageous, although it will take longer to establish than when sown as part of a cultivated pasture mixture, and establishment will be less reliable (Cook and Dolby 1981). While this may not increase overall pasture yield, the legume will provide extra protein into the dry season and allow greater utilisation, without detriment to the animals, and thus, increase carrying capacity to around 2.5–4.0 ha/AE (Table 4). The fully sown grass-legume pasture provided the highest carrying capacity (around 1.5–2.5 ha/AE), and increased animal production/ha up to 7-fold over native pastures with trees, and up to 3-fold over merely killing trees (Tothill et al. 2008). At stocking rates above this, the utilisation rates may become excessive and lead to loss of cover and subsequent pasture decline.

The native grass-siratro pasture was far more floristically rich than the buffel grass-siratro pasture, but animal production on the two pastures was similar at the same stocking rate (Tothill et al. 2008). However, speargrass is less aggressive than buffel grass and can decrease in mixed grass-legume pastures (Scattini and Hall 1987; Orr et al. 2001) owing to selective grazing of the grass in summer. The decline in siratro in both pastures indicates that the pastures need to be well managed to retain siratro, or an alternative more persistent legume used. Pastures may become grass-dominant if sown with a twining legume such as siratro, whereas this is unlikely to occur with shrubby stylo (Jones et al. 2000).

**Conclusion**

Given that most of the southern speargrass region is already cleared, the most appropriate options for development in future would be oversowing a legume into native pasture or establishment of a fully sown pasture. Both options, if well established, will lead to a substantial increase in production, but will require good management in order to maintain their productivity in the long term. Nevertheless, if managed properly in appropriate areas, these development strategies can be economically viable as well as environmentally sustainable.

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**Table 4.** Development options and levels of sustainable use for the southern speargrass region of Queensland, based on the experimental treatments reported here. Utilisation rates were determined from calculated/estimated animal intakes for the various stocking rates and the estimated pasture production. Animal production values are from Tothill et al. (2008).

<table>
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<th>Trees</th>
<th>Legume</th>
<th>Fertiliser</th>
<th>Native Intact</th>
<th>Native Killed</th>
<th>Native Killed + siratro</th>
<th>Buffel Cleared + siratro</th>
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<td>Nil</td>
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